MODELLING INFORMAL LEARNING IN THE PUBLIC UNDERSTANDING OF SCIENCE: THE CASE OF RADON GAS.

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In loving memory of my mother, Doreen Russell.
ABSTRACT

Radon is a naturally occurring invisible gas that seeps into houses and can concentrate without proper ventilation. It is widely recognised as the leading cause of lung cancer after smoking and is estimated to kill over 2000 people annually in the UK. The National Radiological Protection Board estimates that over 6000 houses in the UK have Radon levels where reduction is strongly recommended and in certain geographic areas houses have been recorded with Radon radiation levels at over fifty times the legal dose for nuclear workers. This thesis is a study of the way in which the public learns about this potentially threatening scientific phenomenon.

Studies of informal science learning are in their infancy. To enter this emergent field the approach has been to adopt a model of learning from formal science education and adapt this model to provide a theoretical framework to describe informal learning of science. The theoretical perspective used is the epistemological Conceptual Change Model (CCM) of Strike, Posner, Hewson and Gertzog and building upon recent developments this model is extended to incorporate two additional perspectives; the conative and affective. The emergent Extended Conceptual Change Model (ECCM) is a multi-dimensional interpretative framework to consider informal conceptual change learning.

The ECCM has three perspectives: the original CCM of Strike, Posner et al. provides the intellectual or cognitive perspective. This suggests that conceptual change will take place when matter to be learned is seen to be intelligible, plausible and fruitful. The affective perspective models the emotional nature of learning and describes conceptual change using the conditions salient, germane and palatable. The conative perspective embodies the need for practical empowerment and uses the conditions actionable, trust and control to model conceptual change.

In the tradition of Grounded Theory, the evolution of the ECCM is grounded in the data collected. Through five empirical studies the ECCM is first generated and then validated. The first phase of data collection provides a conceptual review of sources of Radon information that are available in the public domain. The second and third phases explore the understandings of radioactivity and Radon in groups of participants living in Radon affected areas. Through an iterative process these stages are then used to propose the ECCM. In the concluding stages, the model is elaborated, refined and validated by two studies of informal learning: learning from an informal information source (the NRPB Radon Leaflet) and learning in a Somerset village.

The arguments presented in this thesis take conceptual change into the affective and conative domains. The concluding comments examine the implications this has for life-long science learning and make specific recommendations for formal and informal education.

For informal education the research suggests that Radon communications should: i) be more interactive and personalised; ii) be more transformative rather than informative; iii) be more practically empowering and provide information which is actionable, trustworthy and controllable; and iv) acknowledge the emotional nature of learning.

For formal education the thesis recommends that: i) Radon should be part of the school curriculum and ii) school science should give more specific attention to the needs of life-long learning. These needs include conative and affective facets. School science should consider issues of action, control and trust as well as the emotional nature of learning - content should be selected and presented in a way that it is salient, palatable and germane.
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In comparison with radiation doses from Radon the doses to individual members of the public and to the general community from nuclear activities are quite trivial. Doses from Radon in some British homes exceed the statutory dose limit for nuclear workers and the collective dose from Radon is two thousand times the value for nuclear discharges. Yet, too little attention, legal or otherwise, is paid to this radioactive pollutant.

(The UK National Radiological Protection Board, O’ Riodan and O’Riodan 1991)

It was talked about amongst our friends here in the village. Some of them have got quite antiquated views on various things like Radon, but we are a farming community and the attitude of: it never killed anybody before, it never will kill anybody in the future, is rife here - maybe, who knows, we probably won’t know until it is all too late!

(Chris - a case study, Chapter 10)

1.0 AN OVERVIEW

These two quotations capture the problem which forms the heart of this thesis. The first is made by the National Radiological Protection Board [NRPB] - a government agency charged with the responsibility of providing members of the public with information about radioactivity. The second is taken from a case study documented in Chapter Ten and is made by a resident of an area with high levels of the radioactive gas, Radon.
Chapter One: An Introduction.

The focus of this thesis is a meeting point between these two groups, namely, the common ground between members of the public and nuclear scientists. Under scrutiny here is the way citizens learn from information provided by scientists and the 'analytical eye' is brought to bear upon the public groups that are faced with the Radon concerns rather than with the laboratory world of the nuclear scientists.

The focus of this thesis is informal learning, which can be defined as learning which takes place outside of formal educational institutions, and the particular learning under consideration is conceptual change learning (Strike, Posner, Hewson and Gertzog, 1982). The aim of this study is to develop a way of modelling informal conceptual change learning. One of the basic hypotheses made is that learning is a dynamic interpretative process that involves the learner employing prior knowledge to construct meaning.

Typically when considering conceptual change learning the focus is within formal education. Schools, teachers, text books and examinations are on the schedule and there has been a wealth of research which has studied learning in this environment (many of these studies are viewed in Chapter Three). However, people spend considerably more time in informal learning environments than in formal ones as Tressel (1994) succinctly notes, ‘most of the time, most of us learn most of what we know from outside of school’ (p8). Indeed, recent research recognises that ‘informal ideas’ fundamentally shape science learning that takes place in schools (Black and Lucas, 1993).

It is argued that members of the public need to be able to interpret, understand and evaluate information related to scientific and technological matters (for example, by Durant and Thomas, 1987). Science, it seems, is a requirement of contemporary living, as Giddens (1994) writes:

Individuals have to engage with the wider social world if they are to survive in it. Information produced by specialists (including scientific knowledge) can no longer be wholly confined to specific groups, but becomes routinely interpreted and acted on by lay individuals in the course of everyday actions (p.7).
A knowledge of science, it is maintained, takes on key importance when a member of the family becomes ill, or if there are plans to build a chemical plant in a local area (Nelkin, 1982). Leisure pursuits also involve science, for example, fishing, gardening and scuba diving and, for many, a knowledge of science is a vocational requirement (Laetsch, 1987).

Given that scientific knowledge is expanding and many contemporary issues are, by their very nature, contingent and constantly changing it is highly unlikely that any formal education system can provide sufficient knowledge and expertise in science to last a person's life time. For example, those who completed school science in the early 70's would not have had school lessons which considered, global warming, AIDS, depletion of the ozone layer or BSE. Hence, the limitations of a front-loaded educational system become evident.

It seems then that science learning should take place not only during the limited school years but throughout a lifetime. Indeed, Tressel's (1994) phrase could, aptly, be adapted to become: for most of the time, most of us learn most of what we know about science outside of schools.

In the past, research on the public understanding of science has resulted in considerable media noise and criticism of the serious levels of ignorance in the general population. Much of this research (see Chapter Three) has relied upon large scale surveys, leading to the portrayal of the public as 'inevitably deficient'. Since that early work there has been growing criticism of the assumptions and frameworks of this kind of approach (see, Chapter Two), for example, Ziman (1991) notes of his own work:

> a simple deficit model, which tries to interpret the situation solely in terms of public ignorance or scientific illiteracy, does not provide an adequate analytical framework for many of the results of our research (p9).

The need to break new ground has resulted in a range of research initiatives that are smaller in scale and more interpretative in nature. The new era of research has focused
on learning in a particular context or 'cognition-in-practice' (Lave, 1988). Within these studies the emphasis is upon things which are learned outside of formal education and how this knowledge is influenced by the social and cultural context in which the learning takes place, 'including the physical structure, the purpose of the activity, the existence of collaborating partners and the social milieu in which the problem is embedded' (Furnham, 1992, p32).

To broaden the perspectives in this area is to recognise some of the major complexities which abound. For example: the understandings and attitudes of the general public are not monolithic; they are commonly ambivalent inconsistent and contradictory - both towards identifying those issues and contexts which are considered to be within the domain of science, and whether aspects of science are (or are not) a 'good thing' (e.g. see Layton, Jenkins, Macgill and Davey, 1993). For instance, issues which relate to health and personal risk may be causally related to advances in science and technology, at other times these risks may be attributed to 'natural hazards' of life - and scientific and technological solutions are perceived as possible saviours (Beck, 1992).

Few science educators would question the desire to increase the level of public understanding of science and the reasons for a greater level of scientific literacy have been comprehensively argued and debated (The Royal Society, 1985; Thomas and Durant 1987) with few, if any, dissenters.

Traditional approaches to bringing science to the public have been to 'water down' science to meet the needs of lay audiences (Irwin, 1995). However, recent research suggests that the everyday needs are more complex, intricate and multifaceted than merely a form of diluted science (Irwin and Wynne, 1996). Arguably, the calls for the public to understand more science fail to fully embrace the enormity of the task - learning science for many people is difficult as Wolpert writes:

Science is difficult. It is simply is not true that it becomes easy and interesting if you know how to do it. The scientific mode of thought is an alien mode for most of us it is
uncomfortable, unnatural and very difficult. We must face that before we understand the nature of this problem [the Public Understanding of Science]. (Wolpert 1987, p45)

Wolpert discusses the subject in such a way that the possibility of the public genuinely understanding science appears in question (see Wolpert 1992). Such pessimism, however, is open to challenge (see, for example, Lambert and Rose, 1996).

There are many informal sources of science knowledge including; museums, zoos, aquariums, television and radio programmes, newspapers and the Internet. However, as Chen (1994) has noted there is a striking mismatch between the level of funding and effort in bringing science to the public and there is a paucity of any systematic research which has studied informal science learning. Informal science learning as a concept has only recently been developed (Tressel, 1994) and it is still an area where research is in its infancy as Schauble and Bartlett (1997), Chen (1994), and Lucas (1986) all note:

Informal learning has began to be taken seriously only recently by the mainstream research community. Subfields such as educational psychology and instructional psychology have organised around school learning, but as yet, there is no recognised disciplinary subspeciality that has coalesced for the purpose of generating concepts and methodologies to address the challenges of studying informal learning.

(Schauble and Bartlett, 1997. p.792)

From a research perspective the field has gone largely unexamined


So far, there has been little research that focuses on how people learn both in and from informal settings. Knowing how people learn might be more important than knowing what they learn.

(Lucas, 1986. p 343)

Over the last few years research into informal science has been growing (see for example, Dierking and Martin 1997, Hofstein and Rosenfield, 1996). Some media have had more research interest, for example, learning science in museums has been a
popular focus of recent attention (see for example, Tunnicliffe, Lucas and Osborne, 1997). Nevertheless, informal science learning is still an area which is under-researched and the aim of this study is to extend this emerging field.

1.1 THE CONCERN

Within the UK, an extensive publicity campaign was launched in March 1991 aimed at residents living in areas of suspected high background radiation (DoE, 1994). The high radiation levels are due to the naturally occurring gas, Radon. The considerable health risks to people living in areas of high Radon concentration has been comprehensively reviewed; Radon is widely recognised as being the largest contributor to background radiation world-wide, (O’Riordan and O’Riordan, 1991) and the second largest cause of lung cancer after smoking, (US Protection Agency, 1988). Fremlin (1989), for example, claims that Radon is responsible for 10,000 lung cancer deaths per year in the US alone, whilst in the UK the figure has been estimated as 6000 deaths per year, about 4% of all UK annual cancer deaths (Roberts, 1996). The UK National Radiological Protection Board (NRPB) have estimated that currently around 100,000 homes in the UK have Radon levels above the 200 Bq/m³ UK action figure (O’ Riordan and O’Riordan, 1991).

Within the UK, the Radon publicity campaign has been directed towards specific geographic locations hence the residents of the counties of Cornwall, Devon and Somerset have received a leaflet which gives them details of the problem and invites them to apply for a free measurement of the radiation levels in their homes.

This thesis arose out of a concern about the importance of people, living in high levels of background radiation, knowing about the science associated with this potential health hazard. The thesis is a study of how residents living in the UK counties of Cornwall, Devon and Somerset, learn about the radioactive gas, Radon, from the information that is available in the public domain.

Studies of the public’s reaction to Radon, the risks involved, their beliefs, and their Radon testing activities are numerous (see Chapter Five). Research of this nature has
concentrated predominately on the publics’ perceptions of the risks associated with Radon, and the reasons they give for opting for a Radon test. Typically responses are then correlated with a range of socio-demographic factors. Other surveys with a ‘communication studies’ bias examine the major sources which feed the learners knowledge (see, Chapter Three).

Although the arguments presented draw on the aforementioned research, the approach of this thesis is different, it involves a description of personalised informal science learning.

1.2 INFORMAL SCIENCE LEARNING

This is a thesis of the Public Learning of Science (PLS) and under particular focus is the informal learning of Radon. The term ‘informal learning’ is now widely used in the literature in the field but is not clearly defined. Crane, Nicholson, Chen and Bitgood (1994) offer a useful definition which has the particular advantage that it recognises that informal learning can contribute to formal educational settings:

Informal learning refers to activities that occur outside the school setting, are not developed primary for school use, are not developed to be part of an on going school curriculum, and are characterised by voluntary as opposed to mandatory participation as part of a credited school experience. [...] Informal learning activities may serve as a supplement to formal learning or even be used in schools or by teachers, but their distinguishing characteristic is that they were developed for out-of-school learning (p4).

This type of definition links learning to a particular setting and traditionally, studies of informal learning take place in one particular informal education setting such as a museum, zoo and aquarium, or, from an information source like television documentaries, radio programmes, magazines or newspaper articles. In the following chapters it is argued that this approach has shortcomings. It is maintained that by limiting a study of informal learning to one particular source or setting it is possible only to explore part of the picture. This thesis has a ‘learner focus’ rather than a
'source focus' because it is argued that one of the distinguishing characteristics of informal learning is the ability to combine learning from a variety of different sources and settings.

As informal learning is voluntary (as opposed to mandatory) it is significant to consider which types of information informal learner's use, as well as how they learn from this information. It is mistaken to assume that all informal science learning will take place from planned 'intentional sources' (Lucas, 1983). For example, in a recent survey, 'word-of-mouth' was found to be a highly significant source of scientific information about Radon (DoE, 1994).

A 'learner focus' perspective requires an investigation of learning as well as choices of information. With this approach, a key consideration is the learner's motivation and educational goals, and important questions become, 'how and where do learners seek out information?' as well as, 'what do they want to find out?'.

For the purposes of this thesis, informal learning is represented as the interaction of three contexts, as illustrated in figure 1.1.

![Figure 1.1](image_url)  
**Figure 1.1.** A three dimensional representation of informal learning in the context of learning about radioactivity and Radon.
In this representation, the personal context includes factors such as age, sex and formal science qualifications. It also embodies personal characteristics such as conceptions and feelings about radioactivity as well as preferred learning styles, approaches and goals.

The social context embodies the everyday world, the life-world (Shultz and Luckman 1974), of the informal learners. This incorporates the environment in which science is encountered. The study has deliberately focused on adults (aged 18+) living in areas of high Radon concentration.

The information context manifests the availability and content of information as well as sources of information. Members of the public are clearly not party to all information, recent research and draft policy documents are likely to be beyond their easy access. Popular information to which they have immediate access will include news-media (e.g. television, newspapers and radio), information sent directly to 'Radon residents' (e.g. leaflets from the National Radiological Protection Board) as well as other less intentional information sources such as advice from neighbours.

The complexity of informal learning is highlighted by the diversity of these contexts hence studies of informal learning face a multitude of methodological hurdles and compromises (discussed in detail in Chapter Three). For example, it is difficult to study informal conceptual change learning as a non-participant observer because, for the most part, it is tacit (Hewson and Hewson, 1991). It has been necessary to design mechanisms that make learning explicit and recordable without fundamentally compromising the aims of the study. The approach chosen has been not to watch learning from a distance but to intervene in order to examine learning in depth. This is a compromise in that it has not been possible to observe learning in a naturalistic social environment. The approach adopted is ideographic - the aim is to model individual learners with a view to generalising the research outcomes.

In overview, this thesis is concerned with groups of Radon learners living in an area of health concern (the social context) and chronicles:
Chapter One: An Introduction.

1. the sources of information which informal learners use to find out about Radon 
   \textit{(the information context)};

2. the understandings informal learners develop and how they learn about Radon 
   and radioactivity \textit{(the personal context)}.

Through the combination of these contexts the thesis aims to model the informal 
learning of Radon gas.

1.3 THE APPROACH

As models of the public learning of science are in their infancy the approach has been 
to begin with a well established and popular model of science learning and develop 
this into informal learning. The Conceptual Change Model [CCM] (Strike and Posner, 
Hewson and Gertzog, 1982) used is one which is popular in studies of science 
learning in formal education settings (i.e. science classrooms). The following chapters 
document explorations that culminate in the extension of this model. To model the 
eclectic nature of informal learning it is argued that there is a need to go beyond the 
purely cognitive domain and to include two additional learning perspectives: the 
affective and the conative. The affective perspective embodies the feelings and 
emotions which influence learning and the conative perspective considers practical 
learning goals and how these influence learning.

It is to be stressed from the outset that the model proposed has clear boundaries:

1. It is a description of learning derived from a particular theoretical perspective, the 
   learning under consideration is conceptual change learning (Strike, Posner, 
   Hewson and Gertzog, 1982). This is defined in Chapter Three and revisited in 
   Chapter Eight.

2. The study is located in particular \textit{social and information} contexts. It considers 
groups of learners (18 + years old) living in areas of high concentration of Radon 
gas and models how they learn about the science closely associated with Radon - 
science contained in mass media and information leaflets.
Chapter One: An Introduction.

3. Although the extensions to the original model include affective and conative perspectives the model still has a cognitive focus. It is the interactions that these perspectives have with the cognitive which are under consideration. There is no attempt to shape a model of emotional development, nor a model of decision making: the modelling is of the public learning of Radon. This is quite different to an exploration of the reasons influencing Radon testing or the development of radioactivity fears and risks. Studies which have considered these areas are documented in Chapter Three.

A multi-dimensional analysis of learning is some departure from tradition because traditionally, a thesis of learning would limit itself to just one perspective. In science education, this has been predominately the intellectual or the cognitive domain, leaving the conative and affective dimensions still under-researched. Significantly, this thesis develops a model for the learning of science which includes three dimensions, the cognitive, conative and affective. It then moves this model from a formal into an informal educational setting.

1.4 THE SIGNIFICANCE OF THE THESIS

The thesis aims to make contributions to two distinct research fields: the public understanding of science (PUS) and to ‘standard science education’ (Millar, 1989). Perhaps, surprisingly, these two fields have remained separate over time (Dierking and Martin, 1997). Standard science education has tended to concentrate on understanding the learning of science in formal education settings, whereas, the PUS focuses on adult learning outside of these settings.

Recently, Crane (1994) conducted interviews with two dozen leading researchers on informal learning and the researchers all raised similar concerns - the most important area for the advancement of informal learning research was to develop a theoretical framework to understand the informal learning processes. As one of the researcher’s stated ‘We need to learn how people learn, and what people do when they are learning, not just what they learn’ (p.182). This thesis aims, in part, to address this concern and provides a theoretical model for the informal learning of Radon.
Apart from a consideration of informal learning this thesis carries messages for standard science education. In the UK, the present debate is one of 'a crisis in science education' (Levinson and Thomas, 1997) as science education appears to be in a downward spiral - the number of students continuing with science post-16 continues to decline (Braithaupt, 1997) and the percentage of students taking only A-level sciences has fallen from 30% in 1983 to 17% in 1993 (Authors, 1996). The situation has now reached a stage where a rethinking of formal science education is urgently needed. It has strongly been argued that school science should be viewed as a preparation for life-long learning (Fensham, 1997; Millar, 1993; Royal Society, 1985) and recent reforms talk of addressing the public's life-long needs (ASE, 1996; AAAS, 1995) - although there is little research to suggest exactly what these needs are. A study of the public learning of science can provide a basis to consider some of the needs of life-long science learners.

Crane (1994) argues that an understanding of informal science learning can be used to tackle questions which are quintessentially important to standard science education and the public understanding of science, namely:

1. How can we foster the idea among the public that science is an important endeavour that has a positive impact on our lives?
2. How do we continue to reach people with information about science after they leave a formal learning environment?
3. How do we keep the public updated on what is happening in science?
4. How do we create an informed public, however small, that will become involved in science issues?
5. How can we maximise the flow of talented youth into the sciences as a course of study and career?

(Chen, 1994, pp4-7)

Full answers to these complex questions lie beyond the scope of this thesis, however, what this study offers is a step towards these fundamental issues.
1.5 THE RESEARCH QUESTIONS.

The principle aim of this thesis is to investigate how members of the public learn about science in informal learning environments. To achieve this aim a model of science learning originally derived in a formal learning context is modified to model informal learning. Given this approach, the principle research question is:

- To what extent can a model derived from within formal science education be used and adapted to describe informal learning in the public understanding of science?

One way to respond to this question is to focus on a single area of science: in this case, that of radioactivity and Radon. This raises two subsidiary questions which form the basis of the following literature reviews:

- What is known about Radioactivity and Radon from research in the public understanding of science?
- What is known about Radioactivity and Radon from research in science education?

Learning about Radon can be influenced by the availability of information. The opening phase of data collection explores the content of informal Radon information materials (newspaper articles, television programs and Radon leaflets and circulars). This part of the research is driven by the three questions:

- What sources of information are available about radioactivity and Radon gas?
- What information do these sources contain?
- In what ways do these sources communicate this information?

Given that informal learners have some choice over the type of information they consult an additional key question is:
• What sources of information do the sample of informal learners use to learn about Radon gas?

In order to understand the processes of learning, it is necessary to explore what the learner already knows: the knowledge that individuals associate with radioactivity and Radon. Considering those participants living in areas of high background radiation, and others living in areas not associated with radioactivity, the thesis explores the question:

• What knowledge do these individuals associate with radioactivity and Radon gas?

The thesis uses the emerging features of this research to propose a model of informal learning about Radon. This model is then used to explore informal learning and then test its robustness in two different studies.

The first looks at learning from an informal information leaflet: a Radon leaflet. This part of the study is driven by the research question:

• Can the proposed model of informal learning be used to describe learning from an informal information source?

The second studies learning in the context of a rural village which experiences a high level of background radiation. This aspect of the study pursues the research question:

• Can the proposed model of informal learning be used to describe learning about Radon in a rural village?
1.6 THE STRUCTURE OF THE THESIS

The thesis consists of eleven chapters. Each chapter combines to develop a logical story, although the actual development of the research has been more an iterative process.

In Chapter Two the arguments presented in favour of more scientifically enlightened citizens are discussed. Universal definitions of scientific literacy are pushed aside in favour of meeting the scientific 'knowledge needs' of specific public groups, and the particular needs of groups of Radon residents are considered. The importance of interactive communication is highlighted. The chapter then concludes with a technical discussion about Radon.

Chapter Three is the main literature review, although departing from tradition both Chapters Five and Eight supplement this review. In Chapter Three the focus of the review is on learning science. The chapter starts by considering stage-specific models of adult learning or 'andragogy' and continues by documenting research into: i) learning science in schools; ii) the public understanding of science; and iii) learning science from informal information sources. The majority of the research which considers learning is based upon studies in schools. The 'conceptual change' model of Strike, Posner, Hewson and Gertzog (1982) is a well established and popular model of learning and forms the early basis of the research project. The development of this model is considered in this chapter and is then extended in Chapter Eight.

Chapter Four discusses the research methodologies, although, once more, departing from tradition specific issues of methodology are featured in each of the six following empirical chapters. The development of the thesis follows Grounded Theory (Glaser and Strauss 1967) and the principal tools of data collection are case studies, interviews and surveys. The chapter concludes with a methodological overview of the five data collection phases.

Chapter Five considers the subject of enquiry: radioactivity, Radon and the public, in two sections. Section one reviews the literature associated with the learning of
radioactivity and Radon, section two contains a conceptual analysis of information about Radon - information that is readily available to occupants of Radon areas. The analysis considers the content of the materials and their suitability as educational sources.

Chapter Six, presents the results of a study of recent school leavers. Here, the research tool, ‘interviews-about-scenarios’, is developed and used to explore the everyday informal knowledge which the participants associate with radioactivity and Radon gas.

Chapter Seven presents the results of a survey of residents of Devon and Cornwall. The target population are termed Radon confidants and are selected by the participants of the previous study. The focus of this part of the research is the sources of information used to find out about Radon and the participants’ understanding of the terminology associated with Radon.

Chapter Eight is a pivotal chapter. It is here that, a model of informal learning is proposed. The proposed Extended Conceptual Change model (ECCM) has three perspectives: the cognitive, affective and the conative, and the literature is reviewed to support each of these perspectives.

The following two empirical phases are used to refine and validate the proposed Extended Conceptual Change model. In Chapter Nine the ECCM is used to investigate learning from a government information leaflet. A sample of recent school leavers are invited to discuss their learning from an informal information source.

In Chapter Ten the ECCM is used to explore learning in the informal naturalistic educational setting of a rural village. Together Chapters Nine and Ten document a number of cases studies that combine to evaluate the efficacy of the model proposed.

The concluding chapter, Chapter Eleven, provides a summary, considers the research questions, conclusions and suggestions for further research.
CHAPTER TWO:
SCIENCE AND THE PUBLIC

2.0 INTRODUCTION

Anxieties about science and technology are a part of contemporary society. This thesis is written at a time when various political groups, government scientists, journalists, and dedicated individuals are attempting to educate, coerce and cajole the general public into accepting particular solutions to an ever increasing range of contemporary scientific and technological problems. These problems include, for example: local concerns of street pollution; planetary concerns for global warming; the relative merits of particular national energy policies; and endless collections of questions relating to the safety of food products, such as Bovine Spongiform Encephalopathy [BSE], irradiated strawberries, food containers leeching oestrogen, and poly-saturated fats.

With this barrage of technical advice it is little wonder that concerns have been expressed about the public's ability to decipher, decode, understand and cope. Not least because the scientific community can disagree amongst its members as to an explanation. Some scientists have lamented the complacent attitude of the public and the manner in which science becomes trivialised within the public domain (Charlton; 1990 and Roberts, 1996). Chalton (1990), for example, warns of the 'perils of popularisation' (p.34). Other criticisms have been raised by politicians who appear surprised and bemused when their attempts fail to pacify a seemingly reactionary and hysterical public with apparently sound, logical and clearly reasoned scientific advice. This is perhaps best illustrated by the actions of John Gummer, Minister of Agriculture, Fisheries and Food at the time of the 1996 UK BSE crisis when he fed a beefburger to his daughter in an dramatic attempt to reassure public anxieties.
What becomes clear is the distinctive role that science has in our technological society. For some, the risks inherent within modernisation are a defining feature of society (Beck, 1992 and Giddens, 1994). For example, Beck (1992) inextricably binds the social production of wealth with the social production of risks and argues, that, in developed societies, the perceptible risks of starvation and naturally occurring diseases have been overtaken by the imperceptible risks stemming from modernisation itself.

For Beck (1992), science occupies a central role in modern society: it mediates between environmental processes and the perception of these processes as problems. In this way, science is both the identifier and the definer of issues as problems. He writes:

That which impairs health or destroys nature is not recognisable to one’s own feeling or eye, and even where it is seemingly in plain view, qualified expert judgement is still required to determine it objectively. Many of the newer risks (nuclear or chemical contamination, pollutants in foodstuffs, diseases of civilisation) completely escape human powers of direct perception... [these] hazards require the ‘sensory organs’ of science - theories, experiments, measuring instruments - in order to become visible or interpretable as hazards at all (p.27).

In contemporary society, Beck argues, the public has increasingly become reliant upon such ‘second-hand non-experiences’ of scientists rather than the ‘first-hand experiences’ of the everyday senses and, as a consequence, members of the public lose their cognitive autonomy and sovereignty. Giddens (1994) reasserts this point when he writes of expert knowledge systems in society:

A major influence here is the diffuse impact of ‘abstract systems’ - systems of all kinds - on our lives in the present day [...] many aspects of daily life become evacuated of locally developed skills and invaded by expert systems of knowledge. The revolutionary changes of our time are not so much in the orthodox political domain as along the fault-lines of the interaction of local and global transformations. One is speaking here of something more profound than the impact of technological change on people’s lives, far reaching though that is. Abstract systems include technology, but
also any form of expert knowledge that substitutes for indigenous local arts or capacities. (p 95)

Within contemporary society, the scientific expectations of the public can be considerable. Personal decisions about environmental issues appear to permeate society at all levels from the ballot box (e.g. decisions over food policies) to signing a local petition, for example, against the location of a nuclear power or chemical plant.

Decisions of this nature require members of the public to have an informed responsibility - individuals, it seems, are now expected to make decisions over issues of a potentially globally destructive nature (for e.g. nuclear power, global warming and depletion of the ozone layer). These are issues that could not only impinge upon our generation but future generations and transcend national boundaries.

Science is an essential part of our everyday life and experience and yet it has a duplicitous role. For example, within environmental issues as it appears to emerge, on the one hand, as the potential sinner - the creator of the environmental concern and, on the other the saviour - the antidote and solution to environmental catastrophe. As Beck (1992) notes:

science is no longer concerned with liberation from pre-existing dependencies but with the definition and distribution of errors and risks which are produced by itself (p158)

Beck (1992) highlights how in the public domain the status attributed to science is changing as modernity shifts into, what he refers to as, reflexive modernity. In modernity, science is a source of unbroken faith - a universal truth. However, as science has expanded and gained importance, its limitations have now become visible. In this reflexive stage, science has become confronted with the products of its own creation - and has become associated with both the solution and cause of problems. Some old truths, it seems, are now accompanied with new doubts. The consequence of this change, Beck (1992) argues is:
a momentous de-monopolization of scientific knowledge claims comes about: science becomes more and more necessary, but at the same time, less and less sufficient for the socially binding definition of truth ... (p156)

It appears that science as a form of universal truth is challenged as, increasingly, alternative solutions to problems appear and are given status: alternative medicine now supplements traditional medicine; alternative diets compete with traditional diets. In contemporary society, it appears, as Giddens (1992) notes:

an expert has no more than a provisional claim to authority, because that expert’s views may be contested by others with equivalent credentials ... In a socially reflexive era, moreover, expertise does not remain the sole province of the expert; any specialist claim to knowledge relevant to the practical task of social life will tend to be deflated through becoming, albeit often in an imperfect form, common currency (pp 96-97)

The public are now no longer exposed to single opinions but are expected to make sense of competing ‘experts’ - a situation which would appear to require a considerable degree of additional expertise.

2.1 WHY SHOULD THE PUBLIC UNDERSTAND SCIENCE?

A good starting point for a thesis on the public learning of an aspect of science is to consider the arguments given in support of a greater public understanding of science. This question is important because it provides the basis from which to consider what science the public needs to know.

The need for the general public to understand more science has been forcefully argued by an array of scholars from a wide range of different view points. It would appear that few question its desirability. The Royal Society, for example, make their position perfectly clear:

Everybody needs some understanding of science, its accomplishments and its limitations, whether or not they are themselves scientists or engineers. Improving
that understanding is not a luxury: it is a vital investment in the future well-being of our society (Royal Society, 1985b, p.1.)

It should be recognised that the term ‘public’ is extremely wide ranging. For instance, the public consists of interest groups, legislators and policy makers, scientists, teachers, and skilled and semi-skilled workers. Many of these will have occupations which require some knowledge of science. However, by far the largest group in the public are those without scientific vocational or professional need. This group are the principal focus of this thesis. Thomas and Durant (1987) refer to this group as the ‘lay public’, however, in this thesis the term ‘public’ is preferred because ‘lay’ fails to recognise the public’s diversity of experiences and expertise. The public includes both the informed and the not-so-informed as well as the interested and not-so-interested - i.e. the lay and not-so-lay.

Typically, the justification for an increased understanding of science rests on a mixture of utilitarian, democratic, cultural, economic and moral arguments (as set out, for example, by Driver et al., 1996, Shamos 1995, Millar 1989, Thomas and Durant 1987, Laetsch 1987, The Royal Society 1985, Miller 1983). Among these arguments are the following:

- The utilitarian argument, this maintains that people require a knowledge of science for day-to-day coping. The claim here is that people need knowledge of science in order to function practically and successfully in a scientific and technological world. The scope here is wide-ranging and covers, for example, both controlling technological gadgets and wiring a plug, as well as making decisions about health care and personal safety. In these cases, scientific knowledge has an instrumental emphasis.

- The democratic argument, this claims that people need some knowledge of science in order to take part in democratic decision-making and to exercise civic responsibilities. In a democratic society citizens are expected to make decisions about a wide range of issues. These include environmental issues, such as nuclear power, or more local environmental concerns, such as the pollution of a local lake.
or stream. The assumption here is that by increasing the public understanding of science, citizens are in a position to make informed democratic choices. As science itself is considered to be publicly accountable it is through the democratic argument that the public regulate science.

- The *cultural argument*, suggests that a knowledge of science has some intrinsic value in itself. Thomas and Durant (1987, p7) divide this into intellectual and aesthetic benefits. Essentially, the *cultural argument* maintains that, in much the same way as literature, music and art are considered to be major cultural achievements, people should also understand and appreciate the cultural achievements of science.

These are wide ranging arguments and, as such, embrace a multitude of instances of where knowledge of science can be argued as beneficial. As they are broad, unfortunately, they allow for a variety of different interpretations of scientific requirements. Indeed, while pleas for an increased PUS are common, there is much less agreement over the ‘goals’ of these efforts - i.e. the precise ‘science’ the public needs to know, or what it actually means to be ‘scientifically literate’.

### 2.2 SCIENTIFIC LITERACY

Scientific literacy is a term which was originally coined in the late 1950’s in the US (DeBoer, 1991) since which time it has been the source of considerable disagreement and debate (Shamos 1995). The expression has become closely associated with a type of educational utopia - a fully educated public who are able to draw upon science to meet all their contemporary needs. An analysis of the term shows that a multitude of different definitions have existed (e.g. Shamos, 1995 and Miller, 1983). However, these have all included some, or all of, the following four broad areas:

- key scientific concepts and constructs;
- the scientific approach to enquiry;
- science as a social enterprise, and
• attitudes towards science.

Early attempts at defining scientific literacy accentuated the importance of the citizen having a comprehensive grasp of contemporary scientific concepts. The justification for this is provided by the cultural argument. This is, perhaps, epitomised by the writings of such eminent scientists as Huxley (1880), Bronowski (1956) and Snow (1959). Essentially, these academics consider science to have an endless amusement and potential for pleasure. For these scholars, a member of the public could not be considered as truly ‘learned’ without a detailed knowledge of science. Bronowski (1956), for example, used Orwell’s well known novel in an essay entitled ‘The Educated Man in 1984’ to consider the future of society: a society where science is supreme - but not without some words of warning:

It is certain that the educated man in 1984 will speak the language of science. This is not an issue. The issue is something else. Will the educated man in 1984 be a specialist, a scientist or a technician with no other interests, who will run his fellowman by the mean and brutal processes of efficiency of George Orwell’s book? Or will he be a statesman, an administrator, a humanist who is at home in the methods of science, but does not regard them as mere tools to efficiency? (Bronowski, 1956).

The importance of science as a cultural achievement was the subject of the widely cited Cambridge Rede Lectures given by C. P. Snow concerning the ‘Two Cultures’. For Snow (1959) a test for scientific literacy was the question: “what do you know of the second law of thermodynamics?” Although, incidentally, in a later lecture Snow retracted this test in favour of a subject which was more at the forefront of modern science: “What do you know of molecular biology?” (Snow, 1963).

Reviews of scientific literacy draw attention to the post-Second World War period (the late 40’s and 50’s) as the turning point in the debate. Shamos (1995) writes:

the active pursuit of universal scientific literacy is essentially a post - World War II phenomenon, having its origin in “civic” or “societal” concerns. Following the war, many scientists, having witnessed the horror brought on by one of their major

23
scientific/ military achievements (the atom bomb), believed that the best way to avoid such catastrophic use of science in the future was to educate the public to the potential of employing science for evil as well as for good, and to seek civilian control of nuclear energy (p.76).

The nuclear age had taken society to the edge of destruction and the only perceived way of avoiding mass annihilation in the future was to involve the public in the regulation and control of scientists. This hurled the public understanding of science into the political world of science policies and dramatically changed the emphasis of scientific literacy from being 'learned' to being able to cope with the societal implications of science by understanding what science does, and then exercising control over it.

Since the 1940's, the number of major scientific societal issues has considerably broadened and the extent to which it is realistically possible for the public to acquire sufficient competence in science to truly challenge policy decisions is a continuing source of concern:

The complexity of public decisions seems to require a highly specialised and esoteric knowledge, and those who control this knowledge have considerable power. Yet democratic ideology suggests that people must be able to influence policy decisions that affect their lives (Nelkin, 1975).

Attempts to quantify scientific literacy were a noteworthy feature of research in the 1980s. Miller (1992a, 1983, 1987) has become widely recognised as the instigator of these measures and they have gained considerable international recognition and use (the results of these surveys are discussed in Chapter Three). Miller's measurements are derived from a three-dimensional model of scientific literacy which contains an understanding of: i) key scientific terms; ii) the methods of science and iii) the impact of science and technology on society (Miller, 1983). Questions in each of these areas have been used to judge levels of scientific literacy in a large number of countries. This approach has been forcefully criticised by some due to the 'deficit model' it
presents (see for example Layton, 1986) - this criticism is explored in detail in Chapter Three.

Other scholars have extended Miller’s analysis in favour of a definition of scientific literacy which encompasses literate individuals correctly applying scientific knowledge and reasoning to solve specific problems (for example Laetsch, 1987). In these cases, scientific literacy is more than an intellectual habit, it also includes an essential applied component, a knowledge-in-action requirement. Other definitions have focused on cognitive preferences for science, or an interest or positive attitude towards science. For example, Tamir (1985) defines a scientifically literate person as ‘somebody who wants to do and actually does something of a scientific nature’ (p 56).

Although the debate has been widened - not least - by Leavis’ challenge to Snow (see, for example, Trilling, 1962), and the writings of Foucault (1980) and Habermas (1983) - the goal here is not to develop a rationale for scientific literacy but to focus on the pragmatic case of the public understanding of Radon.

In part, the problematic nature of reaching a clear definition of scientific literacy stems from the universal nature of the arguments presented in its favour. As scientific literacy is itself unlikely to be universal and will depend markedly upon the purposes for which the concept is advocated, different kinds of ‘literacy’ are required for different purposes. In this case, the key question is: What is scientific literacy for?

Shen (1975) addresses this question when he distinguishes between three different types of scientific literacy designated as: practical, civic and cultural. ‘Practical scientific literacy’ enables the individual to cope with basic everyday problems (c.f. the utilitarian argument); ‘civic scientific literacy’ enables citizens to contribute to discussions about science related issues (c.f. the democratic argument) and ‘cultural scientific literacy’ enables individuals to recognise and appreciate the achievements of science (c.f. the cultural argument).

Other authors have extended these to include other forms of scientific literacy. For example, Layton (1993, p15) adds ‘industrial literacy’ (related to the management of
workers in an occupational context) and 'vocational literacy' (related to hobbies and pastimes). Similarly, Nelkin (1995) has considered the requirements of members of the public to understand the scientific content of the media - which could be called: a functional scientific media literacy.

Nevertheless, each one of these functioning literacies is again broad in extent and the definitions fail to highlight the many different requirements they encompass. For example, civic literacy is itself a requirement to understand a large number of scientific issues such as global warming and nuclear power - each of these, potentially, requires a quite different scientific expertise.

It would appear that scientific literacy is far from monolithic, but then this is true too of the public, who have different interests, values and experiences. More important than a universal definition of scientific literacy is the need to recognise that different groups of the public are likely to have different needs at different times. Once this is acknowledged, the 'public' can be categorised according to their needs. This is the approach, for example, of Nelkin (1982) who has identified three clear public groups:

1. the geographic neighbours of science, for example, people who are wary about a nuclear power station; or the site of a new airport;
2. the recipients of health care, who include people who are, for example, affected by the availability of new drugs; and
3. consumers of the products of science and technology who are, for example, concerned about food additives, and food preservation.

Layton (1993), Irwin (1995) and Wynne (1991) have identified other groups. In the majority of these cases, the justification for these groups to understanding science rests on arguments of a democratic and utilitarian kind. However, importantly, this separation provides a meaningful, focused and, above all, manageable context in which to consider scientific literacy.

This is the approach adopted in this study as scientific literacy is explored within a discrete public group. In this thesis the public are situated in a geographic area of
health concern from resulting high levels of Radon gas. In this social context (see Chapter One) members of the public are in a potentially life-threatening situation and science provides expertise to ameliorate this situation. In broad terms, the justification for the public to understand the science of Radon is based on a utilitarian argument: the public requires a knowledge of science to act practically to reduce the health risks to which they are exposed.

2.3 THE RELATIONSHIP BETWEEN SCIENCE AND THE PUBLIC

Considered from a social context, studies of the public understanding of science are concerned with the interaction of three broad social groups, scientists or 'insiders', the general public or 'outsiders' (Ziman, 1978) and communicators or 'educators' of science. However, it should be noted that, although this representation is useful for the following discussions, it is an over-simplification as none of these 'archetypes' are homogenous, for example:

- scientists include, in any one area of science, a 'core set' working at the cutting edge of research as well as the wider scientific community (Collins, 1995). This group could also include science policy makers, such as the Department of the Environment (DoE) and the National Radiological Protection Board (NRPB) as they have direct access and involvement in research;
- communicators include both formal and informal educational sources.
- the public includes, scientists, interest groups (e.g. wildlife and environmental groups); members of the public with hobbies involving science (e.g. fishing or gardening) as well as members of the public with a general interest (or not) in science.

Figure 2.1, depicts these three broad groups. At one extreme is the scientific community. This is a restricted social group primary concerned with the production and validation of scientific knowledge as well as its regulation. Within this view scientists are seen as forming a selective group the members of which share a given expertise. At the other extreme are members of the public. This second group comprises of people without professional involvement in science and, as such, they
are removed from the scientific community. The public are not actively involved in scientific knowledge production but, may, for example, be involved in using scientific knowledge in personal decisions or in suffering the influences of scientific discoveries and technological gadgets.

**Figure 2.1**, a representation of the relationship between science, the public and communicators

Located between these two groups are the 'communicators'. This group is also diverse and contains a collection of institutional bodies. In the majority of cases, scientific information will pass through this group, which acts as a kind of filter of scientific information. Communicators will frequently adapt information to suit their intended audience, for example, by making scientific explanations more intelligible, relevant and interesting. In this respect, they are not neutral messengers, but are influenced by
social, political, and institution pressures of their own (see for example, Nelkin, 1995 and Dunwoody, 1992).

The science communicators are divided into formal and informal learning providers. The formal learning providers are predominately represented by the social institutions of schools, colleges and universities. These formal educational settings are seen as providing a bridge between science and the public in two ways; first, by providing a platform and gateway for future scientists - through undergraduate and then post graduate research, and second, by acting as a source of scientific information for the public. The informal learning providers are groups who intentionally make scientific information available to citizens outside of formal institutions. This group includes, for example, museums, zoos, the media and government agencies.

In figure 2.1, the term 'dissociation' is used to represent differences between the scientific community and the general public. Layton (1986) claims this dissociation has occurred relatively recently. He maintains that throughout the eighteenth and nineteenth centuries, science for specific social purposes (science-for-the-people) manifested itself in both the scientific community and in formal and informal education. At this time, science courted huge popularity at many levels within British society. However, this position changed during the twentieth century when science for specific social purposes was replaced with a 'canonical science': a science based on the ideology of pure research and driven by a philosophy of science for science’s sake. As a consequence, Layton asserts that science in the context of use has become downgraded (to an applied science and technology) and, with this change of status, attempts to make science relevant to the needs of everyday life then ceased.

The magnitude of the separation between the public and scientists has been the focus of recent research concerns. Ziman (1984) and Wynne (1991), for example, conclude discussions about the public understanding of science by suggesting that:

There is a serious mismatch between the interests of those who are already inside science and those whom they would like to draw in (Ziman, 1984, p23);
Chapter Two: Science and the Public.

It is necessary to stress that ordinary social life which takes contingency and uncertainty as normal and adaptation to uncontrolled factors as routinely necessary, is in fundamental tension with the basic culture of science which is premised on assumptions of manipulability and control. (Wynne, 1991, p128)

It appears that a considerable difference can exist between the interests and the cognitive practices of ‘insiders’ and ‘outsiders’ (Ziman, 1978).

In this thesis, the concern is with residents living in areas of high Radon concentration and it is the utilisation of science within this everyday social context which provides the rationale for increasing the public understanding of Radon. A consideration of social context is significant here because, in part, it defines the problem. A consideration of Radon may raise different questions and, accordingly, different answers depending upon, for example, whether it is asked in the laboratory, a political debate or by somebody living in a Radon area. Given that the world of ‘knowledge-use’ [everyday life] is far removed from that of ‘knowledge-production’ [the scientific community], it may be that members of the public living in Radon affected areas with local expertise and distinct concerns raise different questions to those of radiological scientists.

2.4 THE SCIENCE-CENTRED COMMUNICATION PARADIGM

Rather paradoxically, in a science-centred paradigm the lime-light is directed away from science and is focused on members of the public. From this viewpoint, scientific knowledge is essentially recognised as universal and attempts at informing the public become a case of simply telling them science. Once the public have become conversant in science, the assumption is that they can then use this knowledge in their personal situations. In this way a greater knowledge of science is equated with the ability to make better decisions.

From this enlightenment perspective, the current problems associated with low levels of scientific literacy rest firmly on the shoulders of the public who are viewed as lacking the knowledge and interest in science. Concerns about the public
understanding of science then become concerns of public ignorance - later to be equated with irrationality. Wynne (1992, p42) writes of the consequences of this perspective for studies of the public understanding of science:

Formulated in this way the problem throws all the critical research attention onto the public and the media. The only problems within science are to do with inducing scientists to communicate more clearly and entertainingly in lay terms.

An illustration of a science centred perspective comes from a recent publication of the Royal Society where Roberts (1996) explores the public’s reaction to nuclear power. In this article, he equates the public’s fear and rejection of nuclear power with their lack of understanding of radioactivity. Roberts purports that, with a fuller scientific understanding, the public would be more accepting of nuclear scientists and nuclear power. The problem he perceives is one of public ignorance (of which he presents no evidence) and, with a more comprehensive knowledge of science, the public would ‘naturally’ be more reasoned and therefore supportive of nuclear scientists.

Incidentally, recent research would suggest otherwise. It appears that attitudes to nuclear power and knowledge about radioactivity are not so closely linked. In a recent study, members of the public with negative attitudes towards nuclear power were actually motivated to acquire scientific knowledge and then to construe it in support of their case rather than to change their allegiance and support nuclear scientists (Lee, 1987).

The above example illustrates features of a science-centred paradigm which rests upon a number of assumptions about scientific knowledge, these include that:

- Scientific knowledge is universally applicable;
- Understanding science will always result in better decisions;
- Positive attitudes towards science are related to expertise in science.
However, it seems, that each of these assumptions is open to challenge (see, Ziman, 1991; Wynne, 1991; Layton, 1991 and Irwin and Wynne, 1996) and as this thesis progresses this work is explored more fully (see Chapter Three).

Irwin (1995) maintains that when scientists communicate with the public it is essentially on their own science-centred terms, indeed, he is critical of the Royal Society’s report into the PUS for its science centred recommendations:

There is no suggestion in the Royal society report that the organisation of science is open to change or that it should incorporate citizen views within research policy. The goal is to make the public better informed about science but not to encourage a critical evaluation of the scientific institutions. For the Royal Society and most of the contemporary apologists of science, science itself is not the problem - the problem is gaining public understanding and hence acceptance of science.

(p16)

Recent research has highlighted problems associated with science-centred communication, as it emerges that often when scientific advice is offered to the public it is found wanting and not directly useful in meeting their everyday needs (for example, Irwin and Wynne, 1996, see Chapter Three). Ziman (1991) summarises the importance of this finding:

In this program of research, we have seen many simple everyday questions that cannot be addressed properly, let alone answered simply in terms of a shortfall in potential scientific understanding.


It seems that scientific advice is found wanting because it overlooks, and is ignorant of, the practicalities and constraints of complex everyday situations (see, for example, Layton et al., 1993).

It may be that experts find it difficult to see problems in any other way than on their own terms - a member of the public who is dealing with a scientific issue may have a
quite different and unique viewpoint (Turney, 1997). However, it appears that when scientists talk to the public the basic rule of communication - *know your audience and think what they need to know* - is too frequently forgotten (see, for example, Layton *et al.* 1993 reviewed in Chapter Three).

The research presented in this thesis seeks a more critical approach and a different way of thinking. This *interactive approach* acknowledges scientists as sources of useful information but revokes simple science-centred communication. This is an approach which is sensitive and responsive to the public’s needs. In this sense, a meeting point is sought - a common ground, between scientists and the public - for the purpose of addressing these needs.

**Figure 2.2.** A representation of two models of communication with the public

![Diagram of communication models](image)

A uni-directional, science centred, model of science communication. A bi-directional interactive model of communication.

The differences between a science-centred and an interactive model of communication are summarised in figure 2.2. In a science-centred approach the information flow is unidirectional - from scientists (the provider of information) to the public (the consumer), whereas an *interactive approach* is bi-directional and enables exchanges of information - significantly, it recognises that the public and scientists can both have expertise.
Interactive models of science communication are not new, they have been emphasised by constructivist science education research throughout the last twenty years (at least). Teachers and curriculum materials, for example, acknowledge the importance of exploring children’s scientific ideas and building on these ideas (see Chapter Three). However, as Prewitt (1983) ironically comments about the emphasis of existing research; ‘the public probably knows more about science than the scientists know about the public’ (p.23).

This thesis aims, in many respects, to turn the traditional debate on the public understanding of science on its head and to focus on the public. The aim to explore how some of its members learn science. The approach taken recognises that people living in areas of Radon concern have specific needs and expertise. With a better understanding of how this audience learns about Radon it may be possible to communicate more successfully.

2.5 THE SCIENCE COMMUNICATORS

While considering cries for a greater public understanding of science, it is significant to note the often implicit assumption that the public can be educated or can educate themselves in science. As Layton, Jenkins, Macgill and Davey (1993) note:

Implicit in recommendations for a greater public understanding of science, and in measures designed to achieve this end, is the blind belief in the ability of all members of the public to learn the science that is important to them. Few have questioned the achievability of the goal, and fewer still its desirability. (p. 2)

Science ‘communicators’ have a key role to play in providing science learning opportunities - they are recognised as a central group on figure 2.1. This group is composed of formal and informal educational providers. However, this distinction is not always clear and is an over-simplification in that informal learning providers (such as museums) are commonly used by formal education providers (schools). Similarly, museum and exhibition staff are frequently drawn from the ranks of trained school teachers. Definitions abound in the literature, Wellington (1991, p.365) for example,
provides a distinction between informal and formal learning as summarised in table 2.1.

**Table 2.1, features of formal and informal learning, Wellington (1991, p.365)**

<table>
<thead>
<tr>
<th>INFORMAL - e.g. field trips</th>
<th>FORMAL - e.g. schools</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voluntary</td>
<td>Compulsory</td>
</tr>
<tr>
<td>Unstructured</td>
<td>Structured</td>
</tr>
<tr>
<td>Unsequenced</td>
<td>Sequenced</td>
</tr>
<tr>
<td>Nonassessed</td>
<td>Assessed</td>
</tr>
<tr>
<td>Open-ended</td>
<td>Close-ended</td>
</tr>
<tr>
<td>Learner-led</td>
<td>Teacher-led</td>
</tr>
<tr>
<td>Learner centred</td>
<td>Teacher centred</td>
</tr>
<tr>
<td>Out-of-school context</td>
<td>Classroom context</td>
</tr>
<tr>
<td>Non-curriculum based</td>
<td>Curriculum based</td>
</tr>
<tr>
<td>Many unintended outcomes</td>
<td>Fewer unintended outcomes</td>
</tr>
<tr>
<td>Social intercourse</td>
<td>Solitary work</td>
</tr>
<tr>
<td>Nondirected or learner directed</td>
<td>Teacher directed.</td>
</tr>
</tbody>
</table>

One problem with this approach is that it can be over simplistic. For example, visits to museums can be both voluntary or compulsory, structured or unstructured, sequenced or unsequenced etc., as noted by Hofstein and Rosenfield (1996).

In the following discussions, formal science education means activities that occur in a school, university or college settings and form part of an accredited system. On the other hand informal science education is more wide reaching and includes all learning activities which occur outside of formal settings. In both cases, the importance of this central group is considered for the public understand of science.

2.5.1. FORMAL SCIENCE EDUCATION.

The story of formal science education seems to be one of good intentions which have failed to materialise. After compulsory school science education the majority of pupils (>70%) will not choose to continue with science to a higher level or to use it in their future careers. For this large group, the principle aim of school science must be to provide a basis for scientific literacy. As Millar (1993) writes:
The issue of public understanding of science - what that might mean and how it might be promoted is of central importance to all [school] teachers for it provides the rational for what they do. (p. 357)

The Royal Society's (1985) report is also clear about their expectations of formal science education:

A proper science education for all must be the starting point for any attempt to achieve a level of public understanding adequate to meet requirements [of citizens]....The formal education system should provide all members of society with the base of knowledge, skills and understanding on which their subsequent development at home and at work will build, irrespective of subject or occupation.

(p. 17)

Scientific literacy is now widely recognised as a fundamental curriculum aim (Fensham, 1997). It is common-place for science educators, curriculum designers, and teachers to repudiate the idea that scientific knowledge is, or should be, essentially esoteric or exclusive: that only experts can make decisions relating to the impact of science on society. This social theme has been highly influential throughout the 1980 and 90’s, where science curriculum reforms have developed policies of 'science for all' - constructed with an aim to cater for needs of all citizens (for example, see Fensham, 1993; 1997).

In England and Wales, for example, the National Curriculum (DFE, 1995) requires the teaching of ‘science in everyday life’ throughout the age range 5 to 16, with the implication that it should lead to ‘responsible citizenship’ (p 3). In the US, the American Association for the Advancement of Science have recently published their ‘Benchmarks for Scientific Literacy’ (AAAS, 1993). This syllabus for schools is a blend of traditional science curriculum content interspersed with a consideration of the nature and history of science.

Science, Technology in Society (STS) has become an umbrella term associated with the challenge to make science relevant and interesting to all citizens (Solomon and
Aikenhead, 1994). Hofstein et al. (1988), for example, define STS teaching as 'teaching science content in the authentic context of its technological and social milieu'. (p 357). In content, STS curriculum courses are often wide ranging and pay attention to:

- Addressing real-life situations
- Relating science to wider societal and technological issues
- Developing scientific literacy
- Promoting science as a cultural phenomenon (Eijkelhof, 1994, p563.)

There are no shortage of materials and courses dedicated to the STS approach. Many of these are now in their third decade. STS courses include: Science and Technology In Society, [SATIS] materials in the UK (Hunt, 1988); the PLON materials in the Netherlands (Eijkelhof and Kortland, 1988); Science Education for Public Understanding Program [SEPUP] in the US (SEPUP, 1992) and STEPS in the Philippines.

However, despite the rhetoric of curriculum aims and the availability of curriculum materials, science curricula have, on the whole, failed to adjust to this STS approach - school syllabuses still stress a high factual load and contain abstract content which is related to contexts which are more important to practising scientists than the general public (Fensham, 1997; Watts and McGrath, 1998; Dillon and Gilbert, 1994). Claxton (1991) makes the point when he says:

the public image of science, and especially that which informs the vast majority of science education, is wrong or misleading at almost every point. With the exception of the odd lesson about Brave little Galileo and the Stupid Old Church, and a nod at ‘phlogiston’ and ‘caloric’, the social and historical context are ignored in favour of a routine transmission of a body of (true, unequivocal) knowledge. (p74)

The reasons for the lack of change in science classrooms have been widely considered. Some attribute blame to a lack of definition in the approach ('a unifying framework is required' - Dillon and Gilbert, 1994) or the failure to place technology at
the centre of these reforms ('the missing T' - Layton, 1993). In these cases, the curriculum seems at fault, as Shamos (1995) writes:

[STS Courses] while seeming brighter on the surface, remain rather bleak for much the same reasons that have long plagued the scientific literacy movement itself, namely, a lack of a clear-cut definition of STS and want of adequate incentive on the part of the students. More than this, however, STS suffers from a terminology that seems to promise more than it can deliver in the way of science understanding or awareness (pp. 139-140).

Others focus on classroom tensions: teachers have been educated in traditional content and approaches and lack understanding of STS and there is little curriculum time for STS teaching (see for example, Watts and McGrath, 1997). Fensham (1997) highlights the low status associated with STS courses (courses which have been traditionally designed for the non-scientists or 'science-phobics'), as well as, the emphasis that science education research has placed on traditional concepts.

In any case, these approaches have failed to offer the reforms they promised, science curricula still continue to teach for the elite, the few which intend to study science at a higher level and fail to address the needs of all (Claxton, 1991, Millar, 1996). Ogborn (1995) refers to a 'lack of nerve in science education' as it has failed to embrace its social component.

Recent publications reinforce the need for radical reform (see for example, Claxton 1991 & Driver et al. 1996) and highlight 'the problems and crisis with science today' (Levinson and Thomas 1997). As noted in Chapter One, things may well again be changing. For example, in the UK, the Association for Science Education (ASE 1996) has begun a curriculum review for the year 2000 (Project 2000) and the Nuffield Foundation have funded a seminar programme, Beyond 2000 (Osborne, 1997). It would appear that curriculum change is in the air once more and at the top of the agenda is the public understanding of science.
2.5.2 INFORMAL SCIENCE EDUCATION

Given that learning science is a life time commitment the limitations of a front-loaded educational system become evident. Informal sources of education will need to play a central role in any attempts to increase the public understanding of science.

The Royal Society (1985) highlights the powerful influence that the mass media, public lectures, museums and libraries have on the public understanding of science. Their report, for example, urges:

Newspaper editors and their senior staff to take a much more positive attitude to the role of science in their newspapers, to encourage their science, technology and health correspondents to produce more material and enable it to get space in the newspapers, and to encourage their journalists in general to consider the scientific connotations of their stories. (p.33)

There are, potentially, a vast number of informal science sources. Lucas (1983) provides a helpful and comprehensive review of many of these and supplies guidelines to distinguish between 'accidental' and 'deliberate' encounters with learning sources as well as 'intentional' or 'unintentional' sources, see figure 2.3.

![Figure 2.3](image_url). A representation of Lucas's (1983) categorisation of informal learning.
This analysis, can be used, for example, to distinguish between science sources where learning is intentional (such as a museum) and those where learning science is unintentional (reading a science fiction novel or watching television programmes like The X-Files). Furthermore, it takes into account the intentions of the learner (accidental or deliberate). It is possible to have a deliberate encounter with an intentional source (e.g. visiting a doctor to find out about birth control); a deliberate encounter with an unintentional source (e.g. asking a neighbour about nuclear power); an accidental encounter with an intentional source (e.g. switching on the television and discovering a documentary on dinosaurs); and an accidental encounter with an unintentional source (e.g. reading a magazine which contains an article on evolution whilst waiting for the dentist).

In each of these four categories, the informal learner encounters, and may learn, science. This heuristic is useful because it emphasises the wide range of potential learning situations - many of which could be unintentional.

Given such a variety of experiences, a key consideration is to evaluate which of these encounters are the more significant. As Collins and Bodmer (1986) ask:

Do individuals get most of their understanding of science from school, from television, radio and newspapers, from their jobs, from leisure activities, from magazines and books, from museums and libraries, from special events designed to promote understanding of science? What is the balance between these sources for different segments of the public, and what should the balance be? (p.103)

These are complex questions to which there are currently only partial answers. Traditionally, informal science education research has concentrated on intentional sources and as a consequence can lose sight of the multiplicity of informal learning. Indeed, it can be argued that a defining characteristic of informal learning is the ability to learn from a number of sources (intentional and unintentional) as a result of deliberate and accidental learning encounters.
In the current thesis, the information context (see Chapter One) incorporates informal sources of information about Radon that are readily available to members of the public living in ‘Radon areas’. These are likely to include NRPB leaflets, the media such as, newspapers, television and radio documentaries, as well as advice and guidance offered by a neighbour. The content and style of communication of these information sources is considered, as well as, the potential significance that each source has for the public understanding of Radon.

As previously described, this thesis explores conceptual change learning (Strike et al., 1982) in a sample of people living in locations with high levels of radioactivity (the social context). Radon gas is a serious threat to public health and is largely overlooked by the media, the public and science education. This chapter concludes with a technical explanation of Radon and its estimated risks.

2.6 RADON GAS: A TECHNICAL SUMMARY

Details about Radon are not commonly documented possibly because it is so contemporary. The technical summary which follows provides a review of key scientific concepts and includes details about measurements and reduction techniques.

Radon is a colourless, odourless gas formed by the decay of Uranium (isotopes 238 and 235). It occurs in three isotopes, Rn\(^{219}\), Rn\(^{220}\) and Rn\(^{222}\) (Rn\(^{220}\) is commonly known as Thoron). The most radiologically significant isotope is Rn\(^{222}\) due to its longer half-life and occurs in the Uranium-238 decay series, listed in table 2.2.

Uranium-238 is present in most rocks, soils and building materials in trace amounts and when it decays Radon is generated. Radon is a noble gas, is unreactive, and moves through these materials and is released into the air. When Radon is released outdoors it rapidly disperses into the atmosphere and concentrations of the gas remain low. However, if released into a confined space its concentration can increase.

Radon is a short-lived radioactive gas which decays via an \(\alpha\) emission. The main health concern is not directly with Radon but with its short lived radioactive
daughters, isotopes (Polonium, Lead and Bismuth - see table 2.1). When in air these solid elements form an aerosol. If inhaled, these radioactive particles can be deposited in the nose and bronchial regions of the lungs. Once lodged in the mucus of these areas they continue to decay and emit $\alpha$ and $\beta$ radiation.

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Emission</th>
<th>Half-life</th>
<th>Activity of 1g of pure substance (Ci)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uranium-238</td>
<td>$\alpha$</td>
<td>4.5x10^9 yr.</td>
<td>3.4x10^7</td>
</tr>
<tr>
<td>Thorium-234</td>
<td>$\beta,\gamma$</td>
<td>24 days</td>
<td>2.3x10^4</td>
</tr>
<tr>
<td>Protactinium-234</td>
<td>$\beta,\gamma$</td>
<td>6.75 hours</td>
<td>2.0x10^6</td>
</tr>
<tr>
<td>Uranium-234</td>
<td>$\alpha$</td>
<td>2.5x10^5 yr.</td>
<td>6.0x10^3</td>
</tr>
<tr>
<td>Thorium-230</td>
<td>$\alpha$</td>
<td>1600 yr.</td>
<td>1</td>
</tr>
<tr>
<td>Radon-222</td>
<td>$\alpha$</td>
<td>3.8 days</td>
<td>1.5x10^5</td>
</tr>
<tr>
<td>Polonium-218</td>
<td>$\alpha$</td>
<td>3 min</td>
<td>2.9x10^4</td>
</tr>
<tr>
<td>Lead-214</td>
<td>$\beta,\gamma$</td>
<td>27 min</td>
<td>3.3x10^7</td>
</tr>
<tr>
<td>Bismuth-214</td>
<td>$\beta,\gamma$</td>
<td>19.7 min</td>
<td>4.3x10^7</td>
</tr>
<tr>
<td>Polonium-214</td>
<td>$\alpha$</td>
<td>0.5 s</td>
<td>1.0x10^11</td>
</tr>
<tr>
<td>Lead-210</td>
<td>$\beta,\gamma$</td>
<td>21 yr.</td>
<td>82</td>
</tr>
<tr>
<td>Bismuth-210</td>
<td>$\beta,\gamma$</td>
<td>5.01 days</td>
<td>1.24x10^6</td>
</tr>
<tr>
<td>Polonium-210</td>
<td>$\alpha$</td>
<td>138 days</td>
<td>4.5x10^5</td>
</tr>
<tr>
<td>Lead-206</td>
<td>Stable.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2.2. The uranium decay chain, Fremlin (1989, p317), $\alpha$ = alpha particle, $\beta$ = beta particle and $\gamma$ = gamma ray.

Presently, Radon is widely recognised as the second largest cause of lung cancer in humans after smoking (Lee, 1992, The US Environmental Protection Agency, 1992). However estimates of the harmful effects of Radon are not without controversy. Typically risk estimations are based upon data collected from studies of uranium miners. The International Commission on Radiological Protection [ICRP] (1993) provides specific details of 7 epidemiological studies on miners [N=30,000] in which 700 lung cancer deaths were recorded. These studies provide quantitative information about the effects of exposure to high concentration of Radon, which are then extrapolated to estimate the effects at lower concentrations. However, there is some methodological uncertainty about this approach and it has to be open to criticism. For example, Marx (1993) recounts two studies which look at low-level radiation exposure (10-20 mSv/year) and which suggest that low levels can actually suppress cancer - not increase it.
In view of these uncertainties, direct evidence from studies of residents exposed to low levels of Radon have been sought. Studies of this nature face a number of methodological difficulties concerning the joint affect of Radon and smoking. To illustrate, Cornwall has the highest levels of domestic Radon in the UK but has the lowest rate of lung cancer (O’Brien, 1996). Wozniak (1993) suggests reasons for this unexpected trend:

Domestic Radon comes from the ground close to or beneath our homes. Although we know that local geology largely determines the domestic level of Radon, an important determinate of Radon concentration is whether you live in a large detached house (high catchment area so high levels of Radon); a more modest terraced cottage (lower Radon) or a one bedroom flat on the top floor of a tower block (tiny Radon). But the bigger your home, the richer you are, the less likely you are to die of lung cancer, as you are less likely to smoke, to have a poor diet or live in the polluted inner city. So the level of domestic Radon is a surrogate for wealth. (p 42)

Woznaik suggests that these inter-related correlates make it impossible to determine Radon risk directly through epidemiology and, currently, the estimates of risks adopted by the ICRP are based on extrapolated data (ICRP, 1993).

These figures have been used to provide guidelines for domestic Radon reduction, commonly termed action levels. The ICRP recommends that national authorities should use their results and decide the levels which best suit the conditions in their countries. Amongst those countries who have set action levels are: the USA [150 Bqm$^{-3}$]; Australia, the Republic of Ireland and the UK [200 Bqm$^{-3}$]; Germany [250 Bqm$^{-3}$] and Sweden [200 Bqm$^{-3}$] for future dwellings and [400 Bqm$^{-3}$] for existing dwellings (Muirhead, 1994).

In the UK, the National Radiological Protection Board [NRPB] has the duty to advise government departments and statutory bodies with responsibilities for radiation protection. The NRPB (1995) have inferred the following risks, which they use to support their [200 Bqm$^{-3}$] action level, set in 1990 (see table 2.3).
Chapter Two: Science and the Public

<table>
<thead>
<tr>
<th>Average concentration of Radon in air (Bq/m³)</th>
<th>Annual dose: (milli-Sievert)</th>
<th>Life time risk of lung cancer</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 (UK national average)</td>
<td>1</td>
<td>1 in 300</td>
</tr>
<tr>
<td>200</td>
<td>10</td>
<td>1 in 30</td>
</tr>
</tbody>
</table>

Table 2.3. The life time risk of Radon exposure at two average Radon concentrations.

Recently, Radon has been linked to cancer from exposure to electromagnetic fields (Henshaw, Ros, Fews and Peece, 1996). The research conducted at Bristol University claims that electric fields can attract and concentrate the aerosol containing Radon decay products - a process which increases skin deposition, inhalation and lung retention of the radioactive aerosol. Using a model of how Radon can spread through out the body, the team have linked increased doses of Radon to leukaemia. The research has been used to account for the higher occurrences of leukaemia in residents living near power stations and power lines (Wilkie, 1996). Although this research is in its infancy and further studies of residents of high Radon levels who are exposed to electric fields are planned in the next few years (Track Analysis Group, 1997). However, presently, the NRPBs are sceptical of the these claims (O’ Brien, 1996).

For many years, Radon has been recognised as the largest contributor to background radiation. However, only recently have levels of Radon in domestic homes been measured and in some cases they have been found to be alarmingly high (O’ Riordan and O’ Riordan 1991). Levels of Radon in buildings are determined, principally, by the concentration of the Radon in the subjacent ground and the mechanisms of influx. The pressure differences between indoors and the ground induces a flow of the gas. Once indoors, Radon is found to concentrate in building with poor ventilation (Cliff et al. 1991).

In the UK, the NRPB began recording levels in the mid 1980’s and an extensive publicity campaign was then launched in Cornwall and Devon in March 1991. Initially, the counties of Devon and Cornwall were selected as they have an abundance of granite, a rock which often has large trace elements of uranium (NRPB, 1990).
This publicity campaign was led by an eye-catching leaflet entitled 'Radon in Houses' (see Appendix I) which was delivered free to every household in Cornwall and Devon in March 1991. This provided some details about Radon and invited the householders to apply for free measurements. Measuring Radon is very straightforward. Two small yellow disk detectors are sent by the NRPB with detailed instructions. One disk needs to be placed in the living room and one in an occupied bedroom. These disks should then be returned to the NRPB after a period of three months. Once returned, the householders receive a note of their measurement level within a few weeks. However, by the end of 1991 only approximately 12% of households had taken advantage of the service (DOE, 1994) - the public's reaction to Radon is explored more fully in Chapter Five.

In 1995, the publicity campaign was broadened to include the English counties of Derbyshire, Northampton and Somerset and Scotland and Northern Ireland (NRPB, 1996, 1997). By 1996, it was possible to use the data collected to construct a picture of the levels of Radon in domestic property in the UK, see figure 2.4 over leaf.

The highest concentrations of Radon in the UK are found in Devon and Cornwall. The NRPB uses the concept of an affected area - an area where 1% or more of homes exceed the action level. In Devon and Cornwall, the NRPB concluded that there is no significant area that has less than 1% of homes above the action level. In particular cases, measurements were recorded at 50x the recommended 200Bq/m$^3$ action levels (NRPB, 1997).

Current measurements suggest that over 100,000 houses in Britain are above the recommended action Level (NRPB 1996) and other affected areas include Northamptonshire and Somerset. However, Radon levels are found to vary dramatically from property to property and there is a small chance of finding high levels almost anywhere in the UK (Dixon and Gregory, 1992).
When houses are found to be above the action level householders are advised to take remedial action and are provided with general information about Radon (DoE, 1994). Grants for carrying out any remedial measures are presently discretionary and linked to earnings. Nevertheless, remedial techniques tend to be expensive and the NRPB strongly cautions against DIY installation (Dixon and Gregory, 1992). Cliff et al. (1991) cite an example of a householder who managed to treble their Radon levels by incorrect installation. The key to Radon-reduction is ventilation. The choice of remedial technique depends on the house construction, the type of floor limits the mechanisms possible. The most common remedial techniques are: sealing floors and service entries; ‘whole house positive pressurisation’; increased ventilation under suspended floors, and under-floor suction for solid floors. The efficacy of these
techniques have been reviewed by the NRPB (Dixon and Gregory, 1992; Green, 1991 and Miles et al., 1990).

The best form of Radon-reduction mechanisms is under-floor suction. This is effected by excavating a cavity or sump beneath the floor which is then connected to a fan. The exhaust of the fan then discharges the Radon into the atmosphere. This is only available, however, in houses with concrete floors. Sealing wooden floors is expensive, very messy and likely to need continued renewal. Radon reduction mechanisms are currently required in all new houses built in the designated action areas (NRPB, 1995).

This second chapter has discussed the rationale for increasing the public understanding of Radon and the shortcomings of traditional science centred communication approaches. In the following chapter the focus is on learning science. To fully understand the public understanding of Radon it is significant to understand how, and for what purposes, the public learn about this potential health risk.
CHAPTER THREE
THE THEORETICAL BACKGROUND:
LEARNING SCIENCE

3.0 INTRODUCTION

Over the past 20 years, there has been a myriad of studies on how children, adolescents and adults make sense of their world. Considerations of how people come to understand scientific concepts has taken a significant and central role within these studies.

This review starts from a broad perspective and considers theories of adult learning (of andragogy rather than pedagogy). During the 1970's and early 1980's, ‘adult-specific’ models of learning gained acceptance. However, more recently, these models have been challenged in favour of studies exploring ‘cognition within a specific context’. This shift in research emphasis is used here to articulate the assumptions that form the base of this study and which shape the following literature review.

The review of learning in science then proceeds by discussing the constructivist perspective which this thesis adopts. This leads to the heart of the literature - research within the areas of formal and informal science education. The principle focus of this thesis is conceptual change learning. When considering conceptual change the review adopts a quasi-historical perspective and initially considers children’s conceptions and then models of conceptual change in general.

The public understanding of science (PUS) is a growing research area, part of which, relates to adults’ understandings of science. The review continues by presenting the results of a broad range of PUS studies drawn from two different research standpoints - the normative and the ethnographic. Finally, the chapter concludes by considering
learning in informal contexts (such as, museums, newspapers and television programmes) and a summary of seven significant features of the reviewed research.

Only part of the literature review is covered in this chapter - Chapters Five and Eight extend its scope. Chapter Five reviews studies which explore the learning of radioactivity and Radon; while Chapter Eight considers conceptual change learning in more detail.

3.1 ADULT AND CHILDREN AS LEARNERS

Throughout the 1970's and 1980's assumptions were made about fundamental differences between adult and children learners and a number of theories of andragogy were developed (McKenzie 1977, 1979; Knudson 1979; Knowles 1979, 1984; Cross 1981; Brookfield 1986). Andragogy (as distinguished from pedagogy) is derived from the Greek word 'andra' meaning man and has been used as a central organising framework to explore the different needs and learning characteristics of adults in contrast with those of children.

Knowles (1984), a leader in the field, maintains that andragogy is based on four crucial assumptions about adult learners which are different from assumptions made about children as learners. The assumptions are that, as a person matures:

1. his [/her] self concept moves from being a dependent personality towards being a self-directing human being;
2. he [/she] accumulates a growing reservoir of experience that becomes an increasing resource for learning;
3. his [/her] readiness to learn becomes orientated increasingly to the developmental tasks of social roles; and
4. his [/her] time perspective changes from one of postponed application of knowledge to immediacy of application, and accordingly his orientation towards
5. learning shifts from one subject-centredness to one of problem-centredness.

(Knowles 1996, p. 84)
Chapter Three The Theoretical Background: Learning Science.

The continuing debates engendered by the separation of pedagogy and andragogy have been successful in raising the consciousness of practitioners within the field and have had an important role in shaping the practice of adult education (see, Edwards, Hanson and Raggatt, 1996). However, there still exists little theoretical evidence to suggest that the concept of andragogy is a distinctive age or stage of learning. This is not to maintain that differences between adults and children learners do not exist, but to suggest that their differences can sometimes be over-generalised or emphasised and so become misleading. For example, it is clearly the case that adults have lived longer and therefore accumulated more experience. But quantity of experience is not necessarily a measure of quality of learning. Indeed, quantity of experience might act as an obstacle for learning in that learners might become trapped in ‘old ways’ and therefore be reluctant to change ideas.

Initially, Piaget's studies appeared to demonstrate unequivocally that there are differences between a child’s reasoning (at various stages) and the reasoning of an adult (formal operational). However, whilst this may be a general norm, one of the central challenges to Piaget's stage theory has been fuelled by research (for example, that reviewed by Bliss, 1995) which shows that even highly educated adults perform poorly on tasks involving formal, abstract, hypothetical thinking - learning tasks are found to be easier when they are translated into more concrete contexts.

By the late 1980's, andragogy's contribution to the debate about 'age and stage' had many critics (see for example Yonge, 1985 and Podechi, 1987). Hanson (1996), in a comprehensive review of the field, maintains that andragogy is in danger of prescribing a way that adults should learn, because they are adults, rather than describing the various ways that adults actually do learn. She brings attention to the significant differences between individual adults and forcefully maintains that a theory which is grounded in the 'social context of learning' rather than the 'abstract notion of the individual' is a more meaningful area for research (Hanson ibid. p107). Hanson argues that the differences between children and adults, between pedagogy and andragogy result from 'differences of context, culture and power' rather than from developmental stages of learning between childhood and adulthood (Hanson ibid. p107).
One of the limitations of individualist debates of this nature would appear to be the way they mask the potentially much richer examinations of the learner within specific learning contexts. Indeed, studies of 'situated cognition' (Rogoff and Lave 1984; Lave 1988; and Hennessy 1993) raise a multitude of questions concerning the settings in which adults learn (for example the availability of information and the sources of information); what they learn; how they learn; why they learn and their relationships with whom they learn. All these factors are found to have a profound influence on learning and these studies are reviewed later in this chapter.

Knowles (1984) emphasises the importance of reflection in adult learning and the literature promoting reflection is extensive (see for example, Kolb 1985; and Schon 1983, 1986). In his work, Kolb (1985), for example, views learning as a continuous process of reflection rather than a fixed outcome. For Kolb, a fixed outcome of learning is considered to be a type of 'non-learning' because in his view all learning involves a type of re-learning based on reflexive critical thinking. This notion that learning is solely a process and, as such, is divorced from learning outcomes appears open to challenge. The significance of critical thinking and reflection are not particularly unique to adult education. Metacognition, for example, has been widely advocated within science education (the literature is extensive, for example see, Driver, 1991; Gunstone, 1994; Bell and Gilbert 1996).

A criticism of generalised reflexive learning theories turns on the extent to which they are universally applicable. For example, it would seem likely that specific events will take place in life which cannot be easily encompassed within previous experiences, which would appear to highlight the context specific nature of learning and reflection. Certainly Knowles' (1984) 'all embracing' adult learning theory fails to recognise the complex multi-dimensional nature of learning. Adult's are subject to a vast array of learning opportunities (see Chapter 2) and, as a consequence, one of the most important qualities of adult learning would appear to be the ability to be an adaptable learner and learn in different ways from different sources (c.f. Lucas, 1983). In this respect, the all-or-nothing status of andragogy described so far appears prohibitive rather than realistic or practical.
This thesis shifts concern away from the ideals of an ‘all encompassing theory of learning’ towards exploring adults learning about radioactivity within a specific *social context*. In doing so, it rests on a number of assumptions, namely:

1. **adult learning is not age or stage specific - children and adult learners are part of a continuum.**

2. **Learning is complex and multi-faceted - it is neither just simple recall nor is it reserved solely for highly reflexive situations. Learning can be influenced by the subject, context, social milieu as well as the physical structure of the learning environment. As a consequence, a difference can exist between learning in the public domain (informal learning) and learning in formal instructional settings.**

3. **In the public domain, individuals have multiple sources from which to construct scientific and technological knowledge; the depth and breadth of this knowledge is likely to be influenced by the context of both its construction and application.**

4. **There are intricate interactions between individuals’ feelings and attitudes towards areas of science, their understandings of science and their capacities to act on the knowledge they construct.**

5. **Informal conceptual change learning is an area that is currently under-researched. As a consequence, the field is currently open to *test* the applicability and adapt a model of conceptual change learning (Strike *et al.*, 1982) originally developed within a formal educational context to model conceptual change learning in an informal educational context.**
Chapter Three The Theoretical Background: Learning Science.

3.2 LEARNING SCIENCE, AN OVERVIEW

There is an abundance of literature in this area, this review is presented in four sections:

3.3 Constructivism
3.4 Research on learning science in the formal educational system;
3.5 Research on the general public’s knowledge of science; and
3.6 Research on informal learning of science.

Much of this review is drawn from two research domains; standard science education (Millar, 1989) and the public understanding of science [PUS] (Durant, 1992). Standard science education has a long research tradition and many journals are dedicated to its study. It tends to have an emphasis on sectors of formal education - children and science curricula are central to these. The public understanding of science is a relatively new research area. A landmark in the field was the publication of a new journal entitled *The Public Understanding of Science* which was launched in 1992. Studies into PUS originate from a wide variety of different standpoints and have existed in these perspectives before the unified research field was formulated. These standpoints reflect researchers’ backgrounds and carry with them a wide range of differing agendas and philosophies. Consequently, a study into the public understanding of science means different things to different people; a physicist, a politician, a social scientist, a geneticist, a curator of a museum, a television producer and a teacher would all offer different perspectives. In contrast with science education, the PUS tends to concentrate more on the sector of informal education and is concerned with adults and scientific literacy.

The literature review commences with a consideration of constructivism. Constructivism has had a profound influence on standard science education and underpins the conceptual change model of learning developed in this thesis.
3.3 CONSTRUCTIVISM

Constructivism is a many headed beast, however all constructivists would agree on the fundamental axiom that knowledge is constructed. As Driver writes,

The key feature of a constructivist epistemology is that human beings construct mental models of their world and new experiences are interpreted and understood in relation to existing mental models or schemes.

(Driver 1991 p 32).

Matthews (1994) divides constructivism into two traditions. The first has a psychological tradition (see for example, Kelly, 1955 and Piaget, 1929) and investigates how individual’s construct knowledge arising from their interaction with their world. This also includes research which has a psycho-social perspective (for example, Vygotsky, 1962; Rogoff and Lave, 1984)

The second, has a sociological tradition (e.g. Berger and Luckman 1979, Moscovici, 1984) and investigates how knowledge is constructed in a social context. For example, Knorr-Cerina (1981) and Collins and Pinch, (1993) have investigated the construction of scientific knowledge in the social community of scientists.

Psychological constructivism has had a profound influence on the teaching and learning of science, so much so that science education research and curriculum reforms appear currently to operate almost exclusively within a psychological constructivist paradigm. Psychological constructivism has inspired science curriculum reforms and a wide range of publications and conferences have been devoted to its followers and findings. This forms the focus of the following review.

Psychological constructivists have both personal and social traditions. The personal constructivist tradition (e.g. Piaget, 1929; Kelly, 1955) places a particular emphasis on the learner’s cognitive structure in relation to particular events and phenomena both social and physical. From this perspective, learning can be viewed as conceptual change brought about through practical activities which challenge the learner’s current
conceptions. For example, Piaget saw the role of ‘actions’ (both personal and social) as essential for conceptual change, a factor which has been used by post-Piagetians, such as, Kubli (1979) to highlight the significance of practical work in the teaching and learning of science.

The psycho-social constructive tradition (e.g. Vygotsky, 1962 and Lave, 1988) places a particular emphasis on the social world and on social interactions. Within this tradition, conceptual change in science can be viewed as the process through which learners are introduced into the language, models, theories and problems of the scientific community - a process which is frequently referred to as enculturation. Context (both physical and social) is seen as highly influential in studies of this type, as individuals engage in discussions about science in a particular social ‘context’ (Lave, 1988; Rogoff, 1990).

Constructivism has its critics, most notably (and vociferously) Matthews (1995). Matthews criticises the post-positivist epistemology and idealist ontology of personal psychological constructivism and Glaserfield’s (1989) ‘radical personal’ constructivism takes the brunt of these criticisms. Matthew’s argues that constructivism amounts to; ‘a re-statement of a standard empiricists theory of science and suffers all the well known faults of that theory’ (p161) and laments how constructivism has now been transformed into an ‘ideology of teaching’ rather than just a theory of learning.

Osborne (1996), in a balanced critique, highlights the considerable successes and weaknesses that constructivism has had in science education. It has been extremely successful in raising awareness of the learner’s understanding of science and has resulted in the development of innovative pedagogy (reviewed in the following section). However, as a ‘theoretical referent’ constructivism is weak in that it suffers from a naive instrumental epistemology and as such misrepresents science.

Certainly, within the UK, there appears to be a considerable divide between the theoretical and the practical uses of the term. School curricula label themselves as ‘constructivist’ (see for example, Starting Science - Partridge, 1992) when they are
driven by 'active' learning or 'starting where the child is at' - a slogan that has tended to become a current educational cliché without, perhaps, its consequences taken seriously (Watts and Bentley, 1991). While constructivism has offered a rebuff to didacticism, as Matthews (1994) and Osborne (1996) both note, it does not prescribe a particular pedagogical approach.

Bliss (1995) criticises constructivism by drawing attention to the different cognitive demands of learning different science concepts. Some concepts, she argues, are more closely related to personal experiences (e.g. velocity and acceleration), whilst others are less intuitive and have to be established in the absence of everyday knowledge. She emphasises that learning science is not a homogeneous experience and in doing so highlights a dichotomy between individual and psycho-social constructivist traditions. Bliss writes:

> Constructivism rarely distinguishes between making personal sense of the real world, and understanding the socially constructed world of scientific ideas. Von Glaserfield's constructivism reduces all understanding (including science) to making personal sense of the world. Social constructivism reduces all understanding (including science) to learning cultural practices. Neither reduction seems adequate to describe children learning in school (Bliss 1995, p157).

The personal and social demands of learning science are highlighted by Driver et. al. (1994) who write 'learning science involves a complex interplay of personal experience, language and socialisation' (p3). In this case, the boundaries between the social and personal perspectives appear logically blurred.

This thesis draws upon constructivist science education research, however, in doing so it is aware that constructivism as a theoretical referent has weaknesses.
3.4 RESEARCH ON LEARNING SCIENCE IN THE FORMAL EDUCATIONAL SYSTEM

The purpose of reviewing studies of learning science in the formal education system is to select a model to apply to an informal context. Turning to science education for a model of learning has a number of merits:

1. There is a voluminous amount of research which has considered understandings and learning of science within formal settings.
2. The sector of formal education is widely recognised as having a fundamental role in the public understanding of science (Royal Society, 1985; Millar, 1993).
3. Recent research has highlighted the considerable similarities between children’s and adults’ conceptions of science (e.g. Kruger, Summers and Palacio, 1990; Caillot and Xuan 1995).

The review starts by considering the substantial amount of work which has investigated conceptions of science. This supports the first phase of the data collection which charts conceptions of radioactivity. The review then considers the model of conceptual change which forms the basis of thesis’ subsequent empirical phases.

3.4.1 CONCEPTIONS OF SCIENCE

Despite considerable debate within the research of understandings of science most researchers in education and psychology appear to support the following 8 axioms original articulated by Novak (1988).

1. Concepts (scientific and social) are acquired (very) early in life.
2. Misconceptions are acquired early and are resistant to modification.
4. Information processing capacity is inevitably limited.
5. Most scientific knowledge is stored hierarchically.
6. Learners are seldom conscious of their cognitive processes.
7. Epistemological commitments (or cognitive styles) of students influence learning.
8. Thinking feeling and acting are integrated (Novak, 1988, p77).
Inevitably, different researchers debate the meanings and significance of each of these assumptions. Solomon (1993), for example, divides the field of children’s ideas of science into four orientations: ethnographic, misconceptions, cultural effects and mental representation. Of these orientations, ethnographic studies are the more popular and have dominated science education research over the last 20 years (see Pfundt and Druit, 1994). These studies are concerned with exploring the knowledge that individual’s associate with orthodox science - the focus is usually an orthodox science concept (typically part of a science curriculum) and the outcome is the individual’s representation of this concept.

Since early Piagetian days (Piaget, 1929) much research has explored children’s ideas of science and there is now conclusive evidence that children, before any formal instruction has taken place, have a wide array of intuitive beliefs about science. In the majority of cases these contradict the scientific viewpoint. Nicholls (1992), for example, has extensively explored primary pupils’ alternative conceptions of energy and suggests that there is an underlying structure to these conceptions.

Researchers have used a wide variety of different labels for these intuitive beliefs about natural phenomena. These have included, for example; ‘Pre-Conceptions’ (Thijs and Van den Berg, 1995); ‘Conceptions’ (Gilbert and Watts, 1983); ‘Ideas’ (Driver et. al., 1985); ‘Informal Ideas’ (Black and Lucas, 1993); and ‘Mental Models’ (Gentner and Stevens, 1983). Wandersee, Mintzes and Novak (1994) present an analysis of the subtle differences between these terms. This thesis uses the term conception.

‘Alternative conceptions’ (Gilbert and Watts 1983) and ‘misconceptions’ (Novak, 1988) have been used to distinguish conceptions which differ from orthodox science. The term alternative, rather than misconception, has been emphatically used by some researchers to highlight the significant differences between the child’s perception and those of the scientific community, whilst acknowledging the validity, consistency and persistence of the child’s alternative viewpoint (Watts, 1983). The phrase ‘Children’s Science’ (Gilbert, Osborne and Fensham, 1982) emphasises that children construct meanings in terms of their experiences much in the same way as do scientists. Watts and Taber (1996) define ‘Children Science’ as:
an amalgam of largely tacit explanatory ideas, often quite situation specific and highly context dependent. They work because they satisfy an immediacy of description, explanation and logic; they are usually confirmed by everyday experience and social convention, and possess a greater degree of common-sense that the seemingly high-blown, abstract and wholly unnatural explanations of science (p940).

Science education is now replete with studies of conceptions and these have been meticulously catalogued in bibliographies (see for example; Pfundt and Druit 1994; Driver, Squires, Rushworth and Wood-Robinson, 1994; Garnett, Garnett and Hackworth, 1995).

The term conceptions can refer to an individual’s representation of a single phenomena (for example, a conception of an ionic bond - Taber and Watts, 1996) and also a label which encompasses a collection of phenomena (such as a conception of evolution - Demastes, Good and Peebles, 1996). In this study, the label conception is used as a generic term to refer to both single and collections of phenomena.

In particular cases, children’s conceptions have been found to be consistent across a range of contexts and the term ‘framework’ has been used to represent this (Driver and Easley 1978 and Watts, 1983). For example, Gilbert and Watts (1983) argue that a common framework for children’s ideas in mechanics is an ‘Impetus framework’, and Taber and Watts (1996) discuss an ‘Octet framework’ for pre-university chemistry. Other researchers question the logic, internal consistency and coherence of children’s ideas (Champagne, Gunstone, and Klopfer, 1983 and Kruiper, 1994). DiSessa (1986), for example, views naive knowledge of physics as fragmented and loosely connected in nature and emphasises this by using the expression ‘knowledge in pieces’.

A great deal of commonality has been observed between children’s conceptions of scientific phenomena from both western and non-western cultures, for example, Thijs’ (1987) study of conceptions of mechanics in Dutch and Zimbabwean high schools. Cross-cultural comparisons between alternative conceptions in mechanics, heat, temperature, light and electricity have been performed by Thijs and Van de Berg
These comparisons provide evidence concerning the ontology of conceptions and Thijs and Van de Berg (ibid.) make the general observations that:

The similarities over history and across countries do suggest that human beings in a completely different culture and a different environment (without electricity etc.) develop conceptions similar to conceptions known from western students. So culture and difference in man-made aspects of the environment may have only a limited influence on transformation or construction of certain physics conceptions (p 325).

While this appears to be the case for some intuitive conceptions of physics, there is ample research evidence to suggest that cultural and social environmental factors play a fundamental role in the teaching and learning of science and the literature here is vast. For example, Solomon (1983, 1992) emphasises the social dimension in learning; Sutton (1992) stresses the centrality of language in learning; post-Piagetian studies stress the importance of context (e.g. Donaldson 1978); Cobern (1996) indicates the significance of 'world views'; and Resnick (1987) highlights the importance of the physical environment.

Recent innovative science curricula have attempted to incorporate these conceptions into methodologies of formal instruction (for example, Bentley and Watts, 1989, 1992; Osborne and Freyberg, 1987 and Driver, 1991). In the UK, one of the more influential approaches is that of the Children’s Learning of Science project (see, Scott, 1987). These curricula highlight that teaching is a process of conceptual development rather than ‘filling empty minds’.

The perceived need for primary teachers to have competence in science has also spawned a research agenda which investigates primary teachers’ conceptions of science (see for example, Science Processes and Concepts Exploration (SPACE), 1986-1990; Primary School Teachers and Science Project (PSTS), 1988-93; Summers et al; 1993 and Harlen and Holroyd, 1997). The results of these studies indicate a high level of similarity between adult and children’s conceptions of science.
For the most part, traditional school based science concepts have been the focus of science conception research and in this respect the emphasis has been upon the physical world rather than the social or emotional world. As Fensham (1997) writes:

if any of us had bothered to conduct the same sort of research into students' conceptions of socio-scientific issues (like the history of science) or of technological and environmental concepts (like social risk, product shelf life and radiation damage) we would, I am sure, have found a similarly amazing range of alternative views and misinformation, and useful pedagogies. (p135)

Fensham (1997) suggests that with a change in emphasis STS curriculum reforms would have been better supported. This would appear to be an oversight, as there is little doubt that social and emotional factors have a fundamental role in learning (see for example, Gardner, 1983). A study of conceptions by Oldham, Black, Solomon and Stuart (1986), for example, has highlighted the emotions which pupils' associate with the concept electricity.

3.4.2 CONCEPTUAL CHANGE LEARNING IN FORMAL EDUCATIONAL CONTEXTS

Eylon and Linn (1988) review four learning perspectives which have emerged from science education research. These they characterise as: i) concept learning; ii) developmental focus; iii) differential focus; and iv) problem solving.

Conceptual change is a concept learning research perspective which evolved from the alternative conceptions movement in the early 1980's. During the last decade or so it has become a central organising concept of both science education and science teacher education (Scott, Asoko and Driver 1991).

Contemporary theories of conceptual change surround the processes of engendering, altering, adjusting and, or, replacing learners’ conceptual frameworks. During this meaning-making process, individual learners may interpret new information, alter new perspectives on ideas and knowledge they already hold, elaborate their thinking by adding new details, and, or generate relationships between new and old ideas and
perceptions. Quite which learners form which conceptions, how, why and when, are still open to questions, though are thought to be associated with such factors as: the general disposition of the learner towards learning (and learning science in particular); the spread and variety of personal and social life experiences; the novelty and relevance of the objects and the content of learning, and the quality of the learning experience.

One particularly influential view of science concept learning originated from Cornell University in the early eighties: The conceptual change model (CCM) of Strike and Posner (Posner, Strike, Hewson and Gertzog, 1982). The model has received considerable attention in the science education literature and many studies have used it as a theoretical base (see for example, Tyson et al. 1997). Over time, the original model has evolved: Hewson (Hewson and Thorley, 1989; Hewson and Hewson, 1992), for instance, offered early elaborations and, a decade after it was proposed, Strike and Posner (1992) revised the model.

The conceptual change model (CCM) of Strike and Posner (1992) provides the theoretical base for this thesis and rest of this section gives an overview of the model and its development. This overview is extended in Chapter Eight where modifications to the model are proposed.

The Conceptual Change Model is a theory of learning drawn originally from the literature on epistemology of science. More specifically, the model employs the rationality theories of scientific development of Kuhn (1962), Toulmin (1972) and Lakatos (1970). The CCM considers the conditions necessary to alter conceptions which are in some way central, organising and generative in learners’ thoughts. In this manner, conceptual change is compared with the notion of: a Kuhnian paradigm shift, a Lakatosian shift between research programs and Piagetian accommodation. Indeed, the CCM adopts the language of Piaget and uses the term accommodation to refer to large scale conceptual changes and assimilation to refer to ‘kinds of learning where a major conceptual revision is not required’ (Strike and Posner, 1985, p 215).
The CCM is based on the assumption that new conceptions are understood, acquired, judged and then accepted, or rejected, rationally within a conceptual context. The model has two components: the first describes the conditions which need to be met to experience conceptual change; the second describes the learner's 'conceptual ecology', providing the context in which the change takes place.

The model maintains that learners will construct a new scientific conception if they view this conception as superior to an existing one. Strike, Posner et. al. (1982) propose four conditions that are used by learners to judge conceptions:

1. There must be *dissatisfaction* with existing conditions. Scientists and students are unlikely to make major conceptual changes until they believe that less radical changes will not work.
2. A new conception must be minimally understood [it must be *intelligible*]. The individual must be able to grasp how the experience can be structured by a new conception sufficiently to explore the possibilities inherent in it.
3. A new conception must appear initially *plausible*. Any new conception adopted must appear to have the capacity to solve the problems generated by its predecessors, and to fit in with other knowledge, experience, and help. Otherwise it will not appear a plausible choice.
4. A new conception should suggest the possibility of a *fruitful* research program. It should have the potential to be extended, to open up new areas of inquiry and to have technological and/or explanatory power.

(Strike and Posner 1992, p 216)

The extent to which a conception is more *intelligible*, *fruitful* or *plausible* is termed the status of the conception and the more of these conditions a conception meets the higher its status. It is important to note that conceptual status is determined by the learner and not, for example, by the teacher or researcher. Methods of judging conceptual status are considered in more detail in Chapter Eight.

The status of a conception is a key feature of the CCM as conceptual change will not occur without some concomitant change of conceptual status. A conceptual change
involves lowering the status of an existing conception and raising the status of a new conception before it will be accommodated.

The second component of the CCM is called conceptual ecology, and this provides the context for conceptual change. Conceptual ecology is an adaptation of an epistemological metaphor originally proposed by Toulmin (1972). Using this metaphor, conceptual change is depicted as a competition between old and new conceptions, on the basis of conceptual status, for a particular conceptual niche. The conceptual ecology is viewed as providing the learner with both the cognitive resources to judge the status of a conception as well as the niche which will be occupied by the higher status conception.

In their later version, Strike and Posner (1992) explicate the intended scope of the CCM and stress that it is a theory designed to identify the conditions necessary for wholesale paradigmatic restructuring, or accommodation of concepts. However, some other authors use the CCM in broad terms, as a model of ‘learning’ (e.g. Hewson and Hewson, 1991) and these different interpretations are considered in more depth in Chapter Eight.

While there is some disagreement in the literature concerning the nature of conceptual change (minor or major conceptual revisions), there is considerable agreement concerning the conditions necessary for conceptual change (intelligible, fruitful or plausible), and it is this part of the model that has received the most attention.

In response to rationalistic criticisms the original CCM was extended by Strike and Posner (1992). In this revision the conceptual ecology element was expanded and given a more central role, the five modifications proposed were:

1. A wider range of factors need to be taken into account in attempting to describe a learner's conceptual ecology. Motive, goals and the institutional sources of them need to be considered. The idea of a conceptual ecology thus needs to be larger than the epistemological factors suggested by the history and philosophy of science.
2. Current scientific conceptions and misconceptions are not only objects on which a learner's conceptual ecology acts, they are themselves parts of the learner's conceptual ecology. Thus they must be seen in interaction with other components.

3. Conceptions and misconceptions can exist in different modes of representation and different degrees of articulation. They may not exist at all but may easily appear to do so, because under instruction or in research they are generated by other elements of a conceptual ecology.

4. A developmental view of conceptual ecologies is required.

5. An interactionist view of conceptual ecologies is required.


In these revisions, conceptual ecology is adjusted to recognise the learner's epistemological commitments, preferred learning styles and attitudes to learning. However, the conditions which determine conceptual status remained unchanged, namely; dissatisfaction, intelligibility, plausibility and fruitfulness.

The CCM offers a powerful account of how learners come to change their beliefs about academic subject matter and has become a significant focus in science education and science teacher education. However, its emphasis remains firmly focused on rationally directed conceptual change. Strike and Posner (1992) were explicit about the limitations of the CCM; they did not envision the model as a detailed description of learning that is directly applicable to schooling. They note:

In describing this view of conceptual change, we did not suppose that we were describing a detailed account of learning that could be immediately applied to the classroom. Instead we saw ourselves as describing the 'hard core' of a research programme that could be extended in profitable directions by further work (p150).

However, the CCM does have clear implications for how learning might occur and this has received considerable research attention in formal education (see for example: Hewson, 1981; Hewson and Thorley, 1989; Bishop and Anderson, 1990; Hewson and Hennessey, 1991; Smith, 1991; Lee, Eichinger, Anderson, Berkheimer and Blakeslee, 1993; Smith, Blakeslee and Anderson, 1993; Songer and Mintzes, 1994; Demastes, Good and Peebles, 1996). In addition, the CCM has also been used successfully as a
The CCM has been very useful in shaping our understanding of learning science. However, its critics highlight its rationality - it is a model which originated from a study of scientist’s learning. For Strike and Posner (1985), learning science has certain generic features whether they concern a ‘scientist struggling with a new idea on the forefront of knowledge’ or ‘a child trying to understand elementary notions of motion’ (p213). Although, the revised CCM acknowledges some affective factors, the core of the model remains rational; learners first have to become dissatisfied with a conception and then search for a new alternative, if they find this alternative intelligible, they then weigh up how plausible and fruitful it might be.

A detailed ‘rationalist critique’ has been provided by Pintrich, Marx and Boyle (1993). In this, the authors challenge the ‘cold and isolated’ view of academic learning the CCM presents. They emphasise:

1. The considerable disagreements which exist between philosophers, historians and sociologists of science as to whether scientific theories are solely products of rational reasoning.
2. Empirical evidence which maintains that academic learning in formal educational settings is highly influenced by more affectively charged motivational beliefs, such as, interest; self efficacy beliefs; goals for learning and social factors such as peer and teacher interactions.

In conclusion, Pintrich et al. (Op. Cit.) advocate the need for a ‘hot model’ of conceptual change which incorporates ‘personal, motivational, social and historical processes’ (p170). Recently, Treagust (1996) has taken these ideas further and proposes a model of conceptual change learning which is dynamic around three primary aspects: epistemological, ontological and social/ affective dimensions, see figure 3.1.
These are linked as a series of triangles depicting change which takes place between time 1 and time 2 as shown in figure 3.2. Treagust treats each of these dimensions as a 'lens' through which to explore aspects of conceptual change learning (although these dimensions can interact and hence overlap). For the epistemological dimension Treagust uses Strike and Posner's (1982) notions of intelligibility, plausibility and fruitfulness (I,P,F). For the ontological dimension he uses Chin and Brewer's (1993) description of ontological beliefs as 'beliefs about the fundamental categories and properties of the world'. For his affective/social dimension he turns to Pintrich et. al. (1993) previously cited. Treagust's multi-dimensional model has now been used as an empirical framework to explore conceptual change (see, Harrison, 1996; Tyson, 1996; Venville, 1996 and Tyson et. al., 1997)

The advantage of this multidimensional framework like this is that it allows discussion not only about what conceptual systems learners seem to hold, and the status which can be attached to them, but how they feel about this knowledge - as well as charting the influences of social and physical learning environment. Watts and Alsop (1997) and Alsop and Watts (1997) have found it more useful to work with a greater level of specificity of the affective domain to include the learners

Figure 3.1. A multi-dimensional framework for conceptual change (Treagust 1996)
‘engagement’ with specific aspects of science. This work is documented in detail in Chapter Eight.

![Diagram of conceptual change model]

**Figure 3.2.** A model representing the dynamic nature of conceptual change as it occurs over a period of time (Treagust 1996)

Using the research findings presented in the following study, the Treagust version of the CCM is tailored to describe adult informal learners located in a specific context.

### 3.5 RESEARCH ON THE PUBLIC’S KNOWLEDGE OF SCIENCE

Until relatively recently, there has been only a modest amount of empirical research in this area. This is perhaps even more surprising given that it is currently a popular research field. Studies considering the public’s understanding of science have two distinctive methodological approaches:

1. Quantitative research with a normative emphasis (e.g. surveys of lay knowledge and attitude towards science)
2. Qualitative research with an ethnographic emphasis (e.g. studies of knowledge in a specific context).
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The following sections reviews the research in each of these areas and starts with quantitative research.

3.5.1 A REVIEW OF QUANTITATIVE STUDIES

Traditionally studies of the PUS have used large-scale public opinion surveys or polls to ascertain the scientific knowledge, attitudes and beliefs from a large sample of the population. The public sample is then normally categorised by sex, age, socio-economic status, region and qualifications. The results often become popularised and can make headline news - however, perhaps unfortunately, these headlines tend to highlight how little the public knows about science (see for example: Misunderstandings of Science, The Guardian, 22nd February, 1992).

Most early work, of this type, was conducted in the USA and focused on the public's attitude to science and technology and did not specifically consider science concepts. For example, a much cited national survey was conducted by the University of Michigan for the National Association of Science in 1957 and 1958 (Withey, 1959). This measured the public's reactions to statements about science and scientists. Respondents were presented with a list of attitudinal statements (e.g. 'science is making our lives healthier, easier, and more comfortable?) and were asked to 'agree' or 'disagree'. The timing of this study was particularly interesting, in that Sputnik was launched while it was being administered. The launch of Sputnik resulted in mass public attention and concern about science and the study enabled a comparison of the public's attitude to science both pre- and post- Sputnik. Results indicated that the public were supportive of science and no significant change in attitude was recorded before and after the launch. It is, perhaps, interesting to contrast this rather laissez-faire attitude with the paranoia of the scientific community and national congress during this time (Raizen, 1992).

Starting in 1972, the National Science Board (NSB) began a biennial survey of attitudes towards science and technology (NSB, 1973). Their 1973 report was very wide-ranging and offered a: 'report on facets of entire scientific endeavour' (p.3). These facets ranged from the measurement of research activity, to indicators of
productivity and the US balance of trade in high-technology products. Contained within the report were the results of a survey investigating the public's attitudes towards science and technology. The research sample comprised 2,209 members of the public (age 18+) and once again, results indicated widespread public support of science. The survey included the following two indicative questions, (results are shown in brackets):

1. Do you feel that science and technology have changed your life for the better or for the worse?:

   [Results: Better 77%, Worse 8%, no effect 2%, no opinion 9%]

2. Do you agree that the degree of control that society has over science and technology should be increased, decreased, or remain as it is now?

   [Results: increased, 48%, decreased, 28%, remain as it is now, 7%, no opinion 17%]

NSB (1973, p.34.)

Starting in the 1960's, public surveys changed emphasis and focused much more directly on assessing the public's understanding of science. A longitudinal research project measuring the public's understanding of the methods and constructs of science, was undertaken in the USA by the National Assessment of Educational Progress (NAEP). On three successive surveys between 1969 and 1977, the NEAP reported declining science achievement in all age groups and nearly all socio-economic groups (Miller, 1983).

In the late 70's and 80's the structure of the NEAP surveys was expanded by Miller (1983) to cover three dimensions of scientific literacy and this composite framework has formed the basis of all recent national and cross-national surveys of the public. The methodology and results of the original NSF survey (NSB, 1979) are summarised in table 3.1-over leaf.

Respondents' performance was judged against three dimensions of scientific literacy (constructs, methodology and science in society - see table 3.1 over leaf) and scores on these dimensions were then combined to give a measurement of scientific literacy.
Using this method, 7% of respondents were found to be judged as scientifically literate. A strong association between formal education and scientific literacy was found, although, rather surprisingly, only a quarter of graduates could be labelled as scientifically literate with this method.

Table 3.1 The methodology and results of the NSF survey (NSB, 1979).

<table>
<thead>
<tr>
<th>Dimensions of scientific literacy</th>
<th>Questionnaire and responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. knowledge of basic constructs:</td>
<td>Respondents were asked if they have a clear understanding of the terms ‘Radiation’, ‘GNP’ and ‘DNA’. About half thought that they have a clear understanding of radiation, about a third had a clear understanding of GNP and about a fifth claimed to have a clear understanding of the meaning of DNA</td>
</tr>
<tr>
<td>2. Understanding of the scientific approach:</td>
<td>Respondents were asked to assess their understanding of the meaning of ‘scientific study’ on a three point scale; ‘clear, general, or little understanding’. Respondents who had a ‘clear understanding’, were then asked to explain its meaning. This was followed by a question about astrology in which respondents were asked to characterise astrology as, ‘very’, ‘sort of’, and ‘not at all scientific’. The results of these questions were combined to construct a single measurement, and for respondents to be classified as scientifically literate they would have to be able to explain what it means to be scientific and recognise that astrology was not at all scientific. 9% of respondents could meet this scientific literacy benchmark.</td>
</tr>
<tr>
<td>3. An awareness of the impact of science and technology.</td>
<td>Respondents were asked to cite two potential benefits and two potential harms for each of the three areas: ‘technology’: ‘nuclear power’; ‘food additives’. A literate respondent was defined as somebody who could name a minimum of six potential benefits or harms out of twelve. Of this sample, 41% of respondents qualified using this criteria.</td>
</tr>
</tbody>
</table>

When a similar survey (N=2005) was repeated in 1985 the number of respondents judged as scientifically literate dropped to 5% (Miller, 1987). Considering that each percentage point represents approximately 1.7 million US adults, 3.4 million less adults qualified as scientifically literate in 1985 compared to 1979. This, amongst other factors, probably highlights the importance of sample selection, however, in support of the survey results, Miller (1987) writes:
This is a statistically significant decline (at the 0.05 level), but it is not substantively important. The essential point is that the level of scientific literacy in the United States remains low and that the informal science education efforts of recent years have not produced any measurable increase in scientific literacy (p23)

In the UK, a survey was commissioned by Lucas (Lucas, 1987a, 1987b, 1988) and undertaken by the public opinion polling organisation, Mori. In this study, the method of data capture was through face-to-face interviews. The survey used multiple-choice and free-response questions to probe the respondents' understanding of a broad range of elementary scientific concepts. Two indicative questions Lucas used were:

<table>
<thead>
<tr>
<th>Which type of organism is attacked by penicillin?</th>
<th>% of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Viruses</td>
<td>33</td>
</tr>
<tr>
<td>b) Bacteria</td>
<td>53</td>
</tr>
<tr>
<td>c) Fungi</td>
<td>4</td>
</tr>
<tr>
<td>d) Protozoa</td>
<td>1</td>
</tr>
<tr>
<td>e) None of these</td>
<td>0</td>
</tr>
<tr>
<td>f) Don’t know</td>
<td>9</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>What temperature does water boil at?</th>
<th>% of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) 100°</td>
<td>43</td>
</tr>
<tr>
<td>b) 212°</td>
<td>9</td>
</tr>
<tr>
<td>c) Other</td>
<td>15</td>
</tr>
<tr>
<td>d) Don’t know</td>
<td>36</td>
</tr>
</tbody>
</table>

Aggregated scores of correct answers were then compiled and about half the respondents ticked the right answers. Again, a strong correlation with educational background (particularly 16+ education) was recorded and men were found to outperform women on physical sciences questions. Interestingly, this survey enabled a correlation between the subjects' competence (measured by the correct answer to the knowledge questions) and their views on a controversial issue. From this comparison, Lucas found no significant correlation between the answers to questions about radioactive decay and opinions as to whether there should be more, less, or the same amount of electrical energy generated by nuclear power. There did appear, however, to be a correlation between the nuclear power response and the general knowledge score - with the more knowledgeable tending to support increased nuclear power production
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(Lucas 1994). This trend has been supported by other surveys (reviewed in Chapter Five).

Perhaps the most widely publicised UK survey was performed in the summer of 1988 by Durant, Evans, and Thomas (1989). This survey was run in parallel with a survey in the USA. Both surveys consisted of a stratified random sample of 2000 respondents of age 18+ and the methods used built on the previous NSF survey techniques.

The UK survey used a list of over 20 questions to measure the respondents understanding of science. These questions now are commonly referred to as the ‘Oxford Science Knowledge Test’. This approach departed from the previous NSF surveys which used self-assessment questions to measure scientific understanding (see, table 3.1). In the Oxford Science Test respondents were asked to reply; ‘true’, ‘false’, or ‘don’t know’ to statements. Five of the statements used are contained in table 3.2.

<table>
<thead>
<tr>
<th>Questions used.</th>
<th>True</th>
<th>False</th>
<th>Unsure</th>
</tr>
</thead>
<tbody>
<tr>
<td>The earliest humans lived at the same time as the dinosaurs</td>
<td>31.5</td>
<td>46.2</td>
<td>22.1</td>
</tr>
<tr>
<td>The oxygen we breath comes from plants</td>
<td>59.9</td>
<td>28.3</td>
<td>11.8</td>
</tr>
<tr>
<td>All insects have eight legs</td>
<td>7.9</td>
<td>83.7</td>
<td>8.3</td>
</tr>
<tr>
<td>Natural vitamins are better for you than laboratory made ones</td>
<td>69.6</td>
<td>17.7</td>
<td>12.6</td>
</tr>
<tr>
<td>The liver makes urine</td>
<td>25.4</td>
<td>53.1</td>
<td>21.4</td>
</tr>
</tbody>
</table>

Table 3.2, results of the Oxford Science Test, figures quoted in percentages (Durant, Evans and Thomas 1989)

The respondents’ understanding of the processes of scientific enquiry were measured by the aggregation of their responses to seven questions: two of these questions are listed in table 3.3.
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Measures of understanding the processes of scientific inquiry

When scientists talk about Einstein's theory of relativity, are scientists talking about:
(i) A hunch or idea 11.2
(ii) A well established explanation 33.3
(iii) A proven fact 39.1
(iv) Don't know 16.4

And when they talk about Darwin's theory of evolution, are scientists talking about:
(i) A hunch or idea 11.2
(ii) A well established explanation 33.3
(iii) A proven fact 39.1
(iv) Don't know 16.4

Table 3.3. Two questions used to measure the public understanding of scientific inquiry, figures are quoted in percentages (Durant, Evans and Thomas 1989)

Once more, the strongest indicator of performance on both question types was found to be educational level. It was also found that younger people tended to know more than older people; males more than females; and middle class people more than working classes. Of particular noteworthy interest were the results of medically based questions - as the respondents appeared both more interested and knowledgeable about this area of science. Durant, Evans and Thomas (1992) have subsequently used these results to suggest that medical science occupies a central place with popular representations of science.

Studies of a broadly similar format have now been performed in the USA, UK, (cited above) the European Community (INRA, 1993), China (Zhang and Zhang, 1993), Japan (Zhang and Zhang, 1993) Sweden (Fjaestad, 1994), Canada (Einsiedel, 1994), Australia (BIE, 1995) and South Korea (Kunlun, 1994).

Although the questions in these surveys are slightly different, there is sufficient common ground to facilitate international comparisons. For example, Fjaestad (1994) compare the Swedish results with the US and EU results and conclude: that Swedes are:

- more interested in medicine than in environmental pollution,
- are heavier consumers of science information,
- they have a better knowledge of scientific findings and they value astrology less (p11).
And Zhang and Zhang (1993) compared the Chinese results with those of the USA and UK and concluded:

Chinese public scientific literacy is at a very low level, and is some way below the levels in the US and the UK. Generally, the Chinese public approve of the impacts of science and technology, and believe in their efficacy. However, there is a huge distance between the degree of approval of science and the public's level of science and technological knowledge [...] The development of science and technology, the development of the Chinese economy and the improvement of peoples' living standards require a greater improvement in Chinese public scientific literacy. This will be a hard task to achieve, and it will require a long term investment of effort...

(p37).

The results of all these surveys show that many people are unable to correctly answer relatively straightforward questions about science - traditionally found in school courses. In this respect, the public appears to have a confused, or at best naive view of a scientific concepts and methodology. If this approach is accepted as an appropriate measure of scientific literacy then levels of literacy would appear to be very low.

The single most significant indicator of performance is found to be the level of formal qualification - although, rather surprisingly, only a fraction of graduates are found to be scientifically literate. A weak association appears to exist between positive attitude towards science and knowledge about science. However, this association is not straightforward, as it also depends upon how salient are the scientific issues and how the survey questions are phrased. But, in general, more knowledgeable members of the public are found to support general science and 'useful science'(e.g. searching for a cure for cancer) but be more strongly opposed to 'morally contentious' and 'non-useful areas of research' (e.g. creating new forms of life or searching for new stars) than less knowledgeable members of the public (Evans and Durant 1995). *Salience* and *personal relevance* are issues which develop as this thesis progresses.

The 'traditional' survey approach to measuring scientific literacy has a number of well rehearsed strengths and weaknesses: some of the more obvious strengths are:
1. It is possible to use a large sample, which provides a powerful way of looking at how much a population as a whole knows about some aspects of science. Using these methods it is possible to explore a broad range of knowledge and attitudes. This information can be monitored over time and international comparisons can be made.

2. The data collected provide useful measurements of how interest, attitude and knowledge can be related to sociological independent variables such as; age, sex and class, and can enable consideration of how formal education affects public understanding.

However, they have a number of well documented shortcomings:

1. The areas of science used may not be considered important (or relevant) by non scientists (the approach is science-centred);

2. The salience of the scientific topics may vary across each of the respondents (for example, those living near to a nuclear power plant may be expected to score more highly on questions on radiation and radioactivity);

3. Some of the questions contained are open to misinterpretation, for example, ‘unsure’ responses cannot be equated with ignorance and questions which ask respondents to judge their level of their understanding are highly subjective.

Critics suggest that the results present a ‘cognitive-deficit model’ of understanding - that the results are best interpreted as a measure of how well the public shares the scientists view of the world rather than a realistic measure of scientific literacy (Layton, 1986). Certainly, the results of this type have only limited use in that they fail to explore the reasons behind the patterns they expose. For example, they do not provide the means to consider why some groups of the public have a different attitudes to science or are more knowledgeable about science.

These criticisms have been used to promote different methodological approaches which segment the public into groups facing particular scientific issues - in essence, these studies are public-focused rather than science-focused.
3.5.2 UNDERSTANDINGS OF SCIENCE IN CONTEXT: THE USE OF CASE STUDIES

Perhaps the strongest critique of science centred quantitative studies comes from the more qualitative case study research. This research paints a quite different picture of the public.

In direct response to the Royal Society’s (The Royal Society 1985) call, a range of PUS research projects were initiated from within the UK. These were funded by Social Research Council (ESRC) and Science Policy Support Group (SPSG) grants. Unlike the previously documented surveys, these studies have aimed to explore PUS within chosen ‘contexts’, focused on specific public groups and employed more qualitative and interpretative research methodologies.

This case study research had a strong social agenda and sought to investigate the interactions of identifiable social groups with scientific, technical or medical experts. In this way, the research moved away from the prevailing science-centred methodologies towards an investigation of both the operation of scientific experts (and institutions) and their relationships with the public. The public groups selected were all faced with a situation where a knowledge of science was considered directly beneficial, for example:

1. **communities or individuals sharing a common health concern,** such as; Cumbrian sheep farmers in the post-Chernobyl period (Wynne, 1990); residents living near a chemical plant (Irwin, 1995); medical patients suffering from familial hypercholesterolaemia (Lambert and Rose, 1996); residents living in areas of high Radon levels (Michael, 1992); Cystic fibrosis carriers (Myers, 1994); the elderly and domestic energy and parents of Down’s Syndrome (Layton et. al. 1993), and

2. **groups with specific vocational needs,** such as; councillors managing methane and trainees attending a British Nuclear Fuel apprentice college (see Layton et. al. 1993).
In these everyday settings individuals' real-world encounters with scientific knowledge were investigated.

Many of the original studies have now been collated: Irwin and Wynne (1996) edit a collection of nine case studies and Layton et. al. (1993) edit four of their own. Additional research has now been performed which supports these original studies, for example, Mulkay (1995) has considered political parties and embryo research; Solomon (1993a) has explored science knowledge in the home; and Caillot and Xuan (1995) have interviewed workers on an electronic assembly workshop about electricity.

These studies challenge a number of the assumptions made by the previous (quiz-type) survey methods. They offer a powerful insight into the public understanding of science by highlighting the limitations of science centred communication and the ways in which members of the public understand and use science in their daily lives. In this review, the emergent features are summarised in three themes.

Theme 1. Science-centred communication has limitations.

As briefly discussed in Chapter Two, a significant feature of this research concerned the failure of scientific advice to meet everyday needs. Scientific advice offered to members of the public was frequently found to be wanting, and on occasions, to be wholly irrelevant. A good example of this comes from a study of forty parents of Down’s Syndrome babies. Layton et. al. (1993) wanted to see what use, if any, is made of scientific information about this syndrome. Most of the parents had been provided with a scientific account of the causes of Down’s by their medical consultants, which included a genetic explanation of the syndrome (i.e. the presence of an additional chromosome) as well as the ways it can occur. However, the general feeling of the parents was that the information provided was irrelevant. As one mother stated: “once we know what kind of Down’s Syndrome he’s got, there’s not much we can do about it and we’ve got to get on with things” (p53).
Dealing with Down’s Syndrome is complex: children tend to have poor muscle tone, are unable to feed from a bottle, have difficulty walking and suffer constipation. The researchers found that, despite considerable difficulties, the parents had developed ways of coping with this real-life and practical challenge without the aid of scientific knowledge. In conclusion Layton et al. write:

The body of practical knowledge which parents have themselves constructed was a powerful alternative to the ‘high science’ of Down’s Syndrome available from medical and other ‘experts’. Too often, it seems, parents had received from such ‘experts’ a message of despair when they were desperate for one of hope. Knowledge was offered in the wrong form, reflecting priorities different from those of practical action, [...] discounting understandings which parents had wrought from experience and often at the wrong time, serving the convenience of doctors, ignoring emotional traumas which parents might be undergoing, and undiscerning of the moment of need.

(pp57-58)

Layton et al. (1993) also considered the scientific needs of; the elderly when considering central heating; members of a local authority who are managing methane and workers in Sellafield nuclear power plant. Again, in each case, a serious mismatch was recorded between the science offered and the practicalities experienced.

The researchers note that perhaps the most unfortunate feature of this mismatch is that scientific advice loses credibility and as a consequence those in need of science were found to reject all the advice they were offered - even useful elements of science were not considered. Layton et al. (1993) recount:

Those in the case studies who sought to use scientific knowledge to ground their actions they wished to take found themselves, like many post-modernists, questioning much of what was presented as ‘given’ and discovering that, in some cases e.g. estimates of risk, scientific facts involve a large element of social construction/ subjectivity and or were related to circumstances far removed from those in which they conducted their daily lives (p.139)
There are no doubt other instances where the mismatch between science and the public is not so dramatic, research conducted by Myers and Hopkins (cited by Turney, 1997), for example, recorded a considerable agreement between the public and medical staff about important questions concerning cystic fibrosis screening. However, the results of Layton’s and similar studies (Irwin and Wynne, 1996) warn against complacency. It seems that communicating with the public is more than just simply giving them science. Scientists, it seems, need to listen and adapt their advice in order to cater for the public’s particular needs.

Indeed, Layton et al.’s (1993) study of the elderly and their domestic energy management illustrates how science can become marginalised in everyday use. An elderly lady was found to select her choice of lighting not on economy or efficiency, the scientific advice offered, but for comfort and cosiness. Layton et al. (ibid.) conclude:

The fact that people do not act as isolated, scientifically rational individuals means that if their behaviour is to be understood at all, it must be understood using a variety of concepts, explanations and perspectives. This has profound implications for science education. (p 74)

This research would appear to challenge a simple narrow science-centred model of the public understanding of science. A simple moral here is to find out about your audience’s needs and priorities and adapt advice accordingly.

**Theme 2. The public are active consumers of science**

Another theme of importance emerging from this case study work concerns the notion of ignorance. Ignorance features heavily within traditional surveys of the public. However, It appears that when members of the public are faced with a strong motivation to acquire science they can show considerable skill and expertise. As Layton et al. (1993) conclude:
Far from being passive consumers of knowledge, they [members of the public] were active and selective users, engaged as ‘bricoleurs’ in the resolution of conflicts between different interpretative frameworks and in the translation of scientific knowledge from the rarefied context of its production into the turbulent context of its use (p62).

An illustration of this comes from a study undertaken by Lambert and Rose (1996) concerning patients with the genetic illness familial hypercholesterolemia (FH). These patients were found to be highly dynamic in their search for scientific information and particularly astute at judging the worth of any scientific advice offered. These judgements, the researchers found, where not made directly by considering the content of the advice, but indirectly by considering the source of the advice. Wynne (1991, p115) summarises this significant feature:

> It is normal (and rational) for people to respond not to scientific knowledge per se but to a whole complex of knowledge plus its particular social “body language” - the interests people think lie within it, the social value and relationships it is thought to imply, and so on. These many not be deliberately chosen by scientists but may nevertheless be structured into knowledge, for example, via the questions it emphasises, the degree of standardisation it imposes, or the extent to which uncertainties are withheld.

It seems that questions: “from whom?” and “from where?” are fundamental in the public uptake of science.

In other cases, the public’s uptake of science was found to be influenced by particular social roles and responsibilities. Wynne (1991, p116), for example, found that apprentice electricians at British Nuclear Fuel’s Training College had not bothered learning about radioactivity because they considered it to be someone else’s job - the responsibility of the specialists who had designed the nuclear plant.

Wynne (1991) uses the results of these studies to create a distinction between three levels of PUS: its intellectual contents, its methodology and, a third level, ‘its organizational forms of ownership and control’. He writes:
All of these three are necessary in some degree for a rounded public ability to use and act maturely in relation to science and technology. However, the third level may be as important as the first. Indeed, given that as we have found, the social basis of trust and credibility is a crucial (yet largely neglected) question affecting public understanding of science, neglect of any public discussion of the third factor undermines any attempts to improve the other two (p120).

It seems that what could be recorded as ignorance in traditional surveys (intellectual contents) may in fact be a positive measurement of public understanding of science in Wynne’s third sense.

These findings highlight the importance of considering the PUS in broader terms than a simple measurement of scientific competence. Social dimensions such as trust seem to influence the public uptake of science and these are developed as this thesis progresses.

Theme Three: Science and its potential for practical use.

The third and final theme concerns the manner in which scientific knowledge is required to be reworked and articulated for practical use. The previous discussions have highlighted the considerable disjunction which can exist between scientific knowledge and knowledge suitable to everyday situations.

Figure 3.3. Construction and de-construction of scientific knowledge (Layton et. al. 1993)
Layton (1991) succinctly contrasts research from science education (which highlights learning as knowledge construction, starting from prior conceptions) and knowledge for practical action (which involves a process of de-construction). He represents this as a two stage process delineated in the flow chart above (figure 3.3). Layton maintains that research has concentrated on understanding the left hand side of this chart and there only exists a 'rudimentary' understanding of processes involved in deconstructing and reworking scientific knowledge for practical action on the right hand side.

The distinction between ‘knowledge-for-understanding’ and ‘knowledge-in-action’ has particular significance for this thesis because the justification for the public to understand Radon is based upon utilitarian arguments. This distinction raises further questions concerning the degree of translation required as presumably some scientific knowledge is more closely linked with practice while other requires a considerable degree of reworking. In the context of Radon, it seems important that scientific advice should is easily applicable, or actionable.

The results of these case studies offer a challenge to science centred communication and ignorance (as defined by the traditional surveys), as well as highlighting the complexities of everyday thinking and knowledge-in-action. However, they fall short of integrating factors which influence the public uptake of science into a description of informal learning.

3.5.3 SITUATED COGNITION: AN OVERLAPPING FIELD

The consideration of the public understanding of science in terms of everyday knowledge overlaps with another research domain, that of ‘situated cognition’. A series of studies which place ‘context’ as a central component of cognition are those which come under the headings of ‘cognition-in-practice’ or ‘everyday-cognition’ (Hennessy, 1995; Lave, 1988; Rogoff and Lave, 1984). Rogoff and Lave’s (1984) seminal work explores ‘knowledge-in-everyday-contexts’. Their approach is to study the influences that the different settings (at home, at school, at the supermarket, or on a ski slope) have on the development and use of cognitive skills. These types of
studies follow a psycho-social constructivist tradition and advocate methods of instruction (commonly apprenticeship) based on the Vygotskian (1962) concept of the Zone of Proximal Development (ZPD).

The evidence assembled in Rogoff and Lave's (1984) study unambiguously supports the conclusion that thinking should be considered as intricately interwoven with the context of the problem to be solved. Rogoff and Lave (ibid.) write:

One must attend to the content and the context of the intellectual activity in order to understand the thought processes. This is the case for any given situation in which thinking is studied, including the laboratory context, which is not context-free as researchers frequently assume. Understanding the circumstances of cognitive activity is essential to developing a more sufficient theory of cognitive development. This is quite different from searching for the 'most natural' context or attempting to control for context. Context is an integral aspect of cognitive events not a nuisance variable (p.3).

The conclusions to these studies once more question the validity of survey studies which have characterised everyday thinking as somehow deficit in comparison with expert thinking. Instead, Rogoff and Lave argue that everyday thinking should not be thought of as 'sloppy' or 'illogical' but sensible in handling the practical problems of everyday life.

Mathematics has taken a central pioneering role in studies of situated cognition and a number of studies have focused on the relationship between mathematics learning in school and mathematics learning 'in context'. Mathematics in everyday context has been labelled 'enthnomathematics' and is reviewed by Hennessy (1995). This review draws on a wide range of cross-cultural studies of enthnomathematics from Brazilian street children; tailors in Liberia; dairy workers in the UK; to the influence of a money economy on the mathematics of the Oksapmin of Papua New Guinea. These studies chronicle the mathematical methods which are invented and used successfully and skilfully by adults in practical situations. Often, these methods are often found to be significantly different to the standard mathematical procedures studied in formal education.
Jenkins (1994, p604) proposes that the concept of ‘ethnomathematics’ could be extended to incorporate studies of the public understanding of science or ‘enthnoscience’, which he has defined as ‘scientific knowledge and activity structured into, and by, everyday activities which have a scientific dimension’.

Studies of situated cognition and everyday thinking act as further affirmation that the public understanding of science is far more contextualised and complex than the early deficit models would imply. They highlight the importance of locating studies of learning in a particular context. As Furnham (1992) writes: ‘It is not a case of looking for the “most natural” context in which “to test” or observe people, but rather of conceiving the context as an integral variable, not an artefact’ (p32).

3.6 RESEARCH ON INFORMAL LEARNING OF SCIENCE

Research on learning science in informal settings is extremely diverse and encompasses a multitude of different sources, settings and research methodologies. For example, research has considered learning in the settings of: Aquariums (e.g. Kelsey, 1991); Science Centres (e.g. Beetlestone, Johnson, Quin and White, 1998); Zoos and Museums (e.g. Tunnicliffe et al. 1997, McManus, 1992); Planetariums (e.g Fisher, 1997); Community based programmes (e.g. Ostlund, Gennaro and Dobbert, 1985); in the family home (Solomon, 1993a) and Field trips (Krepel and Duvall, 1981). In addition, the Media has been the focus of considerable ‘communication’ research, see for example: Television (e.g. Chen, 1994); Newspapers (Nelkin, 1995; Dunwoody, 1992) and the electronic press (e.g. Hofstein and Rosenfield, 1996).

These studies have deployed a wide range of methodological approaches. For example, Tunnicliffe et al. (1997), in a study of learning in museums, distinguish between the more naturalistic (e.g. ‘listening-in’, ‘tracking’ and ‘Timing’) and interventionist approaches (e.g. ‘memory prompt’, questionnaires and interviews). While, Rennie and McClaﬀerty (1996) review a number of methodological approaches to measuring informal learning in science centres that include: open ended questions, stimulated recall and investigative thinking.
Although the field of informal science education is diverse, some settings have received more research attention than others. For example, research conducted in museums and science centres remains popular (Crane et al., 1994) and the media (in particular newspapers) have been a source of communication research interest for some time (Nelkin, 1995).

In a broad review of informal learning, Crane (1994) maintains that the majority of research has been evaluative and has principally been directed towards the educational source or setting - rather than the learner. Typically, the purpose of this research has been to evaluate the efficacy of this educational experience. Research of this type can be both summative and formative, although, Crane (1994) notes that the most common form of research is formative (e.g. trials of a television programmes or a museum exhibits), in part, because funding usually ceases once the project has been designed.

Similarly, the focus of much media attention has been the media source. Nelkin (1995) provides a comprehensive review of this work and explores the manner in which the news-press covers science. Other studies have focused on the press coverage of a particular science events or themes. For example, Entwistle and Hancock (1992) have considered the press coverage of health and medicine and Cheveigne and Veron (1994) have considered how the French press covers Nobel physics prize winners. Wellington (1991) argues that the science presented in newspapers can be of value in formal education if used critically. A review of how the press covers Radon forms part of this thesis and is documented in Chapter Five.

Falk, Koran and Dierking (1986) highlight the significance of informal sources of information for learning, they conclude:

it is probably safe to conclude, based on anecdotal and increasing empirical evidence, that informal science settings are extremely important learning situations for conveying certain kinds of cognitive and affective science information (p507).
Studies of learning in museums often contrast studies of students (e.g. school visits) and public visitors (e.g. families, weekend visitors). Tunnicliffe et al. (1997) divide museum studies of learning into three different aspects of response: *behaviour* (e.g. time spent at an exhibit), *learning - focused on process* (e.g. learning style) and *learning - focused on the product* (learning outcomes) (p1040).

Studies of *behaviour* have considered, for example, the flow of visitors through a museum, the pattern of attention, time spent at a particular visit as well as behaviour at a particular exhibit (see for example, Sandifer, 1997; Falk, Koran and Dierking 1986). Research, for example, has found that learning outcomes are closely related to the amount of time the visitor spends at a particular exhibit (Crane et al., 1994).

Hofstein and Rosenfeld (1996) review of five informal learning modes (school-based field trips; student projects; community based science programmes; casual visits to museums and zoos and the press, and electronic media) highlights the importance of considering both affective and cognitive *learning outcomes*. Similarly, Rennie and McClafferty's (1996) review of research conducted in science centres states:

> There emerged a picture consistent at only the most general level, which suggests that some cognitive, affective and psychomotor learning occurs most of the time, but there is considerable variation across science centres and exhibits in centres (p.86).

The importance of establishing interest and curiosity has been considered by Csiksentmihalyi and Hermanson (1995) who talk of establishing 'a flow experience' - a state of mind where engagement in an informal learning activity is maintained.

These studies highlight the importance of considering informal learning in broader terms than just cognitive outcomes. Behr (1994) - the curator of the Children's Museum in Chicago - for example, views museums in terms of experiences which add to an ability to understand science rather than trying to teach science concepts and skills.
Lucas, McManus and Thomas (1986) have considered how the background knowledge of the learner is brought to bear in interpreting and discussing an exhibit (learning processes). In this study, some visitors were found to draw upon their school knowledge while others used 'memories stimulated by the exhibit itself as a basis for giving social meaning to the message in the display' (p498). Kelsey (1991), for example, has considered conceptual change in the setting of an aquarium and highlights the importance that museum instructors adopt constructivist teaching strategies.

Bazin (1987); Cowlishaw (1987), Metcalfe and Halstead (1994) and Metcalfe and Servant (1996), for example, have all considered the efficacy of community-based science workshops and courses. In conclusion, they emphasise the need for informal educators to draw on the life experiences and personal interests of learners - which has a resonance with Knowle's (1979) assumptions discussed earlier.

The numbers of studies which have considered how scientific issues are covered by television are slowly growing (Chen 1994, Ryder 1979). Chen traces the paucity of research in this area to a number of underlying factors including the producer driven nature of television projects, the absence of funding and the methodological challenges associated with this research

This review of informal learning has aimed to give an overview of a wide-ranging field. There appears to be a growing interest in research focused on a broad view of informal science (Dierking and Martin, 1997). The field is far from homogenous, different types of research have explored different research agendas. For the most part, the focus has been upon learning in a particular setting (or from a particular source) and the research has tended to concentrate on evaluation and learning outcomes, rather than the processes involved in learning (Chen et. al. 1994). As Falk (1983) noted some time ago: 'despite the abundant evidence for learning, little is known about the mechanism of learning in informal settings' (p. 83). Although there is some evidence that this is now changing (e.g. see Gilbert and Priest, 1997, McManus, 1992).
Informal learners have an array of different learning agendas. For example, it seems likely that somebody visiting a museum (or the internet) with a clear aim (such as to find out about a personal illness) will display a different behaviour than the casual visitor (or surfer). Similarly, those who visit a museum as part of a formal school based course may have a different agenda to the informal adult visitor. This, once more, highlights the importance of a research perspective which is learner-centred.

3.7 SUMMARY

This broad literature review supports the general and the specific direction of this thesis. Each one of the areas reviewed contributes to the thesis as a whole. In summary, seven key features of the documented research emerge:

1. While children’s and adult’s learning have been treated separately in the literature there is good reason to view these as parts of a continuum rather than distinctive stages.

2. Constructivism is still a powerful basis for considering learning although it has weaknesses as a theoretical referent.

3. Science education research offers a comprehensive picture of alternative conceptions of science and models of conceptual change. Although the focus of research has been the physical world rather than the social or affective. The CCM model is a particularly popular model of science learning which is supported by a wealth of empirical evidence. Recent additions by Treagust (1996) have extended this model.

4. Surveys of the public understanding of science remain popular. They highlight the lack of understanding that the public have of traditional school science concepts. However, these studies are essentially a-theoretical and have been challenged by context specific case studies.
5. The results from contextualised case studies promote an interactionist model of the public understanding of science. In this model, social elements influencing the public uptake of science are emphasised. However, this research falls short of developing a model which describes informal learning in a given context.

6. Studies of situated cognition are powerful and highlight the profound importance of studying learning in context.

7. Research into learning science in informal environments documents the particular demands placed on the learner. These vary dramatically and depend on the learning environment. Studies highlight that learning outcomes should be considered in both cognitive and affective terms. However, these studies tend to 'institutionally focused' and not 'learner focused'. As a consequence they can hide the significance of the interests and motivations of informal learners.

From this review, it has become apparent that the PUS is both complex and multifaceted. Chapters Five and Eight also contain reviews which develop the arguments presented. In the following chapter, the methodological issues associated with a study of informal conceptual change learning are considered.
4.1 INTRODUCTION

To return, for a moment, to the beginning, the aim of this research is to investigate informal learning of science, and it is research which has been driven principally by the question:

- To what extent can a model derived from within formal science education be used and adapted to describe informal learning in the public understanding of science?

The study is confined to a specific scientific content area of radioactivity and explores a particular event, that of a naturally occurring radiation source, Radon gas. Some justifications for this particular focus have already been argued in Chapter Two.

This chapter outlines the research methodologies that have been used and explains the reasons underpinning the choice of research strategy and methods. The thesis as a whole is comprised of 5 empirical phases - each phase is documented in a separate chapter. The purpose of this chapter is to outline the broad methodological issues associated with the research performed in each of the phases. These are then revisited and extended in each of the separate empirical chapters which contain specific details of the data analysis.
4.2 A METHODOLOGICAL OVERVIEW

The present thesis can be best described as an example of a 'theory-in-action'. It has set out to develop a model of informal learning for an area of science. In order to develop this model the approach has been to extend and adapt an existing model of learning, the conceptual change model of Strike and Posner et al. (1982). The CCM has been used extensively in research conducted within formal educational settings and this study extends this model in order to study informal learning.

During the course of the thesis, significant modifications are proposed to the Strike and Posner's CCM. These modifications or adaptations are grounded in the empirical evidence collected. The general methodological approach adopted is congruent with an approach termed Grounded Theory (Glaser and Strauss 1967).

Using a well-developed model of formal science learning has the advantage that research techniques that are well established and accepted within the field of constructivism in science education can be applied to the under-researched field of informal learning in the Public Understanding of Science. This chapter documents these research techniques.

As previously stated, the thesis has five distinctive empirical phases, which are depicted chronologically in figure 4.1. The methodologies of each of these phases are summarised in the concluding sections of this chapter. In order to provide a methodological overview, it is helpful to divide these phases into two broad stages based on their research emphasis.

The first stage is primarily concerned with a study of knowledge and is composed of three phases: (i) a conceptual analysis of written materials; (ii) 'interviews about scenarios' and (iii) a survey of 'Radon confidants'. This stage explores scientific information which is available in the public domain and the participants' understanding of this science. It seeks to address the following broad research questions:
Chapter Four: Methodological Issues.

- What sources of information are available to the general public about Radon?
- What information do these sources contain?
- How do these sources communicate this information?
- What sources do the public use to find out about Radon?
- What knowledge do individuals associate with Radioactivity and Radon gas?

The second stage of data gathering has a differing emphasis; it directly considers conceptual change learning (i.e. changing knowledge). This section itself has two phases: (i) learning from an informal information source and (ii) learning in a Somerset village. These phases are concerned with modelling informal learning of science and seek to address the key research questions:

- To what extent can the conceptual change model be used to model informal learning about Radon?
- What extensions and modifications are required to explain processes involved in:
  i.) learning from an informal information source?
  ii.) learning in a rural village?

The empirical development of the thesis is progressive - each one of these phases builds upon the previous one. Likewise, the first stage provides the basis for the second stage: the study of knowledge is the starting point for research into learning - the constructivist perspective adopted recognises personal knowledge as providing the basis of future learning.
Figure 4.1, A flow diagram showing the empirical development of the thesis

Stage One: Knowledge

Phase One:
Chapter Five
A conceptual analysis of written materials about Radon.

Phase Two:
Chapter Six
‘Interviews about Scenarios’: a comparative analysis

Phase Three
Chapter Seven
A survey of ‘Radon confidants’

Stage Two: Learning

Phase Four
Chapter Nine
Learning from an Informal Information Source

Phase Five
Chapter Ten
Learning in a Somerset Village.

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4.3 THE RESEARCH AS GROUNDED THEORY

The notion of Grounded Theory derives from the work of Glaser and Strauss (1967). It is a methodological approach which places an emphasis on the generation of theory and the data in which the theory is grounded. The approach was originally developed and used in sociology but has now been widely applied to other research areas.

Grounded Theory provides a road map for theory-making processes - a means of 'generating and testing a theory' (Strauss, 1987, p4.). In this approach, a theory is seen to emerge, or is generated from, the data collected. Grounded Theory differs from many other research methods (e.g. deductivist based research methodologies) since it is the act of research which generates the theory, rather than the research being established by a theory.

Grounded Theory is not method or technique specific but, rather, is a style of research which involves a number of distinctive features. These features include: coding, theoretical sampling, theoretical saturation and theoretical sensitivity (Glaser and Strauss, 1967; Strauss, 1987, p.23).

- Coding is the process by which categories are discovered and named. This process is iterative and achieved by closely scrutinising the data to produce categories which fit with the data. Initially, the categories are unrestricted however, as they take shape, the subsequent analysis takes on the form of modifying and hardening of these categories which leads to saturation and verification.

- Theoretical sampling is the process by which on-going data collection is guided by the emergent theory. It is a means 'whereby the analyst decides on analytic grounds what data to collect next and where to find them' (Strauss, 1987, p.38). The key question in theoretical sampling is the choice of sample and the research purpose. Within this approach, samples are not chosen at random but they are selected to replicate previous cases or to extend an emergent theory. Glaser (1978, p.36) describes theoretical sampling as: 'the process of data collection for generating a theory whereby the analyst jointly collects, codes, and analyses his
data and decides what data to collect next and where to find them, in order to develop his theory as it emerges'.

- Theoretical saturation is the end-point of research where further data collection does not increase understanding. This is the point where data is no longer being found which can develop the properties of the categories.

- The methodological emphasis of Grounded Theory research is a process of inductive reasoning. During this process, theory is generated from data through a series of observations. This has two stages: observation followed by creative theory generation. The approach places a particular emphasis on the emergent concepts - those coming from the data. Glaser and Strauss (1967, p46) emphasise the importance of adopting an 'open mind' and use the term 'theoretical sensitivity' to highlight the importance of the researcher being sensitive to the data collected without the influences of pre-existing ideas and biases. Charmaz (1995) makes a similar point when she states that: the 'fundamental premise of Grounded Theory is to let the key issues emerge rather than force them into preconceived categories' (p.47).

Methodologies which are inductivist are criticised as being naive (see for e.g. Chambers, 1982). Mistakenly, Grounded Theory has become associated with only inductive logic however, as Strauss (1987, p12) highlights all three aspects of enquiry (induction, deduction and verification) are necessary in the processes of theory generation. The significant point here is the 'inductivist emphasis' which the Grounded Theory approach places on research. Rather than starting research with a set series of concepts and categories which are extant within the field, the Grounded Theory researcher has a critical mind and a theoretical sensitivity, to the emergent research features which should be led by the data itself. Charmaz (1995) summarises the approach well when she explains that the purpose of grounded theory research is: ‘to develop a theoretical analysis of the data that fits the data and has relevance to the area of study’ (p.48).
4.4 THE RESEARCH DESIGN

In the tradition of Grounded Theory, the research processes used are best characterised by the constant iteration between theory, data and literature (and between the steps of these processes as well). As Glaser (1978, p.16) notes ‘the detailed, conceptual grounded route from data collection to a finished writing is a process composed of a set of double back steps. As one moves forward, one constantly goes back to previous steps’. The iterative processes involved during the present study are represented in figure 4.2 below.

![Diagram of research approach](image)

**Figure 4.2**, a diagrammatic representation of the research approach.

The starting point of the thesis was to explore written materials about Radon and drawing upon the literature, this analysis *coded* the content of these materials into a series of *saturated* categories. These categories were then used to define the focus of the following research (*theoretical sampling*). The next two phases of data collection (phases 2 and 3) were used to explore the participants’ conceptions of the scientific content contained within the written material categorised in phase 1. A set of general categories (conceptions) were generated. The generation of these categories was
achieved through the *iterative* process of gathering experience from the literature and empirical evidence from the data to generate provisional categories and then refine these categories. A key process involved was the use of ‘*constant comparisons*’ (Strauss, 1987, p.19). For phases 2 and 3 of the data collection this involved the comparison of a participant’s response with a scientific concept, the relevant science education literature and the responses made by other participants in the study.

The experience gathered in *Stage One* of the data collection (phases 1, 2 and 3) was used to direct the research design. The evidence collected enabled a series of provisional modifications to be made to the Conceptual Change Model (Strike, Posner *et al.*, 1982). These provisional modifications (the extension of the model to include affective and conative features) were then used to shape the remaining two phases of the research, *Stage Two*. Samples of informal learners were selected to explore the emergent theory (*theoretical sampling*). The experiences gathered from the empirical data, collected in phases 4 and 5 of the research, and the literature were used to adapt, refine and *saturate* the ingredients of the proposed Extended Conceptual Change Model (ECCM). Throughout, care was taken to be critical of the emergent theory and to be sensitive to the empirical data (Strauss 1987, p.18).

In this manner, as the thesis progressed, the research became increasingly more focused. Through this iterative process a model of informal learning was developed which is congruent with Grounded Theory Methodology and the data collected.

In the research outlined in the following chapters, the notion of proving theories is not appropriate, but rather the ideas presented are supported by the evidence collected. It is accepted that the categories formed to interpret and classify the data cannot be assumed to be inherent in the data itself. These categories are not ‘positivist stones’ which have been uncovered, but are personal interpretations based upon the data and are congruent with the researcher’s interpretation of the fields of constructivism in science education and the public understanding of science. Each of the empirical chapters document the methods of data collection and analysis, their primary purpose is to provide evidence of the methodological consistency and authenticity of the research.
4.5 THE CHOICE OF SAMPLE

The two basic questions in theoretical sampling are: ‘what groups or subgroups does one turn to next in data collection and for what theoretical purpose?’ (Glaser and Strauss, 1967, p.47). Glaser and Strauss maintain that it is the ‘theoretical relevance’ (p.49) of the sample which determines its selection as the research sample is specifically chosen to illuminate the problem under focus - i.e. it is not random.

As already discussed, the term ‘public’ is complex and problematic, in some studies it has been used as a category to refer to non-experts or lay audiences in the face of science and technology (e.g. Martins, 1992). However, this study takes a different approach. The public, a ‘purposive sample’ (Robson 1993, p.141), are not primarily selected on educational grounds but because they are situated within the geographic boundaries of an area of health concern.

The motivations for a study of the public learning of Radon has been previously rehearsed in Chapter One. While everybody is exposed to some low levels of background radiation and a component of this is from Radon gas, high radiation levels are associated with particular geographic areas. It is the health threat associated with these areas of high radiation levels which provides the reasons to explore the interactions between science and these groups of the public. Pettigrew (1988) makes the point when considering a research sample that:

Given the limited number of cases which can usually be studied, it makes pragmatic sense to chose extreme situations and polar types in which the process of interest is ‘transparently observable’ (quoted by Eisenhardt 1988, p.5.)

The purposive samples selected in this thesis are drawn from three areas in the South West of England: namely Devon, Cornwall and Somerset. These are action areas (NRPB 1997) that contain the largest numbers of people affected by Radon and highest concentration of Radon in the UK.
The overall sample consists of three distinctive groups:

1. Students attending an institute of higher education in the South West of London \([N=30]\). Half of these students were selected on the basis of their home addresses which were in Devon and Cornwall \([N=15]\) (see phases 2 and 4).
2. Residents of Devon and Cornwall who would act as confidants to the previous group of Devon and Cornwall students \([N=77]\) (see data phase 3).
3. Residents of a Somerset village soon after a Radon publicity and measurement campaign \([N=17]\) (see data phase 5).

Specific details of these samples are documented in each of the chapters outlining the particular phase of the data collection. The sample selection is progressive in so far as it moves from a more ‘formal’ context [an institute of higher education] to an informal context [a Somerset village].

Phase 1 of the data collection is an analysis of written materials about Radon. These materials were selected on the basis of materials specifically about Radon which are easily available to residents of Radon action areas and include:

- i.) newspaper articles (1994-1996);
- ii.) a television transcript;
- iii.) leaflets and circulars aimed at Radon residents.

Specific sample details are provided in Chapter Five.

4.6 THE SAMPLE SELECTION: ETHICAL CONCERNS

A study of the public and Radon raises a number of ethical and moral questions. There is an ever conscious need to balance the desire for reliable and authentic data with a clearly defined moral and ethical code of conduct.
It is important to emphasise that Radon gas is very sensitive topic - particularly within designated Action Areas. It is a subject which is highly emotive, Radon has become strongly associated with cancer and childhood leukaemia. Discussing with people the health risks they lead can be both irritating and disturbing. Healthy people who have lived in Radon areas all their life may not want to be reminded of the high chance they may have of contracting cancer.

Confidentiality is particularly crucial in that some houseowners are understandably very defensive about Radon levels within their homes. If such information were to become widely known, it can reduce house prices and make them difficult to resell. Currently, there is no compensation available for a reduction in house prices due to high Radon levels in the UK. In the questionnaire study, documented in Chapter Seven, a large number of questionnaires were returned unanswered because the participants were anxious about their property values (see Chapter Seven).

In addition, there are also concerns about the number of recent Radon surveys conducted within Devon and Cornwall. The researcher was anxious that a ‘survey saturation point’ might already have been reached. As one respondent in phase two of the data collection, Chapter Seven, rather pointedly commented:

Radon has been around for hundreds of years - it can be irritatingly over-emphasised! (RS12).

By taking into account these concerns the following principles were followed during the research:

i.) All the participants involved were volunteers and were not coerced into taking part in any way. It was hoped that the participants would feel that their involvement was worthwhile. In the interview studies (particularly with the ‘Radon Villagers’) the interviews in some cases continued up to an hour after the formal data collection had finished because the participants were eager to find out more about Radon gas.
ii.) Care was taken to ensure that any information provided or advice offered was in agreement with the information circulated by the National Radiological Protection Board. This is information which is widely available. The NRPB kindly supplied a large number of their Radon leaflets and in some cases, after the interview, these were given out to inquiring participants if they appeared particularly interested to find out more (in phase four of the data collection all the participants received a copy of this leaflet which acted as an ‘intervention’).

iii.) Caution was taken when contacting potential volunteers. For example, to identify students living in Devon and Cornwall it was necessary to complete a search of an institutional database containing student records. Prior to this search, an application was made to the Institute’s Ethics Committee which then granted permission. The Somerset villagers were contacted though a resident of the village who also formed part of the interview sample. This personal approach was considered necessary to counter any concerns previously expressed.

iv.) All the data collected was treated as confidential. Before commencing the data-collection, the participants were assured that their comments would remain anonymous. In the case studies, where quotations are taken from interview transcriptions, the identity of the participants is protected by the use of fictional names. Somerset contains many rural villages and specific details of the village (i.e. its name and geographic location) are not disclosed.

4.7 CONTEXT FREE OR CONTEXT SPECIFIC APPROACHES

Hofstein and Rosenfield (1996), in a searching review of the field of learning in informal educational settings, emphasise that research methods need to be chosen on the basis of ‘the context of the setting’ and the ‘specific questions to be investigated’ (p91). Considering the context of the setting, Lucas, McManus and Thomas (1986) accent the contextualised nature of learning and the importance of performing research in situ:
The major difference between classical studies on learning and learning from informal settings is that the context of informal learning must be preserved if the results are to have validity. Classrooms are places where interactions between teachers and pupils are expected and the replacements of the teacher by the researcher will have much less effect on the validity of the conclusions than the introduction of a researcher into the interaction between museum visitor and the exhibit. (p. 5)

These comments primarily concern research performed within a chosen informal educational setting.

The focus of the thesis is slightly different, it aims to model informal learning about a particular event, i.e. it is ‘learner- and content-focused’, rather than, ‘setting- and activity-focused’. A possible approach to this study would have been to observe learners in a situation where their learning may become apparent. This has been an approach used in other studies of learning, for example, non-participant observation has been extensively used in naturalistic studies of science classrooms (Kahle, 1990) and ‘listening-in’ has been used to record the learning outcomes of a museum and zoo (Tunnicliffe, Lucas and Osborne, 1997)

However, to adopt such a naturalistic approach in this study would pose insurmountable problems. Learning is often tacit and it is difficult to think of a situation which would enable a researcher to reliably assess conceptual status without some form of researcher intervention. There are also an enormous number of potential situations where one can learn about Radon (e.g. talking to a neighbour, reading a Radon leaflet on the bus, watching a television program, etc.). Informal learning is quintessentially learner-driven, opportunistic and can be both ‘accidental’ and ‘deliberate’ (Lucas, 1983). As a consequence, it is simply impossible to observe learners in all their potential learning situations. At best, a selective approach would need to be employed and, even then, these situations may not provide the type of data required.
Whilst recognising some of the advantages of a naturalistic study, a series of ‘interventionist’ methodological approaches were adopted, namely: interviews, case studies and a survey. The main research methodology used was semi-structured interviews. This has the particular advantage that the author could focus on the phenomena under study and then use in-depth probing to explore the interviewees’ responses to a greater depth essential in a study of this nature (the advantages and disadvantages of interviewing are explored in the following section).

However, in choosing not to pursue a naturalist approach, several important issues are raised concerning the context of the studies. For example, it is possible to frame enquiries in science education in such a way that they avoid people identifying with a particular context, event or situation (such as the question: What is radioactive decay?). It is also possible to ask questions which limit responses to a specific context, such as, “Can you define the scientific meaning of the term radioactivity?” - this may limit responses to those of a more scientifically orthodox definition.

The way the study has been designed recognises the context of enquiry, the study was focused on a particular event, that of Radon gas. An early exploration of the sources of information readily available to learners in Radon affected areas (documented in Chapter Five) has been used to determine the scientific content which was used in the subsequent phases of data collection.

When general concepts of radioactivity were explored they were set within a more ‘everyday’ context and sought to explore the ‘everyday’ meanings. For example, the second phase of the data collection (documented in Chapter Six) aims to explore the conceptions the participants associate with the phenomena and events surrounding radioactivity and Radon, i.e. the study was framed in ‘ideographic’ and ethnographic terms rather than ‘nomothetic’ ones.

The last two phases of the data collection model the processes involved in informal learning (Chapters Nine and Ten). In these studies, particular care has been taken of the learning context. Early research found that the Radon leaflet (NRPB 1995) is a particularly important source of information (Chapter Seven). This leaflet was used as
the intervention for a structured study of learning (Chapter Nine). However, it should be noted that a structured study of learning from an informal information source is not identical with a naturalistic study of informal learning. In the structured case, at least part of the motivation to learn is provided by the researcher and not the learner as in the informal learning setting (as discussed in Chapter Nine).

The final phase of the study visits learners in a village to explore their understandings of Radon. In this analysis, learners have been interviewed about their conceptions - and the status they attribute to them - as well as other factors which may have influenced their learning. This study was performed in villager's homes to provide a familiar and more comforting environment.

4.8 THE TOOLS OF DATA COLLECTION

A variety of different methods, then, have been used for data collection. The idea of having more than one type of data as well as more than one type of research tool has enabled the research focus to be explored in different ways. This multi-method approach is commonly labelled ‘methodological triangulation’ (Robson 1993, p.290) and facilitates comparison of research findings from different standpoints, which in turn, provides a means of increasing confidence in the results.

There were three tools used for the data collection:

1. *Conceptual analysis of written materials*; (used in phase 1 of the data collection, in Chapter Five)
2. *Studies of cases using semi-structured interviews*; (used in phases 2, 4 and 5 of the data collection, documented in Chapters Six, Nine and Ten)
3. *Survey methods* (used for phase 3 of the data collection, described in Chapter Seven)

The chief tools for data collection are case studies, interviews and questionnaires. In the following three sections the strengths and weaknesses of these approaches are
considered with direct reference to their deployment in this study. This is then followed by a brief discussion of the approaches used during each phase of the data collection.

4.8.1 USING CASE STUDIES

Robson (1993) describes a case study as: ‘a strategy for doing research which involves an investigator of a particular contemporary phenomenon within its real life context using multiple sources of evidence’ (p.5.). The definition of a case is wide-ranging and can encompass, for example, a person, an event, a community, and an institution. A case study can represent a wide-range of quantitative and qualitative data gathering techniques.

Opinion about case study research is divided, some researchers do not recognise a case study as formal research because it fails to recognise the ‘official reality’ of a phenomenon (Atkinson and Delamont, 1985). Others, on the other hand, accent the tough and rigorous approach case study can provide, as Yin (1984) states: ‘Case study is remarkably hard, even though case studies have traditionally been considered to be soft options (p.26)’.

Case studies have clearly defined boundaries; the purpose of case study research is not to represent the world but to represent the case (Stake, 1994). In the present study, the concept of a ‘case’ can be applied at two levels: (i) at the community level, the case of learners within a particular geographic area and (ii) at the individual level, the set of cases of informal learners of Radon. At both levels, the strengths and weaknesses of this methodological approach apply.

The strengths of the case study lie in its ‘ability to provide a richly detailed portrait of a particular social phenomenon’ (Hakim, 1987, p.61). This is a particular advantage for the present study, as the phenomena under investigation - ideas and learning about radioactivity - are subtle, complex, multifaceted, and abstruse.
A further advantage of the case study approach is that it allows the researcher to portray the study in its real context. This is an advantage when presenting the results of a study, as Cohen and Manion (1989) state: ‘Case studies present research or evaluation data in a more publicly accessible form than other kinds of research report. The case study is capable of serving multiple audiences. It reduces the dependence of the reader upon unstated implicit assumptions and makes the research process itself accessible’ (p150). For the thesis, this is a considerable advantage because the aim is to explore learning in a particular setting - an informal learning environment.

The common criticism of case studies is their lack of generalisability. Yin (1984) cautions that they are only: ‘generalisable to theoretical propositions and not to populations and universes’ (p.21). Robson (1993) notes that it is ‘the investigators role to provide theoretical generalisations (e.g. about processes) and not permit statistical generalisations’ (p405). The key to generalisation is the ability to provide a clear specification of the theoretical framework (i.e. the limitations of the case). This is the responsibility of the researcher as Robson states: ‘those designing studies or making policies [...] need to determine whether or not the case(s) described can be transferred to other settings. The reader or user of specific research can see how that research ties into a body or theory’ (Robson, ibid. p406).

In making generalisations it is important to be cautious, a point made clear in the following passage from Driver (1989), who uses a large amount of research evidence about cases of individual learners to generalise, but, recognises the tradition of the particular research:

the documentation of student’s scientific conceptions and the way these progress is a field of work that has its roots in the ethnographic tradition with its recognition of the centrality of personal meaning and of individual and cultural differences. Yet despite this orientation, there appears to be strong messages about apparent commonalities in students’ conceptions that may have implications for future directions of work in this field (p.488).
Walker (1980) lists a number of additional disadvantages of case study research. The most significant of these for the present study concerns researcher bias. Walker notes that a case study can provide a biased view: ‘a distorted picture of the way things are’ (p105). In answer to his claim, this study uses multiple research methods which enable methodological triangulation. Indeed, the combination of qualitative and quantitative research methodologies, as Eisenhardt (1988) notes, is particularly synergetic in theory building research:

> Of special note is the combining of qualitative with quantitative evidence. The two are particularly synergistic in research designed to build theory from cases. Quantitative evidence can indicate relationships which may not be salient to the researcher and can keep the researcher from being carried away by vivid, but false, impressions in qualitative data (p.8).

**4.8.2 USING INTERVIEWS**

Interviewing has become the ‘bread and butter’ tool of education research as Robson (1993) notes: ‘When carrying out an enquiry involving humans, why not take advantage of the fact that they can tell you things about themselves’ (p227). An interview is a type of conversation: a ‘conversational encounter to a purpose’ (Powney and Watts, 1987). Interviews have been used extensively in studies of conceptual change learning (see, for example, Treagust, 1996 and Watts and Alsop, 1997).

There are several types and styles of interviews; a common distinction is made between interviews which are *structured* (a set of predetermined questions); those which are *semi-structured* (a set of questions which the interviewer can modify during the interview); and those that are *unstructured* conversations which have no predetermined structure). Using these categories, all the interviews used in the current study are *semi-structured* which Robson (1993) defines as:

> ‘Where the interviewer has worked out a set of questions in advance, but is free to modify their order based upon her perception of what seems the most appropriate in the context of the ‘conversation’, can change the way they are worded, give explanations,
leave out particular questions which seem in appropriate with a particular interviewee or include additional ones' (p.231.).

In the present thesis, *semi-structured respondent interviews* were used in phases 2, 4 and 5 of the data collection, studies documented in Chapters Six, Nine and Ten respectively. These chapters contain specific details of the interview protocol.

Powney and Watts (1987) argue that it is fruitful to classify interviews depending on the ‘locus of control’. They divide interviews into the camps: ‘respondent Interviews’ and ‘informant Interviews’ (p. 17). In these terms, the interviews would be classified as ‘respondent interviews’ since a structure is imposed, and the researcher remained in control throughout the interview.

The interviews captured data at two distinctive levels, see figure 4.2. In phase two of the data collection, the focus primarily concerned the conceptions that the participants associate with the phenomena of radioactivity. An adaptation of the ‘Interview-about-Events’ technique (Osborne and Freyberg, 1987) was used and the participants’ responses to a series of scenarios about radioactivity and radiation were documented. Here, the focus is on the participant’s conceptions of established scientific concepts and the interviews were designed to elicit talk of conceptions.

Similarly, the research documented in Chapters Nine and Ten also studied the participant’s conceptions of scientific phenomena. In addition, the research also used interviews to explore the status that individual’s attribute to these conceptions – a requirement of the CCM (Strike and Posner et. al., 1982). This type of analysis requires talk about conceptions (Thorley and Stofflett, 1996). Talk about conceptions is a type of ‘meta-conceptual talk’ which refers to scientific conceptions. In these interviews, for example, this type of talk was elicited using questions, of the nature: ‘What do you think about this conception?’ and “Do you believe it? Why?".
Talk about Conceptions in terms of Conceptual Status

which refers to

Talk of Scientific Conceptions

which refers to

Scientific Concepts

(as currently accepted by the Scientific Community)

Figure 4.3, the two levels of talk elicited by the semi-structured interviews documented in Chapters Nine and Ten.

4.8.3 USING SURVEYS

Surveys have traditionally been a popular approach in studies of the Public Understanding of Science (PUS). They have the distinctive methodological advantage that they can be very efficient in terms of researcher time and effort. Therefore, as a consequence, it is possible to canvas opinion from a large sample and code and process this information. However, as already noted they have significant weaknesses and the data collected can be superficial and it is difficult to check the honesty or integrity of the results.

Robson (1993) describes a ‘simple survey’ as a ‘collection of standardised data from an undifferentiated group of respondents over a short period of time’ (p.130). In the current study, a ‘simple survey’ was used to explore a group of Radon Confidants attitudes towards Radon, their understanding of the scientific concepts and terminology associated with Radon and the practicalities of living with Radon, as well
as, the main sources of their knowledge about Radon. For this purpose, the use of a survey offers particular advantages:

1. It enables the exploration of a large sample of respondents which would not have been possible to reach with other more qualitative methods.

2. It enables comparisons to be made with other PUS surveys. Surveys of the PUS are prevalent (see Chapter Four) and it was possible in some instances to adapt questions that had been used in previous studies. Thus a comparison could be made between the results of large scale national surveys and this smaller scale survey of a selected group.

3. The survey approach contrasted with other methodological approaches used which are qualitative in nature. A diverse mixture of methodologies, is a distinctive advantage in that it provides the opportunity for 'methodological triangulation'.

The general weaknesses of surveys are their 'internal' and 'external validity' (Robson, 1993, p.128). As it was not possible to personally supervise the completion of each questionnaire (the sample was spread across a large geographic area), a key external validity issue concerns the honesty and integrity of the questionnaire responses. It has not been easy to detect if the respondents were treating the exercises seriously and sensibly. In an attempt to ameliorate this weakness a 'cascade model' of data capture was adopted (see, Chapter Seven). In this model, the participants of an earlier study were trained as research assistants. These assistants selected the next research sample and, significantly for external validity, were trained to carefully administer and monitor the completion of the questionnaires - the researcher, in turn, could monitor the assistants. The assistants were then in a position to judge the attitude of the respondents. Furthermore, as the respondents were, in the most part, friends and relatives of the research assistants, it was conjectured that the questionnaire would be taken more seriously and would not appear as hostile as, for example, being approached by a researcher in the street or on the doorstep. This type of arrangement also has the added benefit that it is likely to ensure a good return rate for the data.

Issues of 'internal validity' concern ambiguities, misunderstandings and shortfalls in the survey question design. Driver et al. (1996) highlight particular weaknesses of the
survey approach when deciding on methods by which to explore children’s ideas about the nature of science. They write:

One reason for rejecting the survey approach centred on the nature of the issues we wished to explore and the data we wished to collect. Ideas about the nature of science are subtle and complex and it is often difficult to find the most appropriate language in framing a question and for the respondent, in providing an answer. We are not confident that survey questions will be understood, and responded to, with the meaning the questioner intended. Responses to open items are likely to raise further questions of clarification or elaboration; multiple-choice items constrain students’ responses into pre-determined channels and, by forcing a decision, may misrepresent the frequency of certain views (p.66).

For the most part, these weaknesses can be addressed with a well designed and piloted set of survey questions. As Driver et al. (1996) note:

In any event, the development of a survey instrument would require an initial more exploratory study to determine the key questions, to resolve issues of phasing and intelligibility and, if multiple-choice responses were used, to indicate the range of options which should be offered and the terms in which they should be expressed (p.66).

In this thesis, these issues were addressed because some of the questions used replicated those of previous surveys. This has the advantage that these questions have already been tested in the field. Furthermore, the questionnaire was carefully piloted before use.

The survey contained a mixture of closed and open-ended questions. Where a multiple-choice format was used, a space was provided for an additional response if the participants view was not reflected in the options provided. However, inevitably, the ‘path of least resistance’ is usually just to answer one of the options provided. As Gaskell et. al. (1993) note, the proportion of respondents selecting an explanation presented as an option in a multiple-choice format may be higher than that giving the response spontaneously in an open-ended type question. Furthermore, in ‘normative’
type studies, the selection of an option can be influenced by the other distracters provided. These are methodological weaknesses which are intrinsic and are, in the end, balanced against the ease of analysis - multiple-choice questions that are more straightforward to code and analyze. This study has the advantage that as the questionnaire is a component of a larger study, it is therefore possible to detect and acknowledge any anomalies which may occur through ‘methodological triangulation’.

4.9 THE ANALYSIS

Specific details of the data analysis are contained within each of the separate empirical chapters. Here, comments are briefly made on two aspects of the interview data analysis because these are generic to a number of data collection phases (2, 4 and 5).

All the interviews performed were recorded on audio tapes which were then transcribed in full. Audio recordings concentrate on the interviewees’ spoken responses and only represent a part of the data collected. In this respect, they favour the more articulate, which is an acknowledged methodological weakness. Transcription is itself an interpretative process and decisions need to be taken about the transcription procedure. The type of transcription will vary depending upon the aims and needs of the research design. An early analysis of the transcripts was used to judge suitability of the transcription conventions used and the perceived inaccuracies due to transcription distortion. Where appropriate, transcriptions were modified as a result of these issues. Key features of the transcription schedule used are congruent with those used by Watts (1983) and suggested by Powney and Watts (1987, pp. 146-151).

For all the interview studies, the analysis of the interview transcripts (the coding) was performed by two researchers independently and the results were then compared. Where disagreements occurred, a discussion took place until a consensus was reached or a modification was made to the original research categories. This is a further example of ‘triangulation’ (researcher triangulation) and has the primary purpose of validating research categories. In addition, this approach can improve the quality and accuracy of the research analysis.
Chapter Four has provided an overview of key methodological issues - these are revisited and contextualised in each following empirical chapters. Having provided this methodological platform the following chapters turn attention towards the subject of enquiry, radioactivity and Radon, and the results of the first phase of data collection - a conceptual analysis of the media.
CHAPTER FIVE

THE SUBJECT OF ENQUIRY:

RADIOACTIVITY, RADON AND THE PUBLIC

5.0 INTRODUCTION

The fifth chapter reviews written materials concerning radioactivity and Radon. It is divided into two sections. The first section contains a review of studies which have sought to investigate the learning of radioactivity. It has a similar structure to the main literature review, Chapter Three, and starts with a consideration of studies of conceptions of radioactivity and then continues with a review of studies which have explored radioactivity in a specific context. It then presents a review of studies of the public perceptions of risk associated with radioactivity. This is an area of considerable research and offers an important insight into the public’s reaction to radioactivity. This section concludes with a review of Radon-specific studies.

Section two has a different focus. It reports the results of phase one of the data collection - a conceptual review of information about Radon within the public domain. This includes newspaper articles, television programmes and information that are widely available to residents of Radon affected areas. The emphasis of this analysis is on written materials and the textual analysis performed considers these materials as educational sources.

These two sections offer both an insight into the learning of radioactivity and Radon as well as exploring information about Radon that is available within the public domain. When combined, these sections act as a foundation for the study of informal conceptual change learning about Radon.
5.1 SECTION ONE: LEARNING ABOUT RADIOACTIVITY

Radioactivity is a subject which is remote because unlike other physical phenomena, such as 'forces' or 'light' one cannot directly sense radioactivity. Harre' (summarised by Martins, 1992) uses human experience to divide science into three realms.

Realm one is the realm of possible experience which concerns the world of cognitive objects with pragmatic properties. Theories of this type allow a discussion of the constitution of these objects and to classify and make predictions about observable phenomena. Newtonian Kinematics being an example of such type of theory.

Realm two relates to cognitive objects with iconic properties and to a system which is not, for practical reasons, available for observation, but whose existence has been somehow anticipated through a theoretical means. Theories of plate tectonics, bacteria and viruses are in this realm.

Realm three is the domain of theories which enable the representation of non-picturable objects, for example quantum mechanics and the general theory of relativity. The cognitive objects here are represented in a mathematical form and refer to systems which cannot be directly observed by human beings. (p.31)

In this analysis, radioactivity belongs to realm two. It is a phenomena which is observable and detectable but only with specialist equipment. However, it is unlikely to be directly observed by members the public. In this sense, members of the public require scientists, members of the mass media and other 'experts' to act as their sensory organs (Beck 1992).

Due to its inherent abstract nature, the consideration of how people visualise, conceptualise and hypothesise about radioactivity poses quite fundamental questions of a complex epistemological and ontological kind. The answers to these involve cognitive considerations of, for example, images, analogies and metaphors as held by individuals and as portrayed in the media as well as, complex emotional and social factors.
A consideration of the cognitive, the social and the affective form the basis of this Chapter. The cognitive is explored through studies of conceptions of radioactivity. The majority of these studies are situated in formal educational settings. A number of studies of the public understanding of radioactivity are located within a social context and these studies delineate the important social factors that influence and shape learning. The strong association that radioactivity has with fear and anxiety (the affective) emerges, in part, through all the studies reviewed and, in particular, within the reviewed literature of ‘risk perception’.

5.2 UNDERSTANDINGS OF RADIOACTIVITY

Given the importance of radioactivity it is quite surprising that there have only been a modest number of studies investigating people’s understandings of radioactivity. Indeed, in Driver et. al.’s (1994) compendium of children’s ideas, radioactivity does not feature at all. However, radioactivity has played a significant part in surveys on the PUS and these highlight the public’s partial and often confused understanding of aspects of radioactivity and radiation. For example, Lucas’ (1987b) survey of the general public contained two open-ended questions about radioactivity:

- *During the generation of electricity in a nuclear power station, waste materials are produced which are radioactive. How would you describe in your own words what this term radioactive means?*

1. Harmful or dangerous to people and life (45%)
2. No answer (23%)
3. Emission of rays, molecules, ions, particles (17%)
4. Deadly (11%)
5. Causes cancer or leukemia (10%)
6. Dangerous to cells/ tissues (9%)
7. In atmosphere or wind (7%)
8. Produces/ releases alpha, beta and gamma rays (6%)
9. Generates energy or electricity (6%)

- *And how long do you think it takes before this waste is no longer radioactive*

Responses received ranged from less than 10 years - over 1000 years

Lucas found no significant association between responses to these questions and opinions as to whether there should be more or less electricity generated by nuclear power. However, an association was recorded between general knowledge scores and certain beliefs about nuclear power - the more knowledgeable tended to give support for increased nuclear power. In conclusion, Lucas writes:
Public knowledge of radioactivity is generally poor, and is a function of both level of formal science education and the use of press and television science programmes as informal sources of science knowledge. But, somewhat disappointingly, for those who place their faith in a more informed public making better decisions about science related policy issues the impact of knowledge about radiation on the public's views about British nuclear power policy was very minor (Lucas 1987b, p37).

Correlation between formal qualifications and acceptance of nuclear power have been found by other surveys (e.g. Miller 1992). However, this relationship is found to be less consistent than that of gender. Shapiro and Mahajan (1986), for example, analysed a variety of surveys between the 1960's and 1980's and found persistent gender differences in attitudes about nuclear power - men were less likely to oppose nuclear power than women. Norris (1988) also found a similar pattern when he analysed the results from a series of surveys administered across Europe.

Durant et al.'s (1989) survey of the UK public contained three questions about radioactivity: nearly three quarters of the respondents claimed they knew about the existence of background radiation; about a third of the respondents either did not know or thought that radioactive milk could be made safe by boiling it; and almost half of respondents believed that nuclear power stations caused acid rain.

Significantly, confusion about concepts of radioactivity appears not to be limited only to public respondents. Kaczmarek et al. (1987) conducted a survey of second year medical students at the state University of New York. The survey contained a broad range of health questions associated with radiation, NMR and ultrasound. Almost three quarters of the students believed objects in a radiographic room emit radiation after the completion of a diagnostic examination. The research team found this worrying, particularly:

when one considers that in modern radiological practice, diagnostic examinations are often performed on acutely ill patients in radiographic rooms.

(Kaczmarek et al 1987, p.43).
In conclusion, the research team recommended that:

Education of physicians is essential to allow them to work without fear in these situations. (ibid. p43)

A number of studies have focused on a particular nuclear ‘event’. The nuclear accident at Chernobyl, for example, sparked a number of research initiatives. Conforto (1989) questionnaired a sample of 1023 people aged 16-24. This sample was a mixture of secondary school students and university students both before and after the nuclear accident. They conclude that: (i) a high percentage of students are aware that x-rays are classed as ionising radiation; (ii) knowledge of medical uses of radiation is poor. However, surprisingly, they found few differences between the responses of these two groups. This study and the previous study of medical students would suggest that learner’s alternative conceptions are long lived.

In a different approach, Eijkelhof and Millar (1988) assessed both experts and non-experts’ understandings of radioactivity and ionising radiation by analysing British newspapers which dated back to the Chernobyl accident. They found the press coverage contained: (i) a lack of differentiation between the terms, radiation, radioactive material, and radioactivity; (ii) no clear distinction between irradiation and contamination; (iii) a lack of information about radio-isotopes (iv) a confused use of radioactive units; (v) a view of radioactive sources as having a definite life span; and (vi) an image of radiation as something that cannot be sensed and is strongly associated with fear and danger.

The coverage of the nuclear accident in Brazil at the city of Goiania has also acted as a research focus (for example, Nunes and Zylbersztain 1990). In this accident, a radiotherapy machine was taken from an abandoned hospital and then opened by force. This resulted in radioactive caesium chloride leaking out and causing several casualties. Martins (1992) has investigated pupils’ and teachers’ understandings of this accident. She used a system of semantic networks to explore how people use their pre-existing knowledge to make sense of new information. In her conclusions, she
highlights the significant role that the media has in shaping peoples’ understandings of these events, she writes:

New information [about radioactivity] appears to be interpreted against a background of diffuse knowledge about dangers and risks, which are acquired mainly through the media ... Most common types of misconceptions appear to be associated with ways the topic is dealt with by the media as well as with attempts to derive conclusions from comparisons with examples from other domains (p. 271).

Eijkelhof (1990) has performed by far the largest study of children’s understandings of radioactivity and ionising radiation. These studies also contain a consideration of radioactivity and risk. A component of Eijkelhof’s study included a two-stage Delphi study of experts’ advice for content and context domains to be incorporated into school curricula. The experts’ recommendations for context domains are listed in table 5.1.

**Table 5.1.** Content domains recommended by physics experts for a physics curriculum Eijkelhof (1990).

<table>
<thead>
<tr>
<th>Importance</th>
<th>Content recommended by experts for school curricula</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category One</td>
<td>• Background radiation: from the cosmos, food, rocks, building materials etc.;</td>
</tr>
<tr>
<td>(important)</td>
<td>• Medical applications: diagnostic and therapeutic uses of X-rays and nuclear radiation;</td>
</tr>
<tr>
<td></td>
<td>• Nuclear energy: emission of radioactive substances, normally after an accident;</td>
</tr>
<tr>
<td></td>
<td>• Storage of nuclear waste: underground above ground, on the ocean floor;</td>
</tr>
<tr>
<td></td>
<td>• Fall-out (as a consequence of nuclear weapons explosions);</td>
</tr>
<tr>
<td></td>
<td>• Some applications of ionising radiation in scientific and industrial research (e.g. tracers).</td>
</tr>
<tr>
<td>Category Two</td>
<td>• Other industrial applications (material research, sterilisation, measurement and control);</td>
</tr>
<tr>
<td>(fairly important)</td>
<td>• Immediate consequences of nuclear weapons explosions;</td>
</tr>
<tr>
<td></td>
<td>• Radioactivity from coal fired power plants.</td>
</tr>
</tbody>
</table>

In addition, Eijkelhof has conducted interviews and collected written diagnostic test data from a large sample of pupils (aged 16-19) in the Netherlands. In reviewing these results, Klaasen, Eijkelhof and Lijnse (1990) split the significant features into three
components: the 'undifferentiated radiation concept'; 'conservation of radiation' and 'fear of radiation', summarised below.

1. **The undifferentiated radioactive concept.**
   The use of the concept labels radiation, radioactivity and radioactive matter were found to be undifferentiated in any situation related to radioactivity. Indeed, in some cases natural radiation was conceptualised as not needing a source because it surrounds us like nature.

2. **A lack of conservation of radiation.**
   Radiation was perceived to accumulate in living things, objects and closed space. For example, the contamination from Chernobyl was conceptualised in terms of secondary contamination. Radiation was first 'stored' in vegetables and released into humans when these were eaten. Furthermore, the radiation was seen as being present for as long as physical symptoms of radiation sickness and poisoning existed. The researchers compared pupils' conception of 'radiation storage' to the storage of water by a sponge. They found that any decrease in radiation was perceived as a consequence of it spreading out, rather than a process of attenuation.

3. **A fear of radiation**
   Any situation involving radiation was found to be strongly associated with danger - a reaction that was constantly reinforced by the media. However, in cases where a personal decision had to be made, a feeling of safety was achieved by trusting safety measures, or of steering clear of radiation altogether.

Klaasen, Eijkelhof and Lijnse (1990) maintain that these three components govern most pupils' thinking about radioactivity both before and after formal education. They suggest that as the components appear consistent across a range of ages, the findings 'constitute a layman's knowledge of radioactivity and radiation' (Klaasen ibid. pp. 310). Furthermore, they assert that in everyday situations people do not need deep
theoretical explanations of radioactivity but, rather, should maintain a pragmatic attitude.

More recently, Millar (1994) has extended the work of Eijkelhof in a study of the nature of the radioactivity concept held by individuals in relation to notions of 'containing radioactive matter', 'containing radiation', and being 'radioactive'. The study consists of six probes, administered to 144 sixteen year olds. The results support earlier observations of an undifferentiated 'radiation' and 'radioactive-source' concept - both these concepts were found to be closely associated with the label 'radioactivity'. Moreover, the results suggest that the three ideas of 'containing radioactive material', 'containing radiation' and 'being radioactive' are strongly associated in children's minds but they are not entirely synonymous with the label 'radioactive'.

Souza Barros (1989) and Conforto (1989) have both been critical of school based curricula because of the lack of attention that has been given to nuclear issues. Nevertheless, some of the aforementioned research has been incorporated in teaching schemes - the Dutch Physics Curriculum Development Project [PLON] contains a teaching unit entitled 'The acceptability of risks of ionising radiation' (PLON 1984). This unit evolved from the work of Eijkelhof and Kortland (1988) and Klaasen, Eijkelhof and Lijnse (1990). While, Ronen and Ganiel (1988) and Millar et. al. (1990) have both devised schemes which focus on ameliorating the undifferentiated radiation concept.

Watts, Alsop et. al. (1997) have developed an Event-Centred-Learning (ECL) approach to teaching science in two countries, the UK and Brazil. The main features of the ECL approach are:

i.) The exploration of real events or circumstances constructed from TV and newspaper reports, articles, books and popular accounts;

ii.) An emphasis on 'real life' problem solving through active classroom tasks, such as preparing a television style programme and the use of role-play and drama;

iii.) The integration of aspects linked to science and technology in a social context (p. 349).
Using this approach they have developed two modules which have been used in both countries with pupils (aged 14 -18). One of the modules concerns the 1987 Goiania radioactive accident in Brazil, the other the policy of construction of nuclear power plants in that country. The themes were chosen because there are commonalties in these issues in both UK and Brazil.

5.3 LEARNING ABOUT RADIOACTIVITY IN A SOCIAL CONTEXT

Radioactivity is a subject which attracts considerable public interest, controversy and concern. The siting of nuclear power and reprocessing plants causes considerable public unrest. In the UK, the re-named British Nuclear Fuels Ltd.'s (BNFL) Sellafield plant has been the focus of public concern for many years and has become associated with radiation leaks and accusations of secrecy.

Researchers have explored public groups within areas of radiation concern: workers at British Nuclear Fuels Ltd. (BNFL) (Wynne, 1991); Cumbrian Sheep farmers after the Chernobyl accident (Wynne, 1990, 1991a); residents local to Sellafield nuclear plant (Layton et. al. 1993) and families living in areas of high levels of Radon concentration (Michael, 1992 and 1996).

The general conclusions of these studies has already been summarised in Chapter Three. For example, trust in, and credibility of, the sources of information appear highly influential in the public acceptance of advice about radioactivity. A good illustration of this comes from a case study of Sellafield local residence’s responses to the Black Report (Layton et. al. 1993). This illustrates how common understandings of science can sometimes fail to resolve a social concern.

The Black Inquiry sought to investigate whether or not there was a link between discharges of radioactivity and an apparent excess of leukemia among children who live close to the Sellafield plant. However the inability of scientists to establish a definitive body of scientific knowledge; the problems of scientific information being distorted by available means of communication; and the fundamentally different attitudes towards the nuclear industry resulted in the public rejecting scientific
information in favour of more ‘reliable’ and seemingly consistent personal experiences. In the case of such uncertainties, science, it seems, takes on quite a different appearance to the solid, secure science encountered in many formal settings.

The failure to recognise the importance of local knowledge is highlighted in a study of Welsh sheep farmers (Wynne, 1991). Due to prevailing winds following the Chernobyl nuclear accident, areas of North Wales were contaminated with radioactive fallout of radio-caesium. This was consumed by grazing sheep. Welsh farmers were advised by agricultural scientists that the radio-caesium in their stocks would be flushed out quickly if they grazed the sheep on grass in valleys rather than on the high fells. Both the practicality and credibility of this advice was questioned as it disagreed with the farmer’s local knowledge which saw the valley grass as an essential commodity for future breeding cycles. This resulted in the farmers rejecting the scientific advice offered.

Wynne (1992) uses these results and suggests a set of criteria which the public use to judge scientific advice (table 5.2):

<table>
<thead>
<tr>
<th>Table 5.2. Lay criteria for judging of science (Wynne 1992)</th>
</tr>
</thead>
<tbody>
<tr>
<td>i. Does the scientific knowledge work?</td>
</tr>
<tr>
<td>ii. Do scientific claims pay attention to other available knowledge?</td>
</tr>
<tr>
<td>iii. Does scientific practice pay attention to other available knowledge?</td>
</tr>
<tr>
<td>iv. Is the form of the knowledge as well as the content recognisable?</td>
</tr>
<tr>
<td>v. Are scientists open to criticisms?</td>
</tr>
<tr>
<td>vi. What are the social/ institutional affiliations of experts?</td>
</tr>
<tr>
<td>vii. What issue of ‘overspill’ exists in lay experience?</td>
</tr>
</tbody>
</table>

Once more this emphasises the importance of ‘social-institutional’ factors when considering the public learning of radioactivity.
5.4 RADIOACTIVITY AND RISK PERCEPTION

Considerable insight into how members of the public give meaning to radioactivity in their everyday lives can be derived from studies of the public perception of risks. Studies of risk have proliferated over the last 15 years and radioactivity takes centre stage in these studies. The literature provides an array of classifications of risks, some of which are based on definitions of hazard types (Slovic 1986, Solvic, Fischhoff and Linchenstein, 1982), while others are based on definitions of risk itself (Starr 1969). The terms 'risk' and 'hazard' have a broad set of definitions associated with them (as reviewed for example by the BMA 1990 and Royal Society 1983).

Risk is a large field which is poised for an integrative theory (Krimsky and Golding 1992). Hornig (1993) divides the field into ‘rationalist’ and ‘subjectivist’ perspectives. The rationalists argue that if sufficient data can be collected, and problems solved, it is possible for technical experts to arrive at an absolute measurement of the riskiness of some technological innovation (Fremin, 1989 and Wolpert, 1996). In contrast, the subjectivist standpoint emphasises that all risk assessments are based on a wide range of assumptions, value judgments and priorities - i.e. all risks are perceptions. As Slovic (1992) writes:

... risk is inherently subjective. Risk does not exist “out there”, independent of our minds and cultures, waiting to be measured. Human beings have invented the concept of “risk” to help them understand and cope with the dangers and uncertainties of life. There is no such thing as a “real risk” or “objective risk”.

(p. 90)

The technical analysis of risk (a rationalist approach) has received much criticism from social scientists who challenge the status of experts’ risk assessments. Beck (1992), for example, highlights the complex and multi-disciplined nature of risk assessments:

Risk determinations are an unrecognised, still undeveloped symbiosis of the natural and physical sciences, of everyday and expert rationality, of interest and fact. They are
simultaneously neither simply one nor only the other. They can no longer be isolated from one another through specialization, and developed and set down according to their own set of standards of rationality. They require co-operation across the trenches of disciplines, citizen groups, factories, administration and politics... (p. 29)

For both Giddens (1994) and Beck (1992) risk is an area of science that is key to their deliberations, as they argue it represents an aspect of science where its 'monopoly on rationality is broken' (Beck, *ibid.*, p.29).

The public's perceptions of risk has been studied extensively by behavioural and social scientists for over two decades. The most significant conclusion is that every hazard is found to have a unique pattern of qualities that relate to its perceived risk (see for example, Solvic *et al.*, 1981, 1982; Fischhoff *et al.* 1983; Krimsky and Golding 1992).

![Figure 5.1](image_url)  
*Figure 5.1, A comparison of nuclear power and X rays (Fischhoff *et al* 1979).*
Studies of perceptions of radioactivity have been a prominent part of this research because it is a phenomena associated with extreme risk. The results highlight how the risk associated with different areas of radioactivity are themselves perceived in very different ways. For example, figure 5.1 shows a comparison between the perceived risks of medical X-rays and nuclear power (Fischoff et. al., 1979).

Nuclear power is commonly perceived as high risk and there has been a large amount of research which has looked at this phenomena. Reviews of these studies have been provided by, for example, Solvic et al. (1981); Covello (1983); Lee (1987) and Slovic (1992). The key features of this research are summarised in table 5.3:

Table 5.3 a summary of nuclear power risk perception research.

| a) Nearly all the characteristics associated with perceptions of high risk are associated with nuclear power; it is perceived as involuntary, delayed, unknown, uncontrollable, unfamiliar, potentially catastrophic, inequitable and fatal; |
| b) A strong association exists between nuclear power and nuclear weapons; |
| c) The perceived risk is different for pro-nuclear and anti-nuclear groups. Pro-nuclear groups place greater emphasis on economic benefits, anti-nuclear appear more concerned with social and political risks (Eiser and Plight, 1979); |
| d) Acceptance of nuclear power has strong demographic correlates, with; i) social class; lower socio-economic groups are less supportive than other classes; and ii)sex, men are found to be more supportive than women; |
| e) People living near or within the vicinity of nuclear power stations are found to perceive the reactor less risky than those living further away (Layton et al. 1993; Wynne et al., 1993; Maderthaner, 1979). |

Whilst studies of risk perception have been instrumental in highlighting public views about risk, and provide considerable insight into how scientists and the public judge risks, they actually present an incomplete picture. They have a particular focus on personal judgments and, as such, neglect social and cultural influences. For example, research shows that neighbours of nuclear power stations balance their doubts with considerations of a social and economic kind. It is not uncommon that local areas are relatively poor and the nuclear plant brings with it prosperity and employment (Wynne
et. al., 1993). However, risks studies highlight the need to consider the public understanding of radioactivity in broader terms than subject competence.

5.5 RADON AND THE PUBLIC.

Studies of conceptions of Radon are still in their infancy. In part, this may be because of the lack of recognition that Radon has received in formal schooling. Radon is not mentioned in some curricula (DfE, 1995 and AAAS, 1993) and only receives indirect attention in others (PLON, 1984 and SEPUP, 1992). However, Sang (1997) has proposed a list of ideas which could be discussed in schools congruent with current UK curriculum demands (DfE, 1995):

1. The risk of ionising radiation is cumulative. The risk increases with level of exposure and duration of exposure. Exposure from all sources must be added together.
2. Radon is the largest source of natural ionising radiation.
3. Radon is the greatest health hazard in the natural environment.
4. Radon and its decay products are a source of alpha particles.
5. The ionising radiation from Radon damages cells and this is carcinogenic.
6. There is a distinction between a radioactive substance and the ionising radiation it emits (Sang, 1997, p.105).

A simple yogurt pot detector (based on TRASTRACK, an alpha detector in photographic film format) has been used by a number of primary school children to measure the Radon levels in their homes. Indeed, in 1989 primary school children discovered a previously unknown Radon hot-spot in the town of Street in Somerset which made headline news (Wilkie 1996). Moreover, recently, Austen and Brouwer (1997) have proposed a school experiment in Canada to measure the half-life of Radon. This uses a rubbed balloon to attract Radon dust from students’ cellars and the Radon deposits on these balloons are then used in half-life experiments. As well as being an innovative approach, this highlights the significantly high levels of Radon in Western Canada.
The public’s perception of Radon risks has been widely documented (for example see Lee, 1992; Fischoff et al., 1983; Solvic et al. 1981). Their reaction is paradoxical and, as such, pose a number of complex and interesting questions. Lee (1992), for example, contrasts the public reaction to Radon with their reaction to a planned nuclear power plant. When a nuclear power station was planned in Devon and Cornwall there was public outcry, Lee writes:

At one of the potential sites, protesters laid down in front of a mobile drilling rig and ‘hanged’ an effigy of the CEGB from the gantry. However, since that time, some 20,000 people have died of Radon induced cancers within the UK. Most of these must have been in the West Country (p1.)

The public appear to readily accept Radon and the disparity between the high technical risks associated with Radon and the public’s placid acceptance of these risks has been a source of some international concern. This disparity has been the driving force for a major publicity campaign launched in the UK by the Department of the Environment [DoE] and the NRPB. This campaign, already mentioned in Chapter Two, aims to inform the public about Radon and the risk it presents, as well as encourage householders to have a free measurement of the Radon concentration in their homes. However, by the end of 1991 only approximately 12% of households had taken advantage of this service (DoE 1994).

In 1993, the DoE commissioned a research project to investigate the reasons for the low take-up of Radon measurements (DoE 1994). The study consisted of a postal survey of 3,247 respondents and a follow-up interview survey with 736 respondents. The sample was selected to represent two groups; householders who had applied for Radon measurements and those that had not. All householders involved in the study lived in either Devon or Cornwall. The study found:

i.) Approximately half of households surveyed did not read or recall receiving the free leaflet provided.

ii.) The high cost was the main reason for not have remedial work performed.
iii.) People who applied for a free measurement were more likely to:
   a) have higher incomes; b) come from social groups A & B;
   c) be concerned about health or property values; and to
   d) be middle aged; and

iv.) Concern about property values was the best predictor for having remedial work undertaken.

The DoE report concludes by making recommendations in three areas; (i) how to increase measurement take-up; (ii) how to improve knowledge about Radon and (iii) how to increase remedial action if levels are found to be high.

The DoE study did not explore the respondents’ understandings of Radon, nevertheless, in its recommendations it assumed that the respondents’ lack of interest in having a Radon measurement performed could be explained in terms of a lack of knowledge about Radon. The study recommended that an increase in knowledge about Radon could be achieved by cascading information through targeting specific social groups or by sending packs of information to local organisations. This approach was suggested because it corroborated research findings that those householders who had accepted a Radon test would talk the matter over with their neighbours or friends before coming to a final decision. The role of formal education was also seen as significant and the report requested that information packs should be available in all schools and that teachers should encourage debates and whenever possible, time these to coincide with the launching of governmental projects. It was hoped that children would cascade information by discussing it with their parents following their school work.

A study by Johnson et. al. (1988) in the US concentrated on Radon understandings and found that residents of Radon areas, after a major publicity campaign, were unable to answer simple questions about Radon, how to measure it, and mitigate against it.

The DoE assumption that there is a straightforward relationship between knowledge about Radon and Radon testing behaviour has been challenged. For example,
Sandman et. al. (1993) conducted a survey on 3,329 New Jersey householders living in a Radon area. The results found that; a) thinking about Radon testing correlated with an increased general knowledge about Radon; b) the decision to test related to the perceived likelihood of risk from Radon; and c) actual testing was influenced by situational factors such as location and choice of test kits. It may be significant to note that Radon tests in the USA are not free. However, once more, this is further affirmation of the complexities of the relationship between decision making and knowledge competence.

Michael (1992 and 1996) has conducted a series of cases studies of the public living in Radon areas (N=20). In his analysis, Michael draws a distinction between two kinds of science knowledge: 'science-in-general' - science as an abstract entity or principle (i.e. concepts and constructs of science) and 'science-in-particular' - science directed at specific phenomena and identifiable, often practical goals (i.e. science which is practical and applicable to an everyday context).

Michael found that while people would happily collaborate with his survey and showed interest in his survey findings (science-in-particular) however, they showed little interest in finding out about the science of Radon (science-in-general). Michael (1992) concludes:

There is at once an identification with the science of the council [science-in-particular] and a distancing from science-in-general. This combination allows the speaker [the public] to support the goal of the survey and simultaneously profess ignorance of its techniques and processes (p327).

The distinction between science-in-general and science-in-particular seems to attune with Layton's (1991) distinction between 'science' and 'science articulated for practical action' (see, Chapter Three). These divisions emphasise how important it is that scientific information, offered to Radon residents, is applicable and practical. This conative perspective in learning (i.e. learning for a practical purpose) is developed as this thesis progresses.
Chapter Five: Radioactivity, Radon and the Public

The following section, documents the results of the first empirical phase - a conceptual review of how Radon is presented in the media. The chapter then concludes with a summary of the key features of both sections.

5.6 SECTION TWO: AN ANALYSIS OF INFORMATION ABOUT RADON.

This section considers how information about Radon is communicated to the general public and forms the basis of the thesis' Information context. The research presented here is driven by three research questions:

- What sources of information are available in the public domain?
- What information do these sources contain?
- In what ways do these sources communicate this information?

A comprehensive exploration of how the press covers science and technology would justify a large scale research project - given that Nelkin (1995) has noted, there appears to more science in the mass media every year. However, the amount of information specifically about Radon is quite modest and this forms the basis of the following analysis.

The purpose of this section is twofold. First, it provides an analysis of the kinds of information which is available within the public domain and, more specifically, available to residents of Radon affected areas. Second, it explores the problems related to communicating science to a lay audience and the models of communication employed. However, this analysis has its limitations, it can not provide an exhaustive review of all information available within the public domain about Radon but, rather, it looks to analyse a selection of information taken from a variety of different sources.

The important role mass media plays in disseminating scientific information to public audiences has never been in doubt - studies indicate that adults rely on mass media for scientific information which they use to make decisions concerning public and personal issues (Nelkin 1995, Long 1995 and Smith 1996 - provide comprehensive reviews of research of this nature).
5.7 THE MEDIA SAMPLE

Radon information is available from a number of different sources. However, the more popular are likely to be newspaper articles and television programmes (DoE, 1994). In addition, residents in areas with high Radon levels are also supplied with information and advice directly from the NRPB and the DoE. These three media sources form the sample for the conceptual analysis. Specifically, the sample is comprised of:

i) Newspaper articles which contain the word 'Radon' over the three year period (1994-1996);

ii) A transcript of a television programme about Radon, cancer and overhead electrical power lines (Channel 4, February 1996);

iii) Leaflets and supplementary information about Radon which have been specifically written for residents of Radon affected areas. Much of this information is freely distributed and, in many cases, posted directly to residents.

These sources of information that are widely available to residents of Radon areas (DoE, 1994). It is important for a study of this nature to consider information from a number of different sources as the purpose and aims of the information can be quite different. For example, newspaper articles could focus on the reporting of contemporary news-worthy events, whereas, Radon leaflets and other information may have a more advisory and guiding role. An overview of the media sample is presented in table 5.5.

The following discussions explore the method of sample selection.
Table 5.5 Radon information in the public domain (1994-1996)

| The Newspaper Sample. | 1. The Times, Financial and Sunday Times  
|                       | 2. The Guardian  
|                       | 3. The Observer  
|                       | 4. The Independent  
|                       | 5. The Mirror  
| Government communication with householders in Radon areas. | Phase one: initial information  
| | Phase two: test information  
| | Phase three: test result information  
| Television Programme. | Channel Four television programme:  
| | Dispatches: Electricity and Cancer  

5.7.1 THE NEWSPAPER SAMPLE

A content analysis of seven UK national daily and Sunday newspapers was performed, spanning a three year period from 1994 to 1996. This sample included four daily newspapers (the Guardian, the Independent, the Times, the Financial Times, and the Daily Mirror) and the Sunday newspapers (the Observer and the Sunday Times). All these newspapers have circulations over 375,000 and rank in the top eleven national morning dailies and Sundays by circulation (Smith 1996).

The newspaper cuttings were obtained in computer form by a full text search of the relevant data bases on CD-ROM. As a general representation of the press, the sample is biased in favour of ‘quality’ broadsheets - the Daily Mirror is the only tabloid included in the sample. The sample was constrained to those papers which are available on CD-ROM. In this respect the sample is ‘a convenience sample’ (Robson 1993, p141). In addition, a manual search was performed through back-issues of the Daily Mirror in 1996, in order to extend the study beyond the broadsheets. Details of the sample are provided in table 5.6.
Table 5.6, The Newspaper Sample

<table>
<thead>
<tr>
<th>Newspapers</th>
<th>Number of articles</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Times/Sunday Times</td>
<td>6</td>
</tr>
<tr>
<td>The Guardian</td>
<td>6</td>
</tr>
<tr>
<td>The Observer</td>
<td>2</td>
</tr>
<tr>
<td>The Independent</td>
<td>8</td>
</tr>
<tr>
<td>The Mirror</td>
<td>NA</td>
</tr>
<tr>
<td>TOTALS</td>
<td>22</td>
</tr>
</tbody>
</table>

5.7.2 THE TELEVISION SAMPLE

Television plays a leading role in finding out about science (Crane et al., 1994; Ryder 1979). Again, the present study was to be selective. A full analysis of Radon-related television programmes over a two-year period was not possible because it is not easy to acquire tapes of programmes, nor to perform detailed archival searches of television footage. However, during early 1996 reports surfaced about a possible link between Radon, cancer and electrical power lines and in February, Channel 4’s Dispatches programme investigated these claims. A transcription of the television programme was acquired from the producers and is used in this media analysis.

5.7.3 THE SAMPLE OF MATERIALS AIMED AT RADON RESIDENTS

Part of the study focused on the information leaflets, letters and booklets posted directly, or available on request, to residents living in Radon Action Areas. This information was obtained by writing to the both the National Radiological Protection Board (NRPB) and the Department of the Environment (DoE). Permission was sought and granted to use their text materials in this study. This material is linked to specific regional programmes disseminating Radon information and is structured into three communication stages. The first stage is general information and was posted to all householders, the second stage is information pertaining to the actual Radon test, and the third stage is information which accompanies the test results. The second and third communication stages are initiated by a response to the first. The Details are summarised in table 5.7.
Table 5.7 Free information sent to householders in Radon action areas.

<table>
<thead>
<tr>
<th>Phase</th>
<th>Format</th>
<th>Leaflet Title</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Initial information</td>
<td>Leaflet.</td>
<td>Radon in Houses</td>
</tr>
<tr>
<td>2. Radon test information</td>
<td>Letter containing instructions plus two</td>
<td>At-a-Glance-Series: Radon.</td>
</tr>
<tr>
<td></td>
<td>yellow disks.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Plus an A1 colour leaflet.</td>
<td></td>
</tr>
<tr>
<td>3. Test results and</td>
<td>Letter with test results.</td>
<td></td>
</tr>
<tr>
<td>supplementary information</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

In these phases, the majority of information about Radon is contained within the At-a-Glance leaflet (NRPB, 1995). This leaflet forms the focus of the following analysis.

A list of the Newspaper articles used; copies of the information sent to householders (the leaflets, ‘Radon in houses’ and ‘At-a-Glance series: Radon’) and a section of the television transcript are provided in Appendix I.

5.8 THE ANALYSIS

In a helpful categorisation, Jacobi and Schiele (1993) divide the analysis of scientific journalism into two deductive orientations. The first relates to the teaching and learning of science and the second to semiotics. The following analysis focuses on the teaching and learning of science. It considers not only the materials available but also the readership, through an analysis of the content of the materials and their potential effectiveness at communicating with a public audience.

The method of analysis used is common across the three media sources. The text was coded for: (1) the subject or focus of the article; (2) the presuppositions or the assumptions made about the readership; (3) suitability of the materials for learning about Radon; (4) the degree of sensationalism and bias; and (5) the practical advice offered.
The first two areas were adapted from a study of radioactivity and the press undertaken by Martins (1992). Codings (3) and (4) are standard to a conceptual analysis of written materials (as used, for example, by Nelkin 1995) and Coding (5) derives from Michael’s (1996) analysis of Radon residents as previously described. The codings are elaborated in the following paragraphs.

The Subject or focus is an analysis of the content of the article. This concentrates on the scientific concepts and constructs covered in the article as well as the images, metaphors and analogies used in the article. In addition, it considers the focus of the article and the amount of coverage. For example, a more general newspaper article on risk might include a small section on Radon whereas an article which has a specific focus on Radon would be more comprehensive and detailed.

Presuppositions or assumptions concentrate on the degree of prior knowledge required; the level of abstraction of the article; and the assumptions made about the background knowledge of the reader in general.

The Suitability of the articles for learning are determined by using Rowan’s theory of explanatory writing (Rowan, 1990). Rowan makes a distinction between ‘explanatory discourse’ and ‘informatory discourse’. Explanatory discourse aims to help the reader understand a scientific phenomena of which they are broadly aware - but do not yet fully understand. Informatory discourse assumes the reader understands the scientific phenomena and adopts a reporting stance. Rowan identifies three levels of writing which promote scientific understanding and these form the components of the explanatory discourse analysis, see table 5.8.

Table 5.8. Rowan’s (1990) theory of explanatory writing.

<table>
<thead>
<tr>
<th>Levels of Informatory Discourse</th>
<th>Does the article:</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. <strong>Elucidating</strong></td>
<td>Explain a scientific terms meaning;</td>
</tr>
<tr>
<td>2. <strong>Quasi-scientific</strong></td>
<td>Mentally represents an aspect of reality;</td>
</tr>
<tr>
<td>3. <strong>Transformative</strong></td>
<td>Reject naive theories of science and replace them with acceptable theories.</td>
</tr>
</tbody>
</table>
The coding of Sensationalism considers how the article covers information about Radon. Radon is a potentially life threatening chemical and the extent to which the articles use emotive images and language forms part of this analysis.

And finally, Practical advice looks at the article from the position of residents who seek practical advice, for example, details about Radon reduction mechanisms. This analysis builds on the dichotomy explored earlier between science-centred and public-centred perspectives, and draws upon Michael’s (1992) analysis of science-in-general and science-in-particular.

5.9 THE NEWSPAPER COVERAGE OF RADON (1994-1996)

The first significant point to make is that the newspaper coverage of Radon itself is modest. This is apparent when a comparison is made with the number of newspaper articles about radiation, radioactivity and nuclear power overall. For comparison, the word ‘nuclear’ features in 1236 articles and the word radiation appears in 169 articles in the Independent newspaper in the year 1994, whereas Radon appears in 8 articles in the same year. Admittedly, the word nuclear has other uses (for example, nuclear families) for which this search method is unable to differentiate. Although, the majority of the uses of the word nuclear are actually linked with radioactivity and in any case, the word radiation acts as an illustration.

In general, the press ally Radon with mystery, danger and fear. When featured, Radon is always explicitly linked with its potential damage to health through cancer. Radon is a subject which is shrouded with mystery and attributed with far reaching properties. For example, in 1996 The Times newspaper, in addition to its more common link with cancer, linked Radon to earthquakes (13th March); machines which were found to revive wilting flowers (Sunday 30th June) and ghosts, ghouls and other supernatural phenomena (4th September)!

In considering the subject, Radon newspaper stories have two styles. The first focuses on a particular contemporary Radon event, and the second considers more general issues associated with public health and risk. The majority of the Radon articles have
an 'event' style - a summary of these events is presented in the following tables 5.9, 5.10 and 5.11 for each of the years 1994, 1995 and 1996 respectively.

Radon events tend to focus on a scientific report or a change of governmental policy. These articles summarise and select content from other more technical publications. The written style is short and factual and the content is selected because it links with matters of public health and risk. For example, the results of UK National Radiological Protection Board (NRPB) surveys frequently make Radon news-worthy events (April and May 1996 and November 1994).

Articles of this type contain factual information about survey findings and include details about Radon levels in areas of the UK. The focus of these articles is the causal properties of Radon rather than any details about Radon itself, as exemplified in the following Guardian cutting:

More than 16,000 homes in Britain have been found to have dangerous levels of the radioactive gas Radon, which can cause lung cancer, the National Radiological Protection Board said yesterday. Continuing research could show a further 84,000 homes are involved (Guardian 29th Nov. 1994).

This clipping implies that a definitive link exists between Radon and cancer, although, the link between low levels of radiation and cancer is controversial and empirical evidence is contradictory (see Chapter Two). As a general observation, the press tend to rely on government sources for their information and these are presented as a fact rather than emphasising the controversial or provisional nature of the conclusions. For example, the risk statistics of the NRPB are the most widely quoted figures and these are usually taken as definitive.
Table 5.9 Radon events in 1994

<table>
<thead>
<tr>
<th>MONTH</th>
<th>REPORTED RADON EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>May</td>
<td>• UK Government legislation suggests that employers in Somerset might have to undertake tests on Radon levels at site work by law.</td>
</tr>
<tr>
<td>August</td>
<td>• The book Radon Daughters (Ian Sinclair, Jonathan Cape) is released and reviewed by all national papers. It tells the story of a one-legged X-ray addict set in an apocalyptic East End of London.</td>
</tr>
<tr>
<td>October</td>
<td>• A report in the Lancet links alpha radiation to chromosomal instability.</td>
</tr>
<tr>
<td>November</td>
<td>• UK NRPB announce another 16,000 homes have dangerous levels of Radon. New areas include Buxton, Derbyshire and Northampton.</td>
</tr>
</tbody>
</table>

Table 5.10 Radon events in 1995

<table>
<thead>
<tr>
<th>MONTH</th>
<th>REPORTED RADON EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>• Raised levels of radiation [Radon] from car exhausts fumes are found in the teeth of children who live near motorways [Bristol University].</td>
</tr>
<tr>
<td></td>
<td>• Japanese scientists are able to detect earthquakes using Radon detecting machinery.</td>
</tr>
<tr>
<td>November</td>
<td>• West Devon Council is surveying abandoned mine workings on Dartmoor for levels of Radon to assess the health risk to cavers.</td>
</tr>
<tr>
<td>December</td>
<td>• UK Chancellor of the Exchequer increases duties on super unleaded petrol as it contains more cancer causing aromatics than leaded petrol.</td>
</tr>
</tbody>
</table>

Table 5.11 Radon events in 1996

<table>
<thead>
<tr>
<th>MONTH</th>
<th>REPORTED RADON EVENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>February</td>
<td>• Bristol University scientists link cancer to electro-magnetic field lines through Radon gas.</td>
</tr>
<tr>
<td>March</td>
<td>• Japanese scientists are able to detect earthquakes using Radon gas levels.</td>
</tr>
<tr>
<td>April</td>
<td>• In the UK, the NRPB announces that another ‘Radon belt’ has been detected which runs from Lyme Bay to Hull.</td>
</tr>
<tr>
<td>May</td>
<td>• The NRPB announce a further 100,000 households could be exposed to Radon, new areas include Somerset.</td>
</tr>
<tr>
<td></td>
<td>• Chartered Institute of Environmental Health accuses the government of ignoring advice.</td>
</tr>
<tr>
<td>June</td>
<td>• Bristol University team of scientists announce survey results which conclude that the ‘increased level of Radon gas in the home does not lead to increased cancer’.</td>
</tr>
<tr>
<td>July</td>
<td>• UK government announces a new national environmental health plan which includes Radon reduction.</td>
</tr>
<tr>
<td>September</td>
<td>• Finnish Centre for Radiation and Nuclear Safety establishes no link between lung cancer and Radon levels in Finland.</td>
</tr>
</tbody>
</table>
How the press selectively covers scientific research is highlighted by one year's review of Radon articles. In February (1996) all of the reviewed newspapers covered research which claimed to have established a link between overhead power-lines and cancer - some of the headlines used to attract readers were:

- **Childhood tumours**: Scientists offer first explanation of how radioactive particles from overhead power lines may trigger illness (Independent February 14th)
- **Missing link to cancer power lines near homes stir up killer cocktail say researchers** (The Mirror February 14th)
- **Row over cancer link to power pylons** (Guardian February 14th.)

The reported research was undertaken at Bristol university and was originally published in the International Journal of Radiation Biology (Henshaw et. al. 1996 - reviewed in Chapter Two). However, an article published in the European Journal of Cancer by a different team of scientists at Bristol university four months later challenged any links between lung cancer and low Radon levels. This research, however, did not receive wide press coverage and was only reported by the Times newspaper.

High levels of Radon gas in the home do not generally lead to increased cases of cancer, according to a survey in Devon and Cornwall......David Etherington from the unit [Bristol University Research Unit] said “it is reassuring that our study does not support a large-scale risk from elevated Radon levels”.

(Nigel Hawkes, The Time 14 June 1996)

Articles without an ‘event focus’ tend to cover Radon in a more social and everyday context, for example, the subject of buying and selling a house, or as part of an article with a more general focus on carcinogens and risk. These articles are typically featured in Sunday newspapers. They are longer, have a broader focus and a less factual style. The purpose of these articles is more for advice and guidance. For example, the article ‘Is your home blighted’ offered a general guide to the potential pitfalls associated with house buying and concludes with a comment on Radon:
A good surveyor, preferably one who knows the area well, can save purchasers from numerous headaches later on. Apart from obvious hazards, such as hidden structural defects, they might alert clients to more obscure problems. These could be anything from the hitherto unsuspected absence of mains drainage to a plague of rats. Surveyors should also warn buyers if there is a risk of Radon. This carcinogenic substance occurs naturally in certain parts of the country. The National Radiological Protection Board on 0235 831600 or the Building Research Establishment's Radon Hotline 0923 664707 can supply details.


Similarly, a more recent edition of the Sunday Times offers a personal account of a journalist living in Cornwall, entitled ‘Coming clean on a killer gas’.

Like many others in Cornwall, I have been offered a free Radon test, which I accepted. But in the light of a recent case where an elderly woman was penalised for not revealing a problem with noisy neighbours to her house-buyers, I am having second thoughts. If I went ahead with the test, would I have to reveal any adverse result when I sold my house? Where property is concerned, is ignorance bliss?

(Roger Anderson, 9th June, The Sunday Times 1996)

This emphasises the ambiguous position in which residents may find themselves when deciding to have a Radon test.

Texts tend to differ in their expectations in the level of suppositions made about the reader. An analysis of the terminology of the articles is quite revealing. For this purpose, a word count was performed for each of the newspapers (table 5.12).

The most significant feature of this analysis is the small number of technical terms used. The majority of articles avoid a theoretical discussion about Radon and concentrate on the more applied aspects associated with living with Radon.
Table 5.12 Terms used when reporting about Radon

<table>
<thead>
<tr>
<th>Terminology</th>
<th>1994</th>
<th>1995</th>
<th>1996</th>
<th>Totals</th>
<th>average per article *</th>
</tr>
</thead>
<tbody>
<tr>
<td>General</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiation</td>
<td>21</td>
<td>43</td>
<td>23</td>
<td>87</td>
<td>1.6</td>
</tr>
<tr>
<td>Radioactive</td>
<td>26</td>
<td>7</td>
<td>3</td>
<td>36</td>
<td>0.5</td>
</tr>
<tr>
<td>Decay</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>0.1</td>
</tr>
<tr>
<td>Uranium</td>
<td>8</td>
<td>11</td>
<td>9</td>
<td>18</td>
<td>0.3</td>
</tr>
<tr>
<td>Alpha</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>0.15</td>
</tr>
<tr>
<td>Causal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cancer</td>
<td>28</td>
<td>28</td>
<td>30</td>
<td>86</td>
<td>1.6</td>
</tr>
<tr>
<td>Contamination</td>
<td>9</td>
<td>6</td>
<td>8</td>
<td>23</td>
<td>0.4</td>
</tr>
<tr>
<td>Irradiation</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>11</td>
<td>0.2</td>
</tr>
<tr>
<td>Ionisation</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Units</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Becquerels (Bq)</td>
<td>9</td>
<td>7</td>
<td>9</td>
<td>25</td>
<td>0.46</td>
</tr>
<tr>
<td>Rad</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sievert</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Curies</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

* total number of articles analysed = 55

The demands of texts, *Presuppositions*, can be considered at two levels. At the most superficial level texts simply assume an understanding of the terms ‘radioactive sources’ and ‘cancer’. Articles of this type frequently refer to the cancer-causing properties of radioactive gas Radon; the physical appearance of the gas and its physical origins - but avoid a theoretical discussion about radioactivity and radiation. For example, the following clipping from the Mirror illustrates this approach:

*The Silent Killer Lurking at Home.*

Radiation comes from many different sources but by far the most important is Radon, a naturally occurring odourless and colourless gas that seeps out of the ground. It is also a known cause of disease, being the second most common cause of lung cancer after smoking and has been recently linked to childhood leukaemia. And what is worse is that it has a nasty tendency to collect in our homes.

(Dr. Mark Porter 21 April, The Sunday Mirror, 1996)

As articles become more demanding they make more use of scientific terms and consider the theoretical aspects of radioactivity. In these cases the causal properties of Radon are linked to its decay products rather than the gas itself - a differentiated view of radioactivity (see Eijkelhof, 1990) and the terms ‘contamination’ and ‘irradiation’ are used. This is illustrated in the following cutting from The Independent, which is
particularly technical - the focus of the article is the publication of a scientific report in the Lancet.

Science Update: Cancer Clues
A report in the Lancet may hold clues to the way in which radiation causes leukaemia. Plutonium and the radioactive decay products of Radon gas emit a particular type of radiation known as alpha particles. A team of researchers from the Medical Research Council's Radiobiology Unit have shown that alpha radiation may cause damage that is not immediately apparent. The researchers discovered that bone marrow cells which had undergone alpha irradiation did not show any apparent signs of damage. But after the cells had divided several times in the normal way, the 'daughter' cells showed aberrations and damage to the chromosomes. The report concluded that such 'chromosomal instability could produce genetic changes that may contribute to the subsequent development of leukaemia.'

(Danny Penman 11 October, The Independent, 1994)

The press use the unit of radioactivity, the Becquerel, in preference to any other unit (for example, Rad, Grey or Sivert). This is the unit used by the NRPB - their action levels is currently set at 200 Becquerels per cubic metre. Although Becquerels per cubic metre are frequently cited, the articles do not explain what the units mean.

Rowan's theory of discourse analysis has been used as a basis to explore the efficacy of the textual materials for promoting understanding. The majority of the articles analysed were largely comprised of informatory discourse. For example, the short article 'screen risk' in The Independent is entirely informatory discourse - the writer assumes the reader understands what Radon gas is and the harm it presents:

People working at computer screens are three times more at risk from the radioactive gas Radon than when sitting elsewhere in the room, a Bristol University study found. The tests did not show any harmful effects, though levels were higher than permitted in the nuclear industry

(July 10th, The Independent, 1994)
The article ‘Missing link to cancer’ in the Daily Mirror also adopts an informatory discourse when discussing the link between power-lines and cancer.

The new findings are largely derived from elementary physics experiments of classroom level. The research found electrical leads of ordinary electrical appliances can attract radioactive particles of Radon, which are found in everyday room air.


This article does not explore the reasons behind the attraction of Radon to electrical appliances. Whereas the article ‘Search stepped up for killer gas under our homes’ has aspects of explanatory discourse.

Radon is a natural gas which results from the radioactive decay of Uranium in rocks. It represents the greatest of all radiation risks to the overall population, outweighing manmade sources like X-rays and nuclear power as well as other natural hazards such as cosmic rays. On average, half the radiation dose we receive each year comes from Radon. Its biggest health impact is as a cause of lung cancers; it is blamed for 2,500 out of 40,000 lung-cancers fatalities a year.

(Nicholas Schoon, 17th May, The Independent 1996)

This extract is predominately an example of the first level of explanatory discourse - elucidating discourse. It explains that Radon is a form of natural radiation and is the decay-product of Uranium, as well as presenting the yearly dose and the casual affects of the gas. The manner in which these risk statistics are quoted, though, is misleading as they are presented as universal givens and not linked to a particular source. The actual sources of the figures cited are the UK governmental figures from the NRPB.

Examples of the Rowan’s (1990) explanatory discourse quasi-scientific are difficult to find. When comparisons are made in an attempt to familiarize the reader with Radon gas they tend to be comparisons between Radon and other sources of radiation such as uranium and X-ray machines and the nuclear industry. On the other hand, the following extract contains aspects of quasi-scientific discourse as it explains the limitations of epidemiology by comparing it with a blunt tool.
Chapter Five: Radioactivity, Radon and the Public

So why don’t the population studies find such a risk? NRPB argues they do in the case of the atom bomb survivors - still by far the largest group ever followed. If they don’t in the case of the Finnish population, it is because the excess risk is too small to be detected, given the size of the population sampled. The tool of epidemiology is simply too blunt to discern a difference.


Transformative discourse involves challenging the common alternative conceptions of science. The previous section of this chapter has highlighted the common alternative conceptions of radioactivity: the undifferentiated conception, a lack of conservation and a fear of radiation. The analysis uncovered no discernible evidence of this discourse. Indeed, unfortunately, a case can be made that some of the materials promote these alternative conceptions. For example, the undifferentiated conception of radioactivity would appear to be supported by the large number of the articles that associate Radon gas directly with cancer and do not mention its decay products or differentiate between contamination and irradiation.

The extent to which the press can be labeled as sensationalist has been the topic of contemporary discussions (see for e.g. Dunwoody and Peters 1992). Radon headlines appear to be sensationalist because they clearly aim to catch readers’ attention by emphasising the extreme dangers associated with the Radon gas - illustrated by the following extracts:

- *Search stepped up for killer gas under our homes* (Independent, 17th May 1996).
- *One school, one class...three cancers* (Independent 17th May 1996).
- *Cancer risk run* (Guardian 29th November 1994).

However, in this respect, the headlines tend to be more bold than the body of text, which is more factual. This contrasts with the more sensationalist coverage of, for example, the nuclear accidents at Chernobyl and Three Mile Island (Dunwoody and
Peters, *Op.Cit.*). In the coverage of these accidents Dunwoody and Peter's analysis coded the text and headlines to be *sensationalist*.

A large number of articles in 1994 and 1995 reviewed the book *Radon Daughters* (Sinclair, 1994). This best-seller contains very little information about Radon but evokes a series of powerful apocalyptic images. The story is about Todd Sileen, a one-legged author, who pays for his addiction to Radium in X-rays by selling information to the secret police. This is both *sensationalist* and spectacular in content as well as promoting a confused and undifferentiated view of radioactivity!

The majority of 'event-focused' articles offer little *practical advice* to residents as they are the secondary reporting of scientific publications and, subsequently, tend to focus on science-in-general. In contrast, the more general Radon articles covering house-buying and cancer risks have a more practical emphasis. These articles offer information about Radon testing and financial grants, as well as local concerns about property prices. However, significantly, in three years of newspaper coverage there are no articles which explores the Radon reduction measures in much more than superficial detail.

There is little evidence to suggest that the image of science presented is one with which the public will feel they can become involved, although, there is some recognition of the local knowledge of Radon residents. For example, the Times contains an article about the links between cancer and power-lines and this includes the extract:

> The link between electricity pylons and cancer had been a sort of modern myth, we has all heard of it, we all had friends of friends who had fallen victim to it and we were all secretly relieved that we didn’t live anywhere near one.

*(15th February, The Times, 1996)*

This is a much more personalised, humanised discourse which is missing from the majority of articles analysed.
5.10 THE TELEVISION TRANSCRIPT

Durant (1991) emphasises the considerable popularity of science television programmes and the pivotal role they play in the public understanding of science. He divides programmes into four different types based on the science they contain: philosophical; practical science; political science and para-science. In February 1996, Channel 4's Dispatches programme 'Electricity and Cancer' explored the recent research evidence which linked power-lines, Radon and cancer. This programme contains science of both a practical and political type.

The programme was aimed at a public audience and the subject focused on recent claims that power-lines attract Radon and then cause childhood cancer (Henshaw, Ross, Fews and Preece 1996). The purpose of the programme was to explore the science underpinning this claim and then explore its potential public implications. The programme aimed to explain the science involved in some detail - this is perhaps unrepresentative of general television coverage of science (Durant, 1991). At the level of presuppositions, there are very few assumptions made about the background of the viewer: visual aids and analogies are used to explore the science processes involved. The programme however does assume an understanding of the terms 'atoms', 'particles', 'white blood cells' and 'leukaemia' - all the other scientific terms it uses are described.

The programme has a sensationalist start as it documents the moving story of the death of a 13 year old boy by leukaemia. This boy's bedroom was 15 feet away from an electrical substation and the domestic electricity meter was only inches from his bed-head. The boy's father is currently battling for compensation through the legal system. The programme continues with a detailed explanation of electricity, this is presented in a quasi-historical fashion and charts its development. In the main, the discourse is explanatory and examples of elucidating and quasi-scientific discourse are evident. For example, in the following extract, quasi-scientific discourse is used to explain the manner in which electricity is transported throughout the country:
The pylons of the National Grid striding across the countryside, laden with great high-voltage cables are a commonplace and unremarkable sight. This electricity distribution network is a little like the road system: they are the equivalent of motorways for transporting a lot of electricity over long distances and there are the little country byways over which much less power is carried (Wilkie, 1996 p3)

Throughout the programme a number of analogies are used, for example, a water flow analogy is employed to describe voltage and current and the dangers associated with radioactive particles are compared to the size and magnitude of a punch. However, once more, there is no discernible evidence of Rowan’s (1990) transformatory discourse.

The programme introduces electric fields which surround electrical sources and provides a dramatic demonstration of these fields when the presenter lights a neon light by holding it towards an underground cable. Epidemiological evidence is presented which suggests that a link might exist between cancer, Radon and electromagnetic fields and this is used as the platform to describe Professor Henshaw’s claims (Henshaw et. al. 1996). This research remains centre stage but is contrasted with other research and the scientists who dispute these claims.

Overall, the programme is factual in style although the start is sensationalist. The main focus of the programme is general concepts about radioactivity as there are few examples of scientific advice closely associated with practical measures for Radon residents.

5.11 INFORMATION AIMED AT RADON RESIDENTS

As will be seen later, in Chapter Seven, information from government sources that is posted directly to residents takes on considerable importance. As one resident of Cornwall puts it:

I assumed that the information that arrived through the post would tell me everything I needed to know.... As the information was glossy and was obviously expensive - I
thought that the subject had to be important. (Questionnaire study RS34, Chapter Seven)

The following section contains details of the information available to Radon residents and a conceptual analysis of the NRPB Radon leaflet - the main part of this information.

In the UK, the Radon publicity campaign was led by an eye-catching leaflet entitled ‘Radon in houses’. This leaflet is divided into two sections; ‘Radon the Facts’ and ‘What should I do?’ The leaflet gives a short introduction to Radon and invites the householders to apply for a free measurement of Radon levels in their home. The purpose of this leaflet is to encourage residents to apply for the Radon test. The details about Radon are kept to a minimum, to illustrate, the leaflet only contains the following paragraph about Radon:

*What is Radon?*

Radon is a naturally occurring radioactive gas. We have always received doses of radiation from it and always will.

The leaflet explains the procedure for applying for a test and contains an application form. Householders who complete a Radon test are later sent a letter containing their measurement level. This letter is accompanied by a colourful fold-out leaflet entitled ‘Radon’, which is part of the NRPB ‘At-a-Glance’ series (NRPB 1995). This leaflet explores Radon in some depth and is the focus of the conceptual review here - it also forms the ‘intervention’ in a study of conceptual change documented in Chapter Nine to come. The leaflet is widely available to residents of Radon action areas (NRPB, 1997) and is likely to act as a significant source of information about Radon. A copy of this leaflet is presented in Appendix I

5.12 THE ‘RADON’ AT A GLANCE LEAFLET

The ‘Radon-at-a-Glance’ leaflet is a colourful fold-out A1 leaflet. It’s purpose is to inform public readers about Radon, the risks associated with Radon and the potential
level reduction measures. The leaflet's *subject* is detailed and contains a comprehensive amount of factual information about Radon in domestic houses and is split into six sections:

i) Our biggest radiation dose  
ii) What is Radon?  
iii) Radon in homes  
iv) Radon risks  
v) Radon areas  
vi) Radon reduction

The first contains information about the radiation doses to which members of the public are exposed. The second section provides theoretical information about Radon, for example, its decay series and radio-biological details. The third section focuses on Radon in homes; it depicts the processes through which Radon enters houses and provides an illustration of the measurement equipment supplied and used by the NRPB to calculate Radon levels. The fourth section is statistically based and concentrates on the NRPB estimates of Radon risks. This information is presented in a series of graphs which depict the life-time risks associated with different exposures. The fifth section is a chart which shows Radon affected areas (this is slightly out of date and does not represent recent data). The sixth, and final, section illustrates four potential Radon reduction techniques suitable for domestic houses. The leaflet contains recommendations for further reading (the Householders Guide to Radon and other At-a-Glance publications in the NRPB series) as well as the telephone and fax number of the NRPB.

The leaflet is clearly designed for the public audience and textual information is balanced with diagrams and charts. The *presuppositions* made are assumptions related to the language used, the ability to understand graphical information, and the familiarity with the concepts presented. Although scientific terms are kept to a minimum, and certain terms are defined (i.e. the Becquerel), the leaflet requires an understanding of the terms; radioactivity, disintegration, atoms, radioactive decay, alpha radiation and risk.

The reader is expected to interpret information from a variety of graphical sources. Information is presented in pie charts, bar charts and line graphs. As will be seen later
in Chapter Nine, the interpretation of information in this format is found to be difficult by non-scientific experts.

The conceptual presuppositions made include the ability to interpret risk statistics and a conceptualise micro- and macro-representations of matter. Research indicates that public audiences find risk statistics in this format difficult to interpret (for example see Fremlin, 1989). The leaflet presents risk statistics in a series of bar and line charts, statistics which are quoted as lifetime risk percentages associated with particular Radon levels—measured in Becquerels per cubic metre (see figure 5.2). Understanding these figures is not straightforward, particularly as the general life-expectancy used in these calculations is not stated.

**Figure 5.2, Radon risks, NRPB (1995)**
In more general terms, the leaflet presents a biased risk perspective because only research which claims to have established a firm link between Radon and cancer is cited. There is hint of the professional disagreement which exists over risk estimations of this nature because the statistics are presented as NRPB 'estimates':

'The NRPB has estimated the risk of lung cancer from lifetime exposure to Radon in the home...(Section 4, Radon risks).

The section containing information about Radon is both detailed and comprehensive. It has information about radioactive decay and how Radon enters the lungs. These processes are represented in a macroscopic diagram of the lungs and a microscopic diagram of a radioactive decay chain. Research evidence suggests that relating macroscopic and microscopic phenomena is particularly conceptually demanding (Lijnse, Licht and Waarlo, 1990). Moreover, the decay chain (see figure 5.3) requires a high level of previous knowledge about atoms and radioactive decay. This diagram represents a snap-shot of each of the decay products on a decay time-line but does not contain any information about how long each decay product 'exists' or the harm associated with these products.

Radon is created when uranium undergoes radioactive decay through a number of stages. Radon itself decays to form short-lived radioactive particles which remain suspended in the air.

Figure 5.3, a Radon decay chain, NRPB (1995).
The leaflet aims to inform rather than encouraging debate or take into account existing knowledge and expertise of Radon residents. For example, the rumour that Radon is associated with childhood leukaemia is a source of considerable local concern and has featured in headline news. However, this is not acknowledged or challenged at any point in this leaflet.

The leaflet contains details about the action level - the level which Radon reduction measures are suggested. However, an indication of the range of levels and any geographical 'hot spots' is missing - other than at a very general 'county level'. Property prices are a source of public concern, however, the leaflet fails to consider these.

Contained within the leaflet are a mixture of both explanatory and informatory discourse (Rowan, 1990). Factual information (informatory discourse) is used to describe the geographical areas of Radon gas and the damage it causes to detectors. ‘Explanatory’ discourse is used at two levels; elucidating and quasi-scientific. At the level of elucidation, the text, for example, defines the SI unit Becquerel and the manner in which Radon reduction mechanisms work. In addition, elucidating discourse is used to explain how Radon enters the house and the origins of Radon:

Radon is a natural radioactive gas. It comes from the uranium that occurs naturally in all rocks and soils and is given off at the surface of the ground. We all breathe it throughout our lives. Out of doors, it disperses in the air so levels are very low.

(Section two NRPB leaflet, 1995)

Aspects of quasi-scientific discourse are used in the representation of the radioactive decay chain previously discussed. However, significantly, transformatory discourse is not used in the leaflet.

The leaflet is designed to be factual and there is no evidence of sensationalism. Information is presented in a de-humanised and reassuring form, perhaps designed to not cause public alarm. The leaflet fails to offer very much practical advice, although it needs acknowledging that additional NRPB publications have a more practical bias
(e.g. The Householders’ guide to Radon - DoE, 1993) and the leaflet contains details of these publications with contact telephone numbers. The extent to which it is possible to cover all the information required in a leaflet of this size also needs to be recognised. Nevertheless, as a significant part of the information campaign, this leaflet has a number of limitations.

The leaflet’s emphasis is general radioactivity concepts (science-in-general, Michael 1992) and information - it aims to inform the reader about the science of Radon (concepts of radioactivity and risk) rather than providing the reader with practical advice, for example the science associated with Radon reduction mechanisms (science-in-particular, Michael, 1992). Although, details are provided about how Radon enters houses. The leaflet gives details of risk calculations but could give the actual numbers of deaths which have been attributed to Radon in affected areas - which may be a more meaningful and useful figure. Once more, the information provided fails to explore the uncertainties which are associated with the risk estimations presented.

The NRPB leaflet seems to be based on a model of informing rather than empowering residents. In this model, the public would appear to be considered as witnesses rather than participants. During the publicity campaign as a whole there are few attempts to engage public response or to listen to views and concerns. Again, unfortunately, the implicit model of communication is science-centred - based on assumptions of public ignorance (see Chapter Two). In general, it seems that the information campaign is directed towards universal concepts of radioactivity rather than science more closely allied to practical action in a Radon area.

5.13 SUMMARY

This chapter has reviewed common conceptions of radioactivity (and Radon) and presents the results of an analysis of information about Radon. When combined these act as a base for the future exploration of informal learning.
This review stresses the complexities associated with learning about radioactivity and Radon. Learning is influenced by, and embedded in, a complex web of cognitive, social and emotional factors. Cognitive factors include the remote and intangible nature of radioactivity, it is a subject which by its very nature seems counter-intuitive and thinking is characterised by a number of range of alternative conceptions, the most prevalent of these being the undifferentiated concept (source-radiation) and lack of conservation.

Radioactivity is a highly emotive subject, allied with danger, fear and dread. It is a subject which is often associated with high risk. However, rather paradoxically, Radon would appear to not evoke such strong emotional responses. The public can appear indifferent to living with Radon or indeed finding out about more about it.

The analysis of information available in the public domain has served two purposes. First, it enables a categorisation of types of information that members of the public have available. Second, it raises a number of issues related to communicating science to a public audience. In summary,

1. There is only a modest amount of information about Radon available to members of the public.
2. While all the materials are written for a lay audience most require some understanding and familiarity with basic concepts of radioactivity, atomic structure and risk statistics. Risk estimations tend to be quoted as certainties and the controversies and debates that surround them are on the whole ignored.
3. The information differs in style and purpose with information source.

Overall, it seems that the implicit model of communication is science-centred; one of informing rather than empowering. This leaves residents witnesses rather than participants in any debates about Radon. Using Michael's analysis, the information concentrates on science-in-general rather than science-in-particular and local knowledge concerns appear to be largely ignored.
The conceptual review of Radon sources provides an overview of certain types of information to which informal learners are exposed. The following Chapter documents the first of two studies exploring a sample of the public’s understandings of radioactivity and Radon.
CHAPTER SIX

INTERVIEWS ABOUT SCENARIOS

6.0 INTRODUCTION

Chapter Six presents the results of phase 2 of the data collection. The method of data capture here is by semi-formal interviews conducted with two groups of 'recent school leavers' [Total Sample N=30, the two groups n1=15 and n2=15]. One group was composed of participants living in a Radon 'action area' (NRPB, 1995) the other group consisted of participants from geographic areas not directly associated with Radon or the nuclear industry. The study uses, and develops, the research methodology 'Interviews-about-scenarios' (IAS) to explore and document the meanings and feelings which these individuals associate with radioactivity and Radon. During the data analysis, comparisons are made between the responses of the two groups to infer if living in a Radon action area influences knowledge and feelings about radioactivity and Radon.

Phase 2 of the data collection has been driven primarily by three research questions:

- What conceptions do these individuals associate with radioactivity and Radon?
- What emotions do these individuals associate with radioactivity and Radon?
- Do individuals living in areas of radiation concern have different conceptions of, and feelings about, radioactivity and Radon?

6.1 DEVELOPING THE RESEARCH TOOL (IAS)

White and Gunstone (1992) review a wide range of research methods which facilitate the exploration of students' understandings of science. In the main, these research techniques have been used to explore children's cognitive understandings of traditional school science concepts. In contrast, this study has purposely sought a
slightly different, broader approach: to investigate everyday-understandings of science (or what has been commonly termed as life-world knowledge, Schutz and Luckmann 1973). To achieve this has required an open-ended methodology which allows participants to reveal the meanings and feelings they associate with aspects of science. Where knowledge is well structured and co-ordinated it is possible to use highly formal and closely structured research methods. However, where knowledge is more loosely held, and lacks co-ordination then open-ended methods have advantages as a kind of 'loose fishing net'.

In Chapter Five it has been noted that public information about Radon tends to be event-centred. The methodology developed here builds on this format and uses a series of events (called scenarios) involving radioactivity and Radon. These scenarios were depicted through line drawings and are used, by the interviewer, to elicit meanings which participants associate with radioactivity and Radon.

Using line drawings and pictures to explore individuals’ perceptions of their world has been a rich source of data for psychologists and anthropologists for many years. Both brevity and emphasis mitigate against an exhaustive review of the literature associated with these studies. Instead, the focus here is the specific use of related research in science education, where line images have been used quite extensively. The Interview-about-instances (IAI) technique, initially developed by Gilbert and Osborne (1980), has been a popular research tool within science education over the last two decades.

An Interview-about-instances session (IAI) consists of a tape-recorded discussion about a collection of line-drawn picture images which focus on a specific scientific word. During this discussion, the interviewee is asked whether the card represents an example or not of the application of this word. To illustrate, a line-drawn picture of someone riding a bicycle can be used to scrutinise the scientific word ‘force’ (see Watts, 1983). The interviewer would then ask the participant “is there a force on the bicycle?”. Whatever the interviewee’s response, the reasons are sought. The analysis of the interview tapes then attempts to set boundaries which encapsulate the concept from the respondent’s perspective.
Chapter Six: Interviews about Scenarios

The IAI technique has been used to explore a wide-range of different scientific phenomena (for a review see Gilbert, Watts and Osborne 1985). Interviews-about-events (IAE) is a method which derived from IAI. It is a similar research tool but has a slightly more flexible and open-ended procedure (Osborne and Freyberg 1987). IAE aim to investigate children’s views of everyday phenomena (e.g. light in the home) and use both line drawings and children’s experiences of the phenomena to explore the participants’ understandings. In this case, the focus is on the broad meanings which the participants associate with the depicted phenomenon rather than a scientific concept label (such as ‘Force’).

The methodology introduced in this thesis is termed Interviews-about-scenarios (IAS). This is a flexible approach that builds on the Interviews-about-events methodology. In the scenario case, line drawings are used to depict scenarios in order to stimulate conversation about radioactivity. A scenario consists of a picture which includes a radioactive substance and this forms the stimulus and focus of the interview. Significantly, the approach is open-ended and the participants are free to use their own language and explanatory frameworks to discuss the phenomena presented. In this respect, the conversations are not tied to a single scientific word but have a phenomenological emphasis. The focus is achieved by the context of the scenario so that, for example, by placing the radioactive source next to a metal object it is possible stimulate a conversation concerning the affects of radiation on metal objects. It is possible to have a conversation of this type without, for example, the use of the scientific terms irradiation and contamination.

Interviews-about-scenarios (IAS) differ from Interviews-about-events because they purposefully seek to explore feelings as well as understandings - Interviews-about-events tend to focus only on the cognitive. In Interviews-about-scenarios, a broader approach is adopted with the aim of capturing both cognitive and affective data. The subsequent analysis can then explore the participants’ conceptions of a scientific phenomena and the associated emotions.
6.2 THE SCENARIOS

In total, the study used 20 different scenarios, these took the form of line drawn pictures presented on A4 card. Three indicative scenarios are provided in figure 6.1 - a complete set are contained within Appendix II.

Figure 6.1 Three Sample Scenarios

Scenario 3
A radioactive substance is dumped in the sea.
What happens?

Scenario 10
A box containing a radioactive substance is held near somebody's hand.
What happens?

Scenario 14
A house is built on rock which contains some radioactivity
What happens?

All the scenarios contain a sentence summarising the phenomena and a question to orientate the participants' responses. In the majority of cases this question was “What happens?” - as indicated in the three scenarios above.

In the majority of pictures the ‘radioactivity’ was represented as a box containing a radioactive substance. This representation was used because it avoided drawing the radioactive substance itself and enabled an investigation of how the interviewees conceptualise the appearance of radioactive substances.

6.3 DEVELOPING THE SCENARIOS

The scenarios were developed to facilitate broad discussions in four areas:

1. The general nature of radioactive sources and radiation;
2. The effects of radioactivity and radiation;
3. The dangers associated with radioactivity;
4. The general nature and dangers associated with Radon gas.

All scenarios were drawn with an everyday emphasis and avoided using equipment associated with science and scientific laboratories. For example, the metal object placed near a radioactive substance was chosen to be a candle-stick rather than a piece of sheet metal held in a clamp stand, which represents an image more akin to the science laboratory, see figure 6.2.

Figure 6.2 An everyday scenario.

![Scenario 12](image)

A metal object was placed near a radioactive substance.

What happens?

It was conjectured that everyday, cartoon like images would present a more comforting environment because they do not resemble a traditional science examination. Furthermore, by reducing a scenario to its most elementary form it is possible to minimise distractions - allowing the respondents to focus on the relationship between the two/three essential ingredients of the scene and little else. A photograph, for example, would not have allowed this, and may have burdened the respondent with complexity.

A pilot study was used to both develop and extend the number of scenarios. Additional scenarios were developed during the pilot phase, for example, the scenario depicted above, Scenario 10, was included after a discussion of how radioactivity effects different materials in different ways. Similarly, the scenarios exploring the physical and chemical properties of radioactivity were extended to encompass a
further range of areas by building on the pilot results. In total, 28 scenarios were
developed and 20 of these were used during the final study. This final 20 were
selected on the basis of emphasis, repetition and concerns about the length of
interview. A full range of scenarios was sought to explore the four areas of
radioactivity listed above. Some repetition was built in to check and confirm ideas, as
well as to control for the interview length.

During the pilot study, two minor textual alterations were made:

- Initially radioactive materials were referred to as radioactive sources; however the
  word source was viewed as potentially confusing and so was changed to
  ‘substance’.
- The term container was viewed as hinting that the radioactive material was in a
  liquid form and so was changed to box in the main study.

A list of the scenarios and their intended focus is presented in table 6.1 over-leaf and a
copy of the scenarios are presented in Appendix II. Because each scenario was
designed to facilitate broad ranging discussions the intended focus can only be thought
of as indicative - frequently a scenario was found to generate responses which when
then led to a different focus. The same scenarios were used to explore the causal
properties of radioactivity and the dangers its presents.

6.4 THE METHOD

The interviews consisted of two parts. The first contained a series of set questions
about the interviewee’s, age, sex, formal qualifications and the main sources of their
information about radioactivity. Responses were recorded directly onto pre-prepared
answer sheets.

The second consisted of the Interviews-about-scenarios. Each interview began with a
general introduction and a description of the procedure. The interviewees were assured
of the confidentiality of their responses and that they could stop the interview
Table 6.1. The scenarios used and their intended focus.

<table>
<thead>
<tr>
<th>Area examined</th>
<th>No.</th>
<th>Scenario</th>
<th>Intended focus</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
<td>A box containing a radioactive substance is left open</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>A radioactive substance is heated</td>
<td>• Radioactivity’s sensory appearance:</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>A radioactive substance is dumped in the sea</td>
<td>• How it propagates?</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>A radioactive substance is left for a long time</td>
<td>• How long it lasts?</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>A radioactive substance is cooled</td>
<td>• Where it come from?</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>A radioactive substance is looked at under a very powerful microscope</td>
<td>• How it is increased?</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>A radioactive substance is dropped</td>
<td>• What effects it?</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>A radioactive substance is listened to</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>A radioactive substance is placed near a thermometer</td>
<td></td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>A radioactive substance is placed near a mirror</td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>Chemicals are added to a radioactive substance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>A scientist needs to make a substance more radioactive</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>A radioactive substance is dumped in the sea</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>A radioactive substance is held near somebody’s hand</td>
<td>How radioactivity affects:</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>A Metal object is placed near a radioactive substance</td>
<td>• Living things, and</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>Somebody swallows a radioactive substance</td>
<td>• Non-living things.</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>Somebody breaths in a radioactive substance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>18</td>
<td>A radioactive substance needs to be made safe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>Some parts of the UK have high levels of background radiation</td>
<td>• The properties of Radon gas.</td>
</tr>
<tr>
<td></td>
<td>14</td>
<td>A house is built on rock which contains some radioactivity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>16</td>
<td>A scientist wishes to find out if low levels of background radioactivity is harmful</td>
<td></td>
</tr>
</tbody>
</table>
at any time if they so wished. Usually they took a short while to relax and then started responding to the scenarios presented.

The scenarios were placed on a table in front of the interviewees and the comments summarising each of the scenarios were read out. They were presented in the same order for all the interviews - the original order was chosen at random.

During the interview elaboration and clarification was sought from the participants' explanations where the researcher considered it necessary. In some cases, the conversation would be more factual (concentrating on the scientific phenomena) and, in others, markedly more emotional in nature. During the interviews, responses to scenarios depicting radioactivity adjacent to something living were probed for the dangers involved. This involved questions of the form: ‘Is this dangerous?’ ‘Will it always be dangerous?’ ‘How dangerous is it?’ ‘How is it harmful?’ In addition, the participants were asked to reflect on the sources of their explanation. This discussion was initiated by asking the participants directly either; “where did you found out about this” or by establishing a line of thought and reasoning and then asking “why are you thinking like this”. In the cases where a comparison was evident the interviewer would probe for why this particular analogy, metaphor or simile was used - “Why do you say is it like....?”.

Each interview lasted between 40 minutes and one hour and was tape recorded. The audio tapes were transcribed in full using the transcription protocol noted in Chapter Four. A sample of indicative transcript is contained within Appendix II.

6.5 THE SAMPLE

The sample comprised of two distinctive groups of adults, 30 in total, between the ages of 20 and 30. The participants were all undergraduates attending an institute of higher education in the South West of London.

The sample was selected from students studying a broad range of degree programmes outside of traditional science courses (students of chemistry, biology, physics and
engineering were all excluded) with the intention that this policy would provide rich and variable data.

A sample of undergraduates is highly selective and cannot be considered as wholly representative of the general public. For example, levels of formal qualifications will generally be higher than national averages. However, the exclusion of traditional science students from the sample places an emphasis on the participant’s compulsory school experience. In this respect, it can be argued that this sample is representative of a group of informed and recent school leavers.

The majority of the sample held GCSE qualifications within at least one science subject and had finished studying compulsory science at age 16. Their science qualifications ranged from none, to a BTEC in nursery nursing. The sample consisted of a greater proportion of women than men; 17 women and 13 men. This broadly represents the population across all courses at the institute.

As mentioned earlier, the sample was composed of two different groups. The first was a group of students \(n_1=15\) who volunteered after reading an advertisement placed on an Institute notice board. These students were selected only if they did not have a home address within a radiation ‘action area’ as indicated by NRPB data (NRPB, 1996) or an area associated with the nuclear industry (i.e. students were not selected if they lived in the vicinity of a nuclear power station or reprocessing plant).

The second group was drawn from students who have a home address in Devon and Cornwall \(n_2=15\) an NRPB ‘action area’. For this, application was made to the Institute’s Ethics Committee and a search was performed through the student records: 85 students were found to live in either of these two areas, and 50 students were contacted by letter (20 male and 30 females). 19 students volunteered and 15 were eventually interviewed. Details of the sample are presented in Table 6.5, these include their sex; interview code name; degree subject and level of science qualification.
Table 6.2. Characteristics of those interviewed [N=30].

<table>
<thead>
<tr>
<th>Group</th>
<th>Interview code (name)</th>
<th>Main degree subject studied</th>
<th>Sex</th>
<th>Qualifications in Science</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Karen</td>
<td>Art +QTS</td>
<td>F</td>
<td>GCSE biology</td>
</tr>
<tr>
<td></td>
<td>Anne</td>
<td>Education</td>
<td>F</td>
<td>A level biology</td>
</tr>
<tr>
<td></td>
<td>Simon</td>
<td>Education</td>
<td>M</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>David</td>
<td>English</td>
<td>M</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Linda</td>
<td>Drama</td>
<td>F</td>
<td>None</td>
</tr>
<tr>
<td>GROUP A</td>
<td>Caroline</td>
<td>English</td>
<td>F</td>
<td>O level biology</td>
</tr>
<tr>
<td></td>
<td>Jenny</td>
<td>Education</td>
<td>F</td>
<td>Access science</td>
</tr>
<tr>
<td></td>
<td>Alex</td>
<td>English</td>
<td>M</td>
<td>O level biology</td>
</tr>
<tr>
<td></td>
<td>Martin</td>
<td>English</td>
<td>M</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Aaron</td>
<td>Maths</td>
<td>M</td>
<td>Dual award science</td>
</tr>
<tr>
<td></td>
<td>Fiona</td>
<td>Geography</td>
<td>F</td>
<td>O level biology, O/A human biology, O level physical science</td>
</tr>
<tr>
<td></td>
<td>Barbara</td>
<td>Education</td>
<td>F</td>
<td>GCSE health studies, A level social biology</td>
</tr>
<tr>
<td></td>
<td>Jane</td>
<td>Education</td>
<td>F</td>
<td>GCSE biology</td>
</tr>
<tr>
<td></td>
<td>Anthea</td>
<td>Linguistics</td>
<td>F</td>
<td>GCSE biology</td>
</tr>
<tr>
<td></td>
<td>Liam</td>
<td>Linguistics</td>
<td>M</td>
<td>Dual award science</td>
</tr>
<tr>
<td></td>
<td>Cathy</td>
<td>Music</td>
<td>F</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Joanna</td>
<td>French</td>
<td>F</td>
<td>GCSE biology, chemistry, physics. A/S biology</td>
</tr>
<tr>
<td></td>
<td>Brett</td>
<td>English</td>
<td>M</td>
<td>Dual award science</td>
</tr>
<tr>
<td></td>
<td>Anna</td>
<td>French</td>
<td>F</td>
<td>GCSE biology and chemistry</td>
</tr>
<tr>
<td></td>
<td>Lorraine</td>
<td>English</td>
<td>F</td>
<td>Dual award science</td>
</tr>
<tr>
<td></td>
<td>Adam</td>
<td>History</td>
<td>M</td>
<td>Dual award science</td>
</tr>
<tr>
<td></td>
<td>Mark</td>
<td>Social Policy</td>
<td>M</td>
<td>A level biology</td>
</tr>
<tr>
<td>GROUP B*</td>
<td>Simon</td>
<td>English</td>
<td>M</td>
<td>A level chemistry, physics GCSE</td>
</tr>
<tr>
<td></td>
<td>David</td>
<td>Health Studies</td>
<td>M</td>
<td>GCSE biology, chemistry, physics</td>
</tr>
<tr>
<td></td>
<td>Melody</td>
<td>Art</td>
<td>F</td>
<td>Single award science, A level social biology.</td>
</tr>
<tr>
<td></td>
<td>Louise</td>
<td>History</td>
<td>F</td>
<td>GCSE chemistry and biology</td>
</tr>
<tr>
<td></td>
<td>Melika</td>
<td>Drama</td>
<td>F</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Paul</td>
<td>Geography</td>
<td>M</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Catherine</td>
<td>English</td>
<td>F</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>Treve</td>
<td>French</td>
<td>M</td>
<td>Single award science</td>
</tr>
</tbody>
</table>

*Group B are residents of Devon [7] and Cornwall [8].
6.6 SOURCES OF INFORMATION

In the first part of the interviews the participants were asked to judge the main source of their knowledge about radioactivity and radiation. These results are presented in Table 6.3.

<table>
<thead>
<tr>
<th>Sources of Information</th>
<th>Frequency of Responses [N=30]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Group A</td>
</tr>
<tr>
<td>Formal Education</td>
<td>1</td>
</tr>
<tr>
<td>News Items</td>
<td>9</td>
</tr>
<tr>
<td>‘Fiction’ (films and books)</td>
<td>5</td>
</tr>
<tr>
<td>Radon leaflets</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 6.3, contains the frequency of responses to the question: ‘What is your main source of information about radioactivity?’ for each of the groups A (Non-Radon residents) and B (Radon residents) [N=30].

Surprisingly, only a small number of the participants considered formal education to be a main source of information. This is quite surprising as radioactivity is part of the UK National Curriculum (DfE, 1995) and has been part of GCSE Science syllabuses for many years. School science content is obviously a faded source of information and media sources are perhaps more salient and germane. One participant actually commented about the abundance of media information covering radioactivity:

Radioactivity seems to be in the news all the time. There are always stories about nuclear leaks and cover ups (Anne, Group A)

Several examples of news items were actually cited during the interviews. Almost exclusively these referred to nuclear accidents or incidents (the accident at Chernobyl was widely mentioned). Two of the respondents commented about the general negative style of media coverage:

It’s normally from bad press associated with the scary effects of radioactivity and nuclear power (Martin, Group A).

It comes from News items concerning the bad press associated with cancer and destruction (David, Group B).
Participants also referred to particular films and fiction which contained memorable images of the destructive power of radioactivity. The film 'Silkwood' and the cartoon book 'When the Wind Blows' were both cited as sources of radioactivity information.

Given that the sample are recent school leavers, it was not expected that formal education sources would be considered as a main source of information. That this is not the case does re-emphasise the significance and importance of informal information sources. It is also some confirmation that although the sample are recent school leavers they draw upon information which is available to the public.

The affects of radioactivity presented in the media seem to be long lasting images. In many respects these are 'everyday' experiences of radioactivity. As Martin comments during his interview:

*Martin:* H-bombs and Atom bombs and Chernobyl - this is all I can think about when I think about radioactivity - this is my knowledge. It is in the newspapers all the time.

*(Martin, Group A. S.1.)*

### 6.7 THE SOURCES OF DATA

The analysis of the IAS has drawn from two strands of the data. The first is the 'content' of the conversations - i.e. *what was said*. This contains information concerning the subject matter of the interview, the majority of which relates to the nature and physical processes of radioactive sources and radiation - it provides cognitive data. The second strand concerns the nature and mode of the interview conversation itself - i.e. *the manner in which it was said*. This content contains information of a more affective kind. The nature of communication is split broadly into two further areas: the mode of conversation and the type and style of language used. The sources and types of data are shown schematically in figure 6.3.
Chapter Six: Interviews about Scenarios

1. Content

Data

2. Nature of Communication

- Conceptual Subject matter

- Mode of communication:
  a) factual or emotional
  b) humanised or dehumanised

- Type of language used:
  a) sensationalist or non-sensationalist
  b) involved or detached

Figure 6.3. The sources and types of data used in the analysis of IAS.

The categorising of the nature of communication provides data of an affective nature - data about intensity of feelings associated with the subject radioactivity and Radon.

6.8 THE DATA ANALYSIS

The data analysis was an iterative process which involved five stages - based on the stages of Grounded Theory (Glaser and Strauss 1967) as discussed in Chapter Four. The stages of analysis were:

1. The interviews were studied in depth in order elicit the participants’ meanings.

2. A series of cognitive and affective themes were then identified. The cognitive themes were identified by making comparisons between the interviews and orthodox scientific explanations. The affective themes were identified from extracts of the transcriptions which contained emotional references.

3. These themes were then used to formulate a number of provisional cognitive and affective categories.
4. The data was then revisited several times to check and harden these categories in a continuous and iterative process.

5. When this process was complete, the data was divided between the two groups (Group A and B) and cross group comparisons were made.

This coding process was completed independently by two researchers. Where there was any disagreement a discussion took place so that either a consensus was reached or adaptation to the category was made.

In this chapter conceptual categories are summarised in a Network format (Bliss et al. 1983). This provides a convenient way of representing the data within a series of discrete categories whilst preserving its richness (Cohen and Manion 1989, p.251). In this format, the symbol "{" represents common categories (in Boolean terms: "AND") and the symbol "[ " represents exclusive categories (in Boolean terms: "OR").

6.9 THE RESULTS

The data collected through this IAS methodology is diverse. A wide-range of categories were identified and the key features of these are summarised in the next few pages.

The results are presented in two sections. The first has a cognitive focus and considers conceptions which the two groups associate with radioactivity and Radon gas. The second deals with the affective components of the responses and documents the results of the participants' feelings about radioactivity and Radon. In each section some of the factors which may lie 'beneath' the participants' responses are suggested. These are inferences made of the mechanisms which these participants may use as they attempt to make sense of radioactivity and Radon.

When quotations are taken from the interview transcriptions they are cited in the format; the first name of the individual; the scenario which elicits the cited response; and the participant's group (for example, Caroline, S.1. Group A). The number of
respondents holding particular conceptions are indicated in brackets, these figures are of a total of 30 unless otherwise stated.

6.10 SECTION ONE: THE COGNITIVE PERSPECTIVE

The participants' conceptions of radioactivity can be divided into 1) the nature of the entity and 2) the nature of causation. Participant's conceptions of the entity represent the physical properties of radioactivity, such as radioactive decay, the method of propagation and its appearance. Conceptions of causation relate to the effects of radiation.

6.10.1 THE NATURE OF THE ENTITY.

When considering the notion of entity, four broad categories were identified. These were labelled as; concept labels, appearance, existence, origins and activity. They are represented in the network diagram (figure 6.4). The following five sections document the participants' responses in each of these categories.

![Network Diagram](image)

**Figure 6.4.** A network representation of the entity categories.
6.10.2 DIFFERENTIATED AND UNDIFFERENTIATED CONCEPT LABELS

The majority of the participants [23] were undifferentiated in their use of the concept labels 'radioactive' and 'radiation' (c.f. Eijkelhof, 1990). For example, in the following excerpt Anthea uses the term 'radioactivity' to describe what in traditional terms would be labelled as radiation.

*Interviewer:* What happens when a box containing a radioactive substance is opened.

*Anthea:* Well, it would come out, the radioactivity would come out into the room.

(*Anthea, S.1, Group A.*

Interestingly, although few of the respondents made a distinction between the concept labels associated with a radioactive source and its radiation they did, however, differentiate these in appearance. In these cases, something was given off that was different in appearance and properties than the radioactive source. The differentiation, in appearance, of source and radiation is exemplified in the discussions to follow.

6.10.3 THE EXISTENCE AND APPEARANCE OF RADIOACTIVITY.

Radioactive substances can be conceptualised as a solid [18], a liquid [3] or a gas [9]. Several participants commented that although substances are typically a solid they can come in other states depending on temperature. Commonly, a solid source was seen as a greyish shapeless lump (a type of metal, uranium or plutonium, or some type of lava). Catherine, for example, describes her image of a radioactive substance as metal like:

*Interviewer:* What image do you have of the radioactive substance ...

*Catherine:* It would appear like a piece of metal [...] I have an image of a dull grey metal - like lead.

(*Catherine, S1, Group B*)

A liquid source was seen as a highly viscous 'greeny-orangy' fluid (this was typically conceptualised as waste from a nuclear power plant - an image which appeared to originate from the way it is stored in drums). The gas was perceived as invisible and
typically a-sensory. When conceptualised as a gas the ‘radioactive source’ and ‘radiation’ were always undifferentiated.

The emanations of radioactive substances are conceptualised as appearing in three ways: a gas, a wave or particles, or an immaterial entity and appear to focus around the mechanism of movement.

In the majority of cases [23] the emanations are considered to appear as if they possess the properties of propagation of a gas. This also includes descriptions of the emanation as vapour, clouds and a fine dust. In this gas-like conception, propagation is affected by atmospheric conditions such as drafts and wind as illustrated in the following extract of Lorraine’s transcript:

*Interviewer*  A box containing a radioactive substance is left open What would happen?
*Lorraine* The radioactive matter would float into the atmosphere.
*Interviewer:* How would it come out?
*Lorraine* Very quickly.
*Interviewer:* So, if I open the box at the end of this room how long would it take to reach us [2 metres away]?
*Lorraine* Just a second.
*Interviewer:* Would you be able to see it?
*Lorraine* No.
*Interviewer:* Would it come out in all directions?
*Lorraine* Yes, it will be influenced by winds and draughts in the room.
*Interviewer:* How would draughts affect it?
*Lorraine:* It would move more quickly in a draught, so, it would come in through windows and doors.

(Lorraine C, S1, Group B.)

A minority of respondents considered radiation to be a type of ray or wave [4]. In these cases, it is seen as propagating very quickly and being a-sensory in nature. This conception was often accompanied with a more scientifically orthodox description of the three different types of radiation; $\alpha$, $\beta$, $\gamma$. These were commonly differentiated with reference to their size, potential strength and speed of travel - alpha and beta particles were viewed as being different in ‘size’- one was seen as bigger than the other and they were both viewed as travelling more slowly than the gamma rays. The $\gamma$ radiation was viewed as being the ‘strongest’- it could penetrate further than the
others and travelled more quickly. In all these cases, ideas had been remembered from school science lessons. No one was able to recall the chemical composition of the $\alpha$ or $\beta$ particles. A wave-particle conception of radiation is typified by the following extract from Cathy’s interview.

**Interviewer:** A box containing a radioactive substance is left open. What happens?

*Cathy* It will give off these particles...alpha, beta and gamma seems to ring a bell somewhere.

**Interviewer:** It does. And what are those?

*Cathy* Well, alpha and beta are different sizes. I can’t remember which one’s bigger and which one’s the other. Gamma are rays.

**Interviewer:** Are they different in other ways?

*Cathy* Yes, rays I think travel faster.... yes much faster than the particles. They would travel in about a second.

*(Cathy, S1, Group B.)*

The previous examples are conceptions of radiation which have a material form however, a small number of respondents [2] conceptualised radiation as quintessential immaterial. In these cases, emanations are described as ‘a type of energy’, ‘a type of force’ or just as ‘radioactivity’. Fiona describes an immaterial conception in the following extract of her transcript:

**Interviewer:** What is radiation most like?

*Fiona* Radioactivity, would be like - if you could see electricity, I would imagine it would be as electricity would look. It is something that is there but you can’t see it - I don’t know if it has matter ... it is a very strong force I think.

**Interviewer:** Can you say anything else about it?

*Fiona:* Well, I think it is not a substance, but I think that it maybe it is something - a substance you split that gives the property of radioactivity. I don’t think it necessarily is a lump of something that is radioactive - it is the process of splitting something up I think that creates radioactivity. So lots of things could give you this property radioactivity. It is a bit like you create electricity from different chemical compounds.

*(Fiona, S1, Group A)*

In this transcription a strong comparison is made between radioactivity and electricity. The electricity metaphor, an everyday experience, is used to explain radioactivity.
6.10.4 THE ORIGINS OF RADIOACTIVITY

Radioactivity was viewed as either natural or both natural and man-made. In the majority of cases [21] it is considered a naturally occurring phenomena, although most respondents thought that it was possible to make naturally occurring radioactivity material more ‘dangerous’ by ‘concentrating’ it [27] - illustrated in the following extract of Karen’s transcript.

Interview: Where does radioactivity come from?
Karen: I think it's found all over the earth and in gases in the air, it is all around us. It is natural, but it is concentrated in power stations which makes it much more dangerous.

(Karen, S1, Group A)

This common view was frequently used as an explanation of why natural radioactivity is less dangerous than man-made, artificial, radioactivity [18]. In this case, man-made radioactivity and natural radioactivity are perceived as essentially the same, although the man-made type is more concentrated and dangerous in form. This point is revisited during the discussions about conceptions of Radon.

6.10.5 THE ACTIVITY OF RADIOACTIVE SOURCES

The discussion of the activity of radioactive sources covers three phenomena; radioactive decay; conservation; and things that affect radioactivity.

• Radioactive decay

The analysis revealed three conceptions of the process radioactive decay - each of these corresponds to a different level of differentiation. In some cases, these conceptions were identified by the analysis of a number of scenarios, in others, they were stimulated by a single scenario. Nevertheless, in all cases, the conceptions remained coherent throughout the interviews. The three categories of radioactive decay are summarised in table 6.4, along with the frequency of their occurrence. In the analysis, it is the phenomena radioactive decay which is considered and is
categorised. How the respondents describe the processes involved in the production of radiation is attributed a concept label by the researcher.

Table 6.4, three categories of radioactive decay

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>An undifferentiated, diffusion and evaporation type category.</td>
<td>In this category, the ‘emanations’ are seen as synonymous with the source. The result of opening a container of a radioactive substance is to liberate the substance. In some cases, this is described as evaporating or diffusing. After a period of time when all the ‘source’ has escaped, the container is left empty. Transmutation does not take place. This category is a completely undifferentiated view of source and radiation.</td>
</tr>
<tr>
<td>[14]</td>
<td></td>
</tr>
<tr>
<td>A semi-differentiated plum pudding type category.</td>
<td>The emanations here are seen to be contained in the source; essentially as a ‘foreign body’ (or a contaminate). Radioactive decay is the liberation of these ‘contaminates’. When all the contaminates have left, the source is no longer ‘radioactive’ and is in its ‘original state’ - i.e. ‘transmutation’ does not occur during a radioactive decay. This can be viewed as a semi-differentiated (source-radiation) model as it recognises differences between the source and radiation, however, both are initially ‘parts’ of the original radioactive source.</td>
</tr>
<tr>
<td>[5]</td>
<td></td>
</tr>
<tr>
<td>A changing source conception/radioactive decay category.</td>
<td>This category differs from the previous two because something happens to the source during the emission of the ‘radiation’. This includes descriptions of the source as, for example, ‘decomposing’, ‘decaying’ or ‘splitting’.</td>
</tr>
<tr>
<td>[3]</td>
<td></td>
</tr>
</tbody>
</table>

*7 participants were not classified.

Brett, for example, describes an undifferentiated evaporation category of radioactive decay in the following excerpt of his transcript:

*Interviewer:* A box containing a radioactive substance is left open. What happens?

*Brett:* There will be possible dangers if the fumes from the radioactive source escape.

*Interviewer:* What do radioactive substances look like?

*Brett:* I imagine them to be lava type substance - a thick gooey liquid. I imagine that poisonous fumes come off when they evaporate.

*Interviewer:* What would happen if I left the lid open for a long time?
Chapter Six: Interviews about Scenarios

*Brett:* It will all disperse with the fumes. It would not be there - the box will be empty.

*(Brett, S1& 4, Group B)*

His evaporation metaphor facilitates reasoning which is both plausible and fruitful. He draws on a physical phenomena (evaporation) which is a part of everyday experience. However, in scientific terms, he fails to recognise the transmutation associated with a scientific explanation.

In contrast, Cathy describes a *changing source* category. She considers the source to undergo a type of ‘decomposition’ to release particles. However, the physical appearance of the source apparently remains unaltered during this process. None of the participants considered transmutation to occur in radioactive decay.

*Interviewer:* A radioactive substance is left for a very long time. What happens?
*Cathy:* It will start to decompose.

*Interviewer:* What do you mean by decompose?
*Cathy:* It means that the atoms of the radioactive substance break down and release their particles while the radioactive substance goes shooting off. I don't think it actually visually looks very different, but it might actually shrink over time. I know that the radioactivity goes away and I know it takes a long time because of the half-life thing.

*Interviewer:* So if somebody opened the box in many years time would it look different
*Cathy:* Well I guess not, the decomposing and the bits are going off- but I think it would be a very tiny bit that's coming out.

*(Cathy, S.4, Group B)*

Jenny displays a *semi-differentiated* category of radioactive decay. In this section of her interview she seems to be describing radiation as a contaminate - which she calls radioactivity.

*Interviewer:* What happens to a radioactive substance if you leave it for a long time?
*Jenny:* Well it gives off its radioactivity.

*Interviewer:* How does it do this?
*Jenny:* Well, radioactive substances contain radioactivity - which then comes out until eventually there is no more left.
Interviewer: And then what remains?
Jenny: ... you are left with the original substance.

(Jenny, S.4, Group A)

• Conservation

Radioactive sources were seen as remaining active for a long time. In a number of cases this was quantified and the figures given ranged from over 100 to over 2000 years. These figures were linked to the effects of nuclear incidents (Hiroshima and Chernobyl were commonly cited) which were considered illustrations of the very long lasting and devastating effects of radioactivity. Nuclear ‘events’ were frequently used as a background to describe the properties of radioactivity. All participants conceptualised radioactivity as decreasing in strength over time. This was commonly seen as a gradual process or first a steady then rapid decline. The following excerpt from Caroline’s transcript illustrates how she perceives the intensity of radioactivity to gradually decrease.

Interviewer: A radioactive substance is left for a very long time. What would happen?
Caroline Is it open again?
Interviewer: Yes, it's open, it's just been left open for a very long time.
Caroline I imagine whatever is in it gets out and disperses.
Interviewer: Okay, now supposing the box was completely sealed.
Caroline [Mmm.] I think over a very long time, thousands of years it would become less active. However in our lifetime it would stay more or less the same.
Interviewer: Where did that idea come from?
Caroline: From the media, I think. It must have come from the media programmes on places like Hiroshima being still radioactive. I imagine it as a gradual process in which it gets less radioactive gradually over a very long period of time, thousands of years?

(Caroline. S4, Group A)

The participants did not consider it possible to make something ‘un-radioactive’ by a chemical or physical process as David explains, radioactivity is long lived and can only be made safe by containment:
Interviewer: Can a radioactive substance be made safe?

David: No. Once the actual - as far as I'm aware - my thoughts about it are, once a substance is radioactive all you can do is contain it. Eventually after many many years radioactivity loses it's radioactivity. Whether the actual bits fly off gradually or one at a time I am unsure, but I know the power decreases and it takes a very long time.

(David, S 18, Group A)

All participants were aware that radioactivity could be contained by storing, although they emphasised that this required a lot of care. Radioactivity was described as 'breaking down' or 'eating away' at containers and only certain special materials could withstand this process. It was recommended that storage containers should be made of 'a strong substance', 'lead', 'concrete' or 'metal'. Plastic was also cited, as an example of a 'non-porous' material, which would 'stop the radioactivity escaping through any narrow gaps' (Anne, S18, Group A).

Concerns were frequently expressed about how sources can be made completely safe, and the social implication of nuclear power formed the basis of these discussions. In some cases [9], it was considered as inevitable that radioactivity would escape and it is only a matter of time before the full implications of this will be known. Simon expresses some of these concerns:

Simon: Even if you put it in a strong container and dump it in the sea it will eventually leak and then cause a lot of damage to the ocean life. We just do not know enough about how long these containers will last before they split open.

(Simon. S18, Group B)

Some participants thought that a series of measures might make more successful retention mechanisms [9]. Typically, this would involve a lead container, which
would be surrounded in concrete and buried deep under ground or at the bottom of the ocean as Aaron notes:

Aaron: You need to put it in a lead box and bury it under concrete to make absolutely sure that it will not leak. But I bet radioactivity will eventually get through this in the end.

(Aaron, S18, Group A)

The property of radioactivity as eternal and never stopping was evident in the majority of interviews. This conservation conception has been previously noted (Eijkelhof 1990 and Martins 1992).

- Things that affect radioactivity.

A number of the scenarios depicted a radioactive source being exposed to chemical and physical process. Scenarios were drawn in which a radioactive substance was heated and cooled, dropped and had chemicals added to it. The responses to these scenarios were wide ranging. For brevity and emphasis, they are not all listed here - the following discussions focus on heating and cooling as these are broadly indicative of the other conversations.

The majority of the participants [27] thought that heating and cooling would have some effect on radioactive substances. Heating was seen as altering the state of the source or, in the case of a gas source, causing it to spread out more quickly. In some cases, heating is seen as making a radioactive source more radioactive and consequently more dangerous. Barbara describes this viewpoint in her interview:

Interviewer: A radioactive substance is heated. What happens?
Barbara: It would increase its movements as a consequence. Yes, it would get warmer and become more dangerous. You can make something give off more radioactivity by heating it.

(Barbara, S.2, Group A)
In a later scenario, Barbara describes how cooling would have the opposite effect.

Barbara: Yes, it would make it have less reactions and make it less dangerous. If it is cooled it will give off less radioactivity.
Interviewer: Can you stop something being radioactive by cooling it?
Barbara: No, it will only reduce it by a bit

(Barbara, S.5, Group A)

In the majority of cases it was not seen as possible to stop something being radioactive by cooling it. Although, the need for nuclear power stations to be cited near a source of cool water, was given as an example of how radioactivity can be controlled by temperature changes.

6.11 CAUSAL PROCESSES

Participants conceptualised radioactivity as highly destructive and very powerful. They perceived it capable of provoking transformations in matter and it had a strong association with danger. Melika, for instance, describes the destructive power of radioactivity at the beginning of her interview:

Melika: Radioactivity is a very dangerous substance, it will cause a lot of damage and harm until somebody actually pays attention and reports it

(Melika, S1, Group B)

This section records the causal processes which the participants’ associate with radioactivity. Two broad categories were identified in the data: the effects of radioactivity on living and non-living things. These effects were sub-categorised into two groups: contamination and effects, see Figure 6.5. The following sections present the results in the two categories, living and non-living.
Figure 6.5, a network representation of the Causation categories.

The participants thought that radioactive materials would affect living things differently to non-living things. Living things were seen as particularly vulnerable to 'attack' and in a number of cases [9] were perceived to 'actively attract and soak up' radiation - a perspective noted by Klaassen et al. (1990). In the majority of cases [27], the participants' thought that living things would become radioactive after exposure to radioactivity.

Although radiation was conceptualised in a number of different ways (most commonly as a gas - see previous discussion) these conceptions were not relevant during the discussions of the causal processes. In all cases, the effects of radioactivity were conceptualised in terms of contamination and not irradiation. This is explored in the following sections.

6.11.1. THE EFFECTS OF RADIOACTIVITY ON THE LIVING.

The participants perceived the effects of radioactivity on living things as both internal and external, as well as long and short-term. The external effects might be, for example, seen on the surface of the skin. These effects were likened to 'burning', 'peeling' or a 'type of cancer growth'. The internal effects might be, for example, cancer and genetic mutations - these were thought of as longer term ailments.
In the following excerpt, Linda describes, in some detail, her horrors of radioactivity - perceptions of *internal* and *external* effects:

Interviewer: A box containing a radioactive substance is held near somebody's hand. What happens?

Linda: [...] If you put your hand near a flame it would burn and blister - if you put the skin into the flame it would be corroded, I expect. I imagine the effects from radioactivity would be very similar - probably not as quickly as it happens with an open flame though.

Interviewer: The same sort of effects as burning from a flame?

Linda: Yes, blistering and burning and then peeling. I think radioactivity probably could be absorbed in the same way that our skin absorbs moisture. Then it would corrode up the organs and restrict the natural functions. Well if radioactivity is going in there will be less room for oxygen and other gases.

Interviewer: And then what happens?

Linda: I think it would move inwards, I think it would go in for more points of contacts, the fingertips, the head, but it would move in rather than up the body. Unless you were standing on a conductor for radioactivity it would go up through your feet. If you were standing on a conductor for radioactivity the radioactivity would condense at one spot and that would be the point of entry.

*(Linda, S.10, Group A)*

She conceptualises the effects of radioactivity as both internal and external and perceives the skin as able to absorb radioactivity in much the same way as it absorbs moisture *(c.f. Klaassen *et. al.*. 1990). In her final phrase, she seems to be using an electrical analogy based on conductors and insulators as a mechanism to reason about radioactivity.

The participants’ descriptions of the processes involved in radioactive contamination can be categorised in three ways (see table 6.5).
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<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorption or Permeation.</td>
<td>Radioactivity is absorbed through (or permeates) the surface of the skin; this includes cases where for example, it enters pores or cuts and openings.</td>
</tr>
<tr>
<td>Inhalation.</td>
<td>Radioactivity is inhaled and enters the lungs and then the blood stream.</td>
</tr>
<tr>
<td>Ingestion.</td>
<td>Something is eaten which contains radioactivity. Some individuals referred to radioactivity getting into a food chain after a nuclear leak.</td>
</tr>
</tbody>
</table>

Table 6.5, three different categories of the mechanism for radioactive contamination identified from the data analysis.

In the following excerpt, Barbara describes how radioactivity enters a human body through a cut in the skin - the absorption category.

*Interviewer:* A box containing radioactive substance is held near somebody's hand. What happens?

*Barbara:* They should be wearing protective clothing. They always wear protective clothing with radioactive substances, don't they?

*Interviewer:* What is protective clothing?

*Barbara:* A suit of some kind, a kind of material that protects and a mask and things? Something like a space suit, but I don't know what it would be made of.

*Interviewer:* If the person is not wearing protective clothing, then what happens?

*Barbara:* I think, if there's a cut it would be get into the hand and then it would get into the bloodstream and then they would die.

*Interviewer:* What would the cause of death be?

*Barbara:* I doubt whether the truth would ever be known - these things are always covered up.

*(Barbara, S10, Group A)*

Barbara appears to be using her knowledge about radioactive suits to reason about the properties of radioactivity and radiation. This is an example of reasoning about the properties of radioactivity based on images of the nuclear industry. Barbara’s apparent lack of trust in the nuclear industry is illustrated by her final comment.
Once inside the body, radioactivity is considered to do considerable damage. A longer term effect is thought to be the development of cancer or genetic mutation in any offspring. In the following section of his transcript, Adam describes how radioactivity enters the body though the skin or by inhalation with oxygen - absorption and inhalation categories. He explain how, once inside, it can cause genetic mutations.

*Interviewer:* A box containing a radioactive substance is held near somebody's hand. What happens?

*Adam:* I think a radioactive gas penetrates into the person.

*Interviewer:* How does it get in?

*Adam:* I don't know if it actually goes through the skin or maybe the oxygen. But it gets inside.

*Interviewer:* Then what happens?

*Adam:* It gets into the person's genes and then this results in genetic mutation. Like a virus it will get inside their cells and any future children they have could be abnormal.

*(Adam, S10, Group B)*

In this case, the mutations are perceived the result of 'radioactivity' invading genes which Adam compares with a virus invading a host's cells. A germ model of radioactive decay has also been noted by Eijkelhof (1990).

Mark describes how radioactivity can get into a food chain. In this case he is describing an ingestion category of contamination:

*Interviewer:* A radioactive substance is dumped in the sea.

*Mark:* I think it would get into the fish and plants and then the food chain. This sort of thing happens and radioactivity is then passed on to people who eat fish and sea food.

*(Mark, S3, Group B)*

The ingestion category was often supported with evidence from a environmental news item. For example, one news report cited concerned ‘radioactive shell-fish’ which had allegedly been found near the UK nuclear power plant at Sellafield.

The effects of radioactivity are also described as a type of poisoning or sickness - radiation sickness is a commonly used phrase. Participants used sickness or poisoning...
to refer to the symptoms of receiving too much radioactivity - illustrated in the following excerpt from Anne’s transcription:

**Interviewer:** A radioactive substance is placed near somebody’s hand. What happens?

**Anne:** I know it makes you sick, but I think that depends on how much you have.

**Interviewer:** How does it depend?

**Anne:** Well I think that the body is able to take so much, but if it is given any more it results in a type of poisoning and sickness. Like if you have too much of a chemical it will poison you.

*(Anne, S10, Group A)*

In this case, it is the quantity of radiation received rather than some statistical probability that is significant. Whilst this type of reasoning concurs to a degree with a scientific explanation of radiation sickness, it is unable to account for the harmful effects linked with low levels of radiation. Using this reasoning a small amount of radioactivity would appear to offer no threat because the body is able to ‘deal with it’.

### 6.11.2. THE EFFECTS OF RADIOACTIVITY ON THE NON-LIVING

The scenarios elicited responses concerning the effects of radioactivity on different objects. Interestingly, a significant number of respondents [19] thought that radioactivity would influence metal objects in a different way to non metal objects. In the majority of these cases, metal objects were perceived as having the ability to ‘attract’ radioactivity. The close association between radioactivity and magnetism has been noted by other researchers (e.g. Lucas. 1987b). The following extract from Caroline’s transcription illustrates the conversations about the different effects on metal, plastic and wooden objects:

**Interviewer:** A radioactive substance is placed near a metal object. What happens?

**Caroline:** Maybe it will tarnish in some way? It would definitely become radioactive, you wouldn’t want to touch it afterwards.

**Interviewer:** If the candlestick was made of plastic what would happen then?
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Caroline: It would not be attracted to plastic. I am not too sure why. I've got an idea, things are attracted to metal but not plastic, like magnets. Metal objects need cleaning at home, whereas plastic things you just wipe.

Interviewer: What about if the candlestick is made of wood?
Caroline: It would get into the wood, some things are affected more than others. Living things and ex-living things would all become contaminated.

(Caroline, S12, Group A)

Frequently [13], plastic was thought of as being impenetrable by radioactivity, a reasoning which appeared to be based on an image of scientists wearing plastic suits when they perform radioactivity experiments, as Martin notes:

Martin: ...you see it in the films that people wear plastic suits and these protect them from the radioactivity. There is a natural thing about radioactivity and metal and human flesh - if effects these things more.

(Martin, S12, Group A)

The use of the term ‘natural and unnatural’ has been the focus of recent research (Watts and Taber 1996). In this interview, Martin uses the label ‘natural’ to justify his explanation - as a way of limiting the depth to which his explanation needs to go.

As previously noted, an electrical metaphor appears a common means of describing radioactivity. Electricity is a mysterious everyday experience, as Martin explores here:

Interviewer: What is radioactivity most like?
Martin: I think it to be a lot like electricity.

Interviewer: Why do you say that?
Martin: Well, they are both things which are invisible and they hurt. So I think they are similar, in my head they’re sort of an invisible movement. Explain to me about electrons and all that but still I don’t have a picture in my head. I can’t sort of see radioactivity so its got that same sort of image as though it’s happening.

At a later point in the interview, Martin uses this electrical metaphor to explore the effects of radioactivity on metal, and comments:
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Interviewer: A metal object is placed near a radioactivity source. What happens?

Martin: It is attracted to the metal or the metal is attracted to it. I don’t know why I think this, but it’s the image I have of electricity and radioactivity behaves in a similar way.

(Martin, S12, Group A)

6.12 COMPARISONS BETWEEN THE GROUPS

As the final stage of the data analysis, comparisons were made between the responses of the two groups A and B (non-Radon residents and Radon residents). Significantly, there appeared to be few discernible differences between these groups when discussing the general scenarios, indeed, greater variations seem to exist within each group. This would suggest that residents of areas of high radiation risk are NOT more knowledgeable about radioactivity.

The discussions so far have focused on the general properties of radioactivity and these have revealed a proto-typical image of radioactivity as a high intensity, extremely dangerous and destructive phenomena. However, when considering the specific responses to scenarios about Radon gas (scenarios 14, 16, 17) significant differences were found between the cognitive and affective responses of the two groups. The next subsection documents the cognitive differences - the affective differences are reported within the ‘affective analysis’ a little later.

6.12.1 CONCEPTIONS OF RADON

While there were no discernible differences in their understandings of the physical and chemical properties of Radon, the participants of Group B (the Radon residents) were clearly more knowledgeable about the practicalities associated with living with Radon. 14 out of the 15 the participants interviewed were aware of Radon gas compared with only 2 out of 15 non-Radon residents. All the participants who were not aware of Radon gas assumed it has the general proto-typical properties of radioactivity previously documented. This section focuses on the responses of the 14
Radon residents who were aware of the gas, so that in all cases figures are quoted out of 14.

Discussions about Radon were initiated in two ways, first through the discussion of the Radon specific scenarios and second as part of a general discussion at the start of the interview. The majority of Radon residents recall watching and reading a local news item about Radon. This acted as their main source of information. Only 5 recalled reading the NRPB leaflets [25% of the original sample].

The analysis of the Radon discussions is summarised in the following network, figure 6.5. Two broad categories of responses were identified: Radon-in-practice and Radon-in-general (c.f. Michael’s [1992] Science-in-general and Science-in-particular).

![Network Chart]

**Figure 6.6** A network chart depicting the responses of Radon residents [N=14] using the categories Radon-in-general and Radon-in-practice.

Radon-in-general refers to scientific concepts associated with the general physical and chemical properties of Radon as a radioactivity gas (for example; half-life, radioactive decay and method of propagation). Whereas, Radon-in-practice refers to science which is allied with everyday practical experiences, for example; the ‘action level’ (NRPB, 1995), mechanisms of reduction and how Radon enters houses.
In the majority of cases [13], Radon gas was conceptualised as a natural source of radioactivity, although, one participant thought it was linked in some way to a local nuclear power station (Hinkly Point) and a type of nuclear cover up.

Perhaps surprisingly, the Radon residents appeared to know very little about the properties of Radon gas. They conceptualised Radon as a radioactive gas which possessed the general typical properties of radioactive substances, but in a weaker and less concentrated form. The following extract of Lorraine’s interview typifies discussions about the properties of Radon.

Interviewer: You mentioned Radon. What is Radon?
Lorraine: Radon is radioactive substance.
Interviewer: How does it compare with other radioactive substances?
Lorraine: Well, it's much the same really. It is like the radioactivity which comes out of the box in the previous cases, but in a less concentrated form.
Interviewer: Is it less concentrated?
Lorraine: Yes it is, it’s a lower dosage of radioactivity but over a longer period of time it can be harmful - it is less harmful over the short term though.
Interviewer: What does it look like?
Lorraine: It’s clear, you can’t feel it touch it or smell it?
Interviewer: Would you know if it's in a room?
Lorraine: Er [...] only by measuring it.

(Lorraine, S15, Group B)

All the descriptions of Radon were undifferentiated - the source was considered to be identical to the radiation. In the case of Radon, a radioactive gas, the need to differentiate between the source and the radiation is not immediately obvious, or indeed, perhaps, particularly useful (c.f. Klaassen et. al., 1990).

Radon was described as entering houses slowly through the foundations. Simon, for example, sees this as a gradual process in a way which concurs with current scientific thinking (Simon, S14, Group B):

Simon: Radon is constantly there anyway, it is in the ground and the building materials. It constantly filters up through the ground and slowly enters houses in Radon areas.
Unusually, Brett considers Radon to be capable of causing structural damage to property during this process, he comments:

*Brett:* It could erode the rock and then enter the house, eventually the house could fall down.

*(Brett, S14, Group B)*

As Radon is considered less concentrated, it is not perceived as offering a significant health threat. In the following extract, Mark uses his personal experiences of living in a Radon area to discuss the health risk presented by the gas:

*Mark:* Most things are radioactive and most things are harmful if concentrated. I live in an area of natural radioactivity but it doesn't seem to affect us greatly... Low levels of radioactivity are harmless but when radioactivity is in greater concentrations anything can happen.

*(Mark, S17, Group B)*

The majority of respondents [12] acknowledge the potential health risk which Radon presents, although they did not consider this as problematic. In the following excerpt of Treve's transcription, at the start of the interview, he accepts the threat Radon presents and juxtaposes this with the reactions of the local residents:

*Interviewer:* Where did you find out about Radon gas?

*Treve:* I heard about Radon on the local news and general public information. I know it can be harmful, but I am not threatened by it. Nobody appears to takes any notice of it in the local area.

*(Treve, S1, Group B)*

Paul uses the spectre of government inertia to judge the severity of the dangers involved.

*Paul:* Radon enters the house and then can become concentrated

*Interviewer:* Is this dangerous?
Paul: Yes, it is potentially dangerous, it must be very severe for the
government to spend so much money on it. I know that grants
are available to deal with it, but, we don’t bother about it in
Exeter because we don’t have Radon.

(Paul, S14, Group B)

Several participants claimed that Radon was not associated with the areas they are
living in. The participants strongly associated Radon with particular geographic areas
which contain high levels of granite rock - the Moors was the most frequently cited
Radon area [9].

In this way the participants seem to underestimate the occurrence of the gas. In
addition, in many cases high Radon levels are not considered a deterrent. For example,
in the following excerpt of her interview, Melika seems to be balancing the benefits
associated with living on the Moors with the hazard it could present:

Melika: The Moors contain most of the Radon, but it is a lovely area and
I would like to live there, but I would find out about the levels
before moving.

(Melika, S14, Group B)

Participants appeared knowledgeable about Radon reduction mechanisms [14]. Anna,
for example, describes the ‘sump’ reduction mechanism:

Anna: Radon is very easy to deal with. You fit an underground fan
which pumps the gas out. New houses in Cornwall now have
this fan fitted. It works by sucking the gas out before it enters
the house.

(Anna, S14, Group B)

In some cases [5], participants knew of neighbours who have had a reduction device
fitted. A number of participants [6] expressed concern about the consequences of
reduction mechanisms for the re-sale of houses, as Adam comments (Adam, S15,
Group):
Adam: You need to be careful about having fans fitted, I know this can lower the values of houses. I think this is the main reason why people don’t have Radon tests.

6.13 SECTION TWO: THE AFFECTIVE PERSPECTIVE.

This section records the affective analysis. A summary of both the cognitive and affective results is provided at the end of this section.

Radioactivity is a highly emotive subject which has strong associations with fear and dread (Weart, 1988). The following two excerpts from Caroline and Joanna’s interviews illustrate some of these feelings:

I just don’t know what it looks like but I would be rather nervous about it because I think it would cause cancer.

(Caroline, S1, Group A)

In a nuclear war your skin is supposed to burn - I don’t know - things like that are very nasty and very scary.

(Joanna, S10, Group B)

The everyday discussions initiated by these scenarios contained a blend of both cognitive and affective data. References linking radioactivity to danger were in abundance throughout all the interviews and this section presents the results of the examination of this data.

The dangers of radioactivity were more noticeable in scenarios which depicted a radioactive substance in the proximity of something living (scenarios 3, 10 and 13). During these discussions the participants talked openly and freely about the dangers associated with radioactivity. In some cases, this conversation would be factual and in others markedly more emotional in nature.
In direct response to the these discussion three affective categories were identified, namely:

- *Conditions*,
- *Intensity*, and
- *Expression*.

These categories display similarity to those documented by Oldham *et al.* (1986) in their study of pupils’ views of the dangers of electricity.

The following network, figure 6.7, summarises these results: feelings about radioactivity.

![Diagram](image)

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**Figure 6.7**, the affective analysis: categorisation of feelings about radioactivity

### 6.13.1 THE AFFECTIVE CATEGORIES.

The affective analysis used the responses to a number of scenarios. In some cases a single scenario elicited more of an emotional response than another. For example, some respondents thought that swallowing a radioactive substance was more dangerous than placing a hand near a radioactive source. In these cases, the *intensity* and *expression* analysis was amalgamated across the scenarios. The following subsections document the results for each category:
Chapter Six: Interviews about Scenarios

- **Condition.**

What are the conditions in which radioactive substances are considered dangerous? The responses can be represented in two broad groups: *unconditional* and *conditional.* In the majority of cases [25] the dangers were perceived as *conditional.* In these cases, the dangers of radioactivity depended on range of factors - summarised in table 6.6.

<table>
<thead>
<tr>
<th>Conditions of exposure</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>The nature of exposure</td>
<td>For example, swallowing a radioactive source was considered more dangerous than placing your hand near a radioactive source.</td>
</tr>
<tr>
<td>The length of exposure</td>
<td>A greater exposure was associated with a greater danger.</td>
</tr>
<tr>
<td>The type of source:</td>
<td>Less ‘concentrated’ sources were considered to be less dangerous. For example, nuclear waste was considered as very dangerous, whereas, barium meals, X-rays, ‘natural’ radiation and background radiation were all considered as less dangerous and in some cases relatively safe.</td>
</tr>
</tbody>
</table>

Table 6.6, a summary of the factors which were perceived as influencing the dangers of radioactivity for this sample [30].

The following excerpt taken from Mark’s transcription illustrates a *conditional* response. In this instance, the dangers relate to the concentration of the source.

Mark: Radiation occurs naturally, it's not a major problem. We have radiation from the sun anyway and it only becomes a problem when it is intense. The recent newspaper articles have had discussions about ozone layers. The important point is that the more concentrate - the more potentially dangerous it is.

*(Mark, S10, Group B)*

A minority of respondents [5] mentioned that radioactive substances would always be dangerous - an *unconditional* response:

**Interviewer:** Is it [radioactivity] dangerous?

**Anne:** Yes, I think any amount of radiation is harmful

**Interviewer:** Even in small amounts?

**Anne:** Radioactivity is very dangerous thing, it would always be a
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hazard even if there was only a very small amount

(Anne, S14, Group A).

• **Intensity.**

The second category represents the intensity of participants responses. In this analysis a distinction is made between into two categories: *hot* or *cool*. A *hot* response was when the effects of radioactivity were perceived to be *very* dangerous. A *cool* response is associated with responses of a more moderate nature in which radioactivity was perceived to be dangerous (or in some cases relatively safe).

The following extract from Melika’s interview is an example of a response which was categorised as *hot*.

**Interviewer:** A radioactive substance is dumped in the sea. What happens?

**Melika:** Just about everything would die... The immediate effect being fish feeling off colour or looking a bit dodgy. That's their body stopping and then they will drop dead.

**Interviewer:** And what about the plant life?

**Melika:** ...It would certainly destroy it and certainly effect it so that anything that eats it will also die.

**Interviewer:** How would it destroy the plant life?

**Melika:** Would it sort of burn it ... I keep seeing images of a nuclear war where all the grass is sort of parched. It was scorched all over like acid. Yes -like battery acid - yes.

(Melika, S3, Group B)

Melika refers to images of nuclear war and uses these as a basis for describing the effects of radioactivity and radiation. This contrasts with Treve’s response to the same scenario which was graded as *cool*.

**Interviewer:** A radioactive substance is dumped in the sea. What happens?

**Treve:** I should think it would radiate the sea round the area where the radioactive substance is dropped.

**Interviewer:** What does the word radiate mean?

**Treve:** It spreads, it would spread out within the local area -it would spread out

**Interviewer:** Would it affect the fish?

**Treve:** I think they would be harmed but I'm not sure they would die.
Interviewer: And what about the plant life?
Treve: It might affect it, but not in the short term.

(Treve, S3, Group 3)

Treve's response is less intense than Melika's. Using this analysis, 15 participants' responses were graded as *hot* and 15 *cool*.

- **Expression.**

The third category is an analysis of expression. Respondents who used a more *emotive* expression to describe the effects of radioactivity were coded as *emotional* whereas respondents who provided a more factual account were graded as *factual*. For example discourse which was graded as *emotive* includes phrases such as: 'they would die a horrible death' (*Cathy, S13, Group B*) or 'God help them' (*Anne, S13, Group A*).

In contrast, a more *factual*, less *emotive* discourse is, for example, 'It will probably kill the fish off - it gets into their genes' (*Adam, S3, Group B*) or 'I think it might affect the hand, perhaps it does it slightly' (*Caroline, S10, Group A*).

Using these categories, 8 participants were classified as *emotive* and 22 *factual* in their interview accounts.

6.13.2 COMPARISONS BETWEEN THE TWO GROUPS.

Comparisons between the two groups are again revealing. Few discernible differences were recorded between the responses of the two groups in the general scenarios, however, marked differences exist in the responses to Radon specific scenarios. The most noticeable differences concern the category: *conditions*. Radon residents (Group B) were more likely to judge Radon as conditionally dangerous [10] compared with non Radon residents (Group A) [2]. Indeed, two Radon residents perceived that Radon gas offers no apparent danger as Louise comments:
Louise B Radioactivity from Radon gas is safe, it wouldn’t affect scientists or people,- well, people live there don’t they?

(Louise, S14, Group B)

Louise appears to be using her perception of a social expectation she has to reason about the dangers of Radon.

When considering Radon specific scenarios, the differences between the intensity of the two groups is slight: 12 Radon residents (Group B) exhibited cool responses compared with 10 non Radon residents (Group A). No differences are found when comparisons are made between the expression of the two groups. The majority of responses to Radon specific scenarios were coded as factual: Group A, [12] Group B, [11].

6.14 SUMMARY

Surveys of the public understanding of science present an image of public as ignorant - of lacking any knowledge about radioactivity. This chapter challenges this image and documents a wide-range of everyday knowledge which these participants associate with radioactivity and Radon gas. The approach has been to cast a wide fishing net and what emerges are rich cognitive, affective and conative elements. These are summarised in the network diagram figure 6.8 over leaf.

In broad cognitive terms, the sample perceived:

1. Radioactivity to be an active, intangible entity which is essentially dangerous- it is something highly mobile and not accessible to any senses; although, it can readily be perceived by its effects which are destructive and powerful.

2. Radon to have the general properties of radioactivity but in a weaker and less dangerous form.
Figure 6.8, a network for everyday knowledge of radioactivity [N=30].
A broad range of alternative radioactivity conceptions have emerged. Many of these are consistent with those reported in previous studies (see Chapter Five). While others, augment and complement previous research, for example the categories of radioactive decay, the effects of radioactivity on different materials and Radon gas are new.

Traditionally studies of radioactivity have focused on meanings associated with particular radioactivity concept labels. This study suggests that although the labels 'radiation' and 'radioactive source' are undifferentiated in use the entities themselves could be conceptually differentiated in appearance and form, unless the radioactive source is a gas.

It is evident from this study that danger and fear are a significant part of knowledge about radioactivity. From the affective perspective, the data was represented by three categories; conditions, expression and intensity. Underpinning these divisions are likely to be individuals who vary in their emotional responses to radioactivity. At two ends of a continuum these maybe individuals who are deeply fearful and anxious about radioactivity and others who are coolly objective and emotionally detached from the subject. The reasons for such fear lie beyond the scope of this study. However, in turn, this distinction does raise questions about how these contrasting emotional responses influence learning.

Within the transcriptions there is some evidence to suggest that affective factors can impinge on learning. For example, during his interview, Aaron is unsure if he wishes to know about the effects of radioactivity after digestion:

*Interviewer:* Somebody swallows a radioactive substance. What happens?
*Aaron:* I don’t know - to be honest - I am not sure I really want to know. Sometimes is better not to know about these things. I know it wouldn’t be pleasant.

*(Aaron, S13, Group A)*

A case of the affective influencing the cognitive?
There is a lack of research which has looked at how an emotional response to an area of science affects learning. Radioactivity is a subject which is highly emotive, perhaps more so than any other area of science. It provides an ideal context to explore the interaction of the cognitive and affective during learning. Which is developed as this thesis progresses.

Evidence has been presented about how individuals describe radioactivity and Radon. Descriptions appear based on a diffuse background of common knowledge, salient events, analogies, metaphors and social expectations (c.f. Martins, 1992). An electrical metaphor was common. In this case, the similarity of the properties of electricity and magnetism (appearance and dangers) seem to act as the basis for a comparison.

Significantly, for this sample, everyday knowledge about radioactivity appears to be drawn from everyday sources, the media, television films and fiction books. These carry powerful salient images and episodes: images of nuclear accidents, genetic mutations, drums which store radioactive waste and suits which protect nuclear scientists. This seems to provide a background to rationalise about the physical and chemical properties of radioactive sources and radiation.

This study also sought to investigate how two groups with different backgrounds think and feel about radioactivity. The differences between the groups was slight. Residents of an area which has the highest documented UK levels of Radon appeared no more knowledgeable about general concepts and constructs of radioactivity than a similar group of non Radon residents. Radon residents appeared to underestimate the dangers involved with Radon and lack an understanding of the chemical and physical properties of Radon gas. They did though, significantly, appear more knowledgeable about the practicalities of living with Radon. In other words, they are more familiar with Radon-in-practice rather than the Radon-in-general (c.f. Michael, 1992). As the information available to residents is a mixture of both types of information one possible inference could be that individuals are selecting or remembering some aspects of information more than others - this observation develops as the thesis progresses.
Learning about Radon does not take place within a ‘social vacuum’ and the transcriptions contain evidence that some participants feel it is not necessarily their responsibility to know about Radon (c.f. Wynne, 1991). This is exemplified in the following clip taken from Joanna’s interview:

Joanna I am not too concerned with Radon gas, I tend to leave this all up to my mother, my mother is more concerned and we had a detector in our house. I tend to follow her advice.

(Joanna, S14, Group B)

In this summary a range of factors have emerged which could impinge on the public learning of radioactivity. These include the nature of the science, Radon-in-general [the cognitive], the emotions associated with the science [the affective] and the practicalities associated with living with Radon, Radon-in-practice [the conative]. As this thesis progresses each of these perspectives are explored in more detail and form the basis of the model of conceptual change learning proposed.
CHAPTER SEVEN
A SURVEY OF RADON CONFIDANTS

7.0 INTRODUCTION

This chapter presents the results of phase three of the data collection. It contains a discussion of the methodology and presents the results of a survey, carried out on a target population, in 1995. The target population is a group of Radon confidants - people who the participants of the previous IAS study could turn to for advice and guidance. The study is driven by four main research questions:

- What sources of information do these participants use to find out about radioactivity and Radon?
- What are their attitudes towards Radon?
- What do they understand about the science of Radon?
- What advice would they offer a neighbour about Radon?

In the analysis associations between the participants' attitudes, feelings and knowledge about Radon gas and radioactivity are explored.

7.1 THE SURVEY

Informal learners have many potential sources of information. Chapter Five has explored some of these when it considers the mass media and Radon circulars. This chapter focuses on another source - advice and guidance offered by peers, family and friends. Informal 'word-of-advice' or 'word-of-mouth' is a readily available, potentially rich and useful source of information. Indeed, recent research suggests, for example, that residents in Radon areas are likely to seek advice from a neighbour or friend before applying for a Radon test (DoE, 1994).
The participants of the previous IAS study are themselves part of informal learning communities. This chapter documents research which aims to explore the understandings and attitudes of individuals within these communities. It is a survey of people who act as neighbourly confidants and potential sources of Radon information. The purpose of the survey is to explore the understandings of, and feelings about, Radon in a sample of Radon confidants.

7.2 SELECTING THE SAMPLE

The sample for this study was actually selected by participants of the previous IAS study - documented in chapter 6. The IAS students from Devon and Cornwall (group B) were asked to become research assistants and 14 out of 15 volunteered.

A 30 minute meeting was arranged to brief these participants (henceforth, assistants) where instructions were give out and each person was issued with 15 copies of the questionnaire. The assistants were asked, on returning to Devon and Cornwall during the Christmas vacation, to administer a questionnaire to: “anybody they would talk to, or seek advice from, about Radon”. In this way, the assistants both selected the research sample and administered the questionnaire research probe. This ‘cascade model’ of data capture provided a way of targeting a particular sample - a sample of Radon confidants, the sort of person who the assistants could consult about Radon.

The assistants were requested to supervise the completion of the questionnaires but to refrain from offering advice and guidance about the actual content of the questions. The questionnaire was intended to be completed supervised and unaided and the importance of not offering advice was clearly emphasised.

Cascade models of data collection have strengths but also potential weakness; they are remote and rely on the assistants being fully briefed and precisely following research instructions. An opportunity was provided for the assistants to raise any data concerns when they returned their questionnaires, although, in the end, they had to be trusted to follow the instructions provided. As this is a single phase of a multi-phase study
methodological triangulation was used to scrutinise the potential validity of the data collected.

Significantly, for the purposes of this study, a cascade model does offer a number of advantages:

1. It was conjectured that a good return rate and reliable data would be ensured. Previous surveys of Radon residents have noted the poor data return (DoE, 1994, p.45). The assistants were asked to monitor the completion of the questionnaires and were responsible for the questionnaire returns. The researcher, in turn, could monitor the assistants to create the best conditions for a full return of data.

2. Questionnaires which focus on scientific knowledge can appear reminiscent of formal school examinations, and therefore invoke unpleasant memories. It was hoped that a questionnaire given out by a friend or relative may not be as hostile as, for example, being approached by a researcher in the street or at the door. Furthermore, as the contact with the researcher is removed, it provides a further degree of anonymity, important in a sensitive study of this nature.

The assistants were enthusiastic about being involved in the study. Their involvement was acknowledged by sending a letter of thanks and a memo which was placed in their College files.

155 questionnaires were given out and 76 were completed, a return rate of 49%. This return rate was lower than hoped for and there were two main reasons for this. First, the assistants were selective about giving out the questionnaires and only used a small fraction of the 15 issued. Second, some assistants encountered friends and relatives who were unwilling to be involved in the study. In one extreme case, an assistant was influenced by her parents who preferred her not to be associated with any questionnaire about Radon - she apologetically returned all her uncompleted questionnaires and latter explained that her parents were in the process of selling their house and were concerned about their property prices. In fact, the questionnaire...
contains very few questions about Radon levels - this response acts as a further reminder of the sensitive nature of the subject.

7.3 THE INSTRUMENT

The questionnaire used for data capture is shown in Appendix III. It deals with both general and specific questions such as:

(i) Personal Details:
- the qualifications of respondents;
- how informed about science and Radon do they think they are?
- how interested in science are they?

(ii) The respondents level of understanding of:
- the ideas of radioactivity and Radon;
- the causation processes related to radioactivity
- the vocabulary of radioactivity and radiation safety;
- Radon reduction mechanisms

(iii) The advice they would offer a neighbour about Radon.

(iv) The questions they would want answered about radiation and Radon.

(v) The sources of their science knowledge.
- how often do they read newspapers or watch TV?
- how did they find out about Radon?

(vi) Their feelings about Radon.

The questionnaire contains a mixture of ‘tick-box’ type, closed questions and more ‘open response’ questions (Cohen and Manion, 1989). All the tick-box questions contained an ‘other’ section to enable respondents to expand the choices available where necessary. It was designed to be completed in 15-20 minutes.

The focus of this study and the method of data capture were purposefully chosen to complement phase 2 of the data collection (Interviews-about-Scenarios, Chapter Six). The IAS study has an ideographic emphasis and focuses on everyday meanings and
explanations. This survey has a normative emphasis and focuses on levels of scientific understanding. It explores individuals’ understanding of scientific concept labels and terminology whereas the IAS has a phenomenological slant.

The first section of the questionnaire contains attitudinal-type questions, in these respondents are asked to judge how informed and interested they are about both science and Radon. Attitudinal type questions of this kind are subject to ‘context affects’ (Gaskell et. al., 1993), which occur when a question influences responses to later questions. Gaskell et. al.’s (1993) study found that people’s judgment of their interest in science (measured on a 4-point Likert scale) was influenced by the knowledge questions they were asked. In the present study, the majority of attitudinal questions were given before the knowledge questions, however, the extent to which other ‘context affects’ have influenced the data will remain unknown. For example, it is likely that the process of being asked to complete a survey will have some influence on the data collected.

A particular aim of the survey was to assess the participants’ levels of acquaintance with elementary concepts of radioactivity. For this purpose a ‘bank’ of questions was developed. These questions were designed for a public audience and as such avoided technical language and sophisticated scientific concepts. The questions focused upon those elementary concepts of radioactivity which feature in news media and Radon circulars - an understanding of these concepts is an implicit assumption made by the authors of the informal materials (see Chapter Five).

Some of the questions used were drawn from the authors’ previous work (Alsop, 1993) while others were adapted from other surveys (Miller 1987; Eijkelhof 1990; Durant, Evans and Thomas, 1992). Using previous survey questions has a dual advantage: they are tried and tested research tools and enable cross-survey comparisons. In this manner, this small scale survey of a particular target population can be compared with the results of large scale surveys with nationally representative samples.
A trial of the questionnaire [N=14] took place in November 95. In this trial, questionnaires were completed by non-science specialists who were not part of the final sample. The trial served two purposes, to check the question design and address any structural flaws. In particular, care was taken to determine if a suitable level of technical language was achieved. It also enabled adjustments to be made to the options available in the multi-choice questions. As all the closed questions also contain a space for additional options, it was possible during the pilot analysis to incorporate some of the additional responses as options in the main questionnaire. For example, during the pilot phase, the question 'which of the following are examples of the type of radiation given off by Radon gas?' elicited a number of other responses which included 'micro-waves'- an option which was then used in the main study. In this manner, the pilot acted as 'Delphi type' study (Robson 1993, p.27). The questionnaire was issued in December 95 and the returns collected in January 96.

The responses were coded and the data analysis was performed using Microsoft Excel version 4 and SPSS for Windows version 6. \( \chi^2 \) calculations were used as the basis for a statistical test of association. At the end of the questionnaire was a section which enabled the respondents to evaluate the questionnaire itself. All the comments made were positive for both the structure of the questionnaire and the aims of the survey. For example:

The questionnaire was easy to follow (RS25);
Any information about Radon contamination is important and should be brought to the public attention - this survey should help (RS49).

7.4 THE SAMPLE

The sample consisted of 33 men and 35 women with a wide range of ages, as presented in table 7.1. The assistants were all aged between 21 and 24, although the majority of the sample they selected were older than themselves. The largest age group was 45-64 years old and these are likely to be the assistants’ parents or guardians. Only one respondent was under age 16.
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<table>
<thead>
<tr>
<th>Age of Respondents</th>
<th>Frequency</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Under 16</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16-24</td>
<td>11</td>
<td>14</td>
</tr>
<tr>
<td>25-34</td>
<td>12</td>
<td>15</td>
</tr>
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<td>15</td>
<td>20</td>
</tr>
<tr>
<td>45-64</td>
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<td>37</td>
</tr>
<tr>
<td>64-</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>no response</td>
<td>2</td>
<td>3</td>
</tr>
</tbody>
</table>

Table 7.1 showing a breakdown of ages of respondents, 6 age groups were given on the questionnaire. [N=76]

What is perhaps surprising is that the assistants did not usually issue a questionnaire to an immediate peer, as only 14% of the sample are the same age group as the assistants. This may be because the participants selected people who own or have responsibility for a house and it is unlikely that their peers fit this criterion.

The sample has a ‘broad’ range of qualifications in science: 7% of the sample have degrees in science, 5% have studied science post-sixteen; 23% have studied some science at school, and the largest group 48% have no formal qualification in science at all. A breakdown of the qualifications are shown in table 7.2, percentages in brackets.

The range of qualifications is wide, with the largest group having no formal qualifications. This is perhaps surprising because (i) the sample is selected by a group of students attending an institute of higher education and consequently it might be biased towards a particular socio-economic group, and (ii) it might have been expected that the assistants would seek particular expertise, in which case the group of Radon confidants would possibly have higher than average levels of formal science qualifications.

On returning the questionnaire the assistants were asked to give an indication of who they gave the questionnaire to. As these results suggest, they chose not to seek a particular scientific expertise but, instead, issued the questionnaires to family and friends: ‘the sort of people who would know about Radon and you can talk to,’ as one student commented.
Table 7.2 shows a list of the respondents science qualifications, figures are quoted as number of respondents and percentages in brackets [N=76].

### 7.5 THE PRESENTATION OF THE RESULTS

The results are presented under four main headings:

- **7.6 Attitudes, beliefs, formal qualifications and sources of information.**
- **7.7 Knowledge of radioactivity and Radon.**
- **7.8 Knowledge in Society.**
- **7.9 Feelings about Radon.**

When the more ‘open ended’ questions are presented these are referenced as RS (Radon survey) and the questionnaire number, for example, RS23. The total number of respondents was 76.

### 7.6 ATTITUDES, BELIEFS, FORMAL QUALIFICATIONS AND SOURCES OF INFORMATION

The respondents’ formal science ‘qualifications’ were augmented with three other self-perception variables their: interest in science; how well informed they perceive themselves to be about science and how well informed they perceive themselves to be about Radon. These variables are labeled as: qualifications, interest, informed-about-science and informed-about-Radon respectively.
Self-perception variables can be subjective, nevertheless, they were deemed useful in this study for a number of reasons. It was hypothesised that an individual’s perception of how informed or interested in science they are might be associated with a willingness to use scientific knowledge. Furthermore, to judge people solely on their academic achievements as an indicator of how ‘knowledgeable’ they are has limitations, because it fails to:

1. recognise the informal educational sector, for example, people may have a comprehensive knowledge of science by living in an area of need, working within a science related field or perhaps through a ‘scientific’ hobby;

2. acknowledge respondents who have studied a course and may have narrowly failed an examination. Differences in understanding between a narrow pass or a narrow fail of a public examination are likely to be slight within this context.

The attitudinal variable interest was considered useful as an indication of a willingness to engage with science, for example, a person who is interested in science might spend time studying and researching scientific information and so could be more knowledgeable. The reporting of the results starts with this affective variable.

7.6.1 INTEREST IN SCIENCE

The respondents were asked to indicate if they were ‘very interested’, ‘quite interested’, ‘a little interested’, or ‘not at all interested’ in science on a Likert-type scale. The results are shown in chart 7.1.

Over 85% of the sample displays some interest in science, the majority claimed to be ‘a little interested’ (44%). Interest variables have traditionally featured in PUS surveys, for example, those conducted by Miller (1983) Durant (1989), Shortland (1987) and Lucas (1987a) all contain a similar interest probes. For comparison, in Lucas’ study of the public, 17% of respondents classified themselves as ‘very interested’ in new scientific discoveries on a four point scale. This is broadly
commensurable with this study where 15% of the confidants rated themselves as 'very interested' in science.

How interested in science are you?

![Chart 7.1](image)

**Chart 7.1** provides a breakdown of question: 'How interested in science are you?' as judged against a 4 point scale very interested, quite interested, a little interested, not at all interested. The y axis represents the number of respondents [N=76].

### 7.6.2 INFORMED ABOUT SCIENCE

Respondents were asked to judge how informed they are about science. The results are presented in chart 7.2.

![Chart 7.2](image)

**Chart 7.2** gives a breakdown of responses to the question: 'How well informed about science do you think you are?' as judged against a 4 point scale 'very well informed', 'quite well informed', 'a little informed', 'not at all informed'. The y axis represents the number of respondents [N=76].
Most respondents considered themselves ‘a little informed’ (58%), about a quarter (24%) judged themselves as either ‘very well’ or ‘quite well informed’ and only a minority consider themselves as ‘not at all informed’ (14%) about science.

Again, this type of perception measurement has featured in many recent PUS surveys. EU, Swedish and US surveys have all used a 3 point scale to measure how well informed respondents perceive they are about new scientific discoveries (as reviewed, for example, by Fjaestad 1994). In these national and international studies, the percentages of respondents judging themselves as ‘very well informed’ were: EU (9%), Sweden (7%), USA (12%). In comparison, fewer of the respondents (3%) judged themselves as ‘very informed’. This is perhaps surprising given the link the sample has with higher education. The focus of the questionnaire, radioactivity, may have influenced the results. It is also possible that the participants were more tempered in their self assessments as the questionnaire was administered by a member of the family or a friend; or perhaps, they have higher expectations of what being informed about science means.

7.6.3 INFORMED ABOUT RADON

The confidants were asked to judge how well informed they thought they were about Radon gas.

The results from this question are shown in chart 7.3. Given the wide availability of information leaflets in Radon areas it is perhaps surprisingly that the majority of the respondents felt only ‘a little informed’ (61%) about Radon. Indeed, only a small number of the participants felt ‘very well’ or ‘quite well informed’ (22%). However, it needs acknowledging that the overwhelming majority (80%+) of respondents felt some level of ‘informedness’.
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How well informed about Radon gas do you think you are?

![Chart 7.3](chart.png)

**Chart 7.3** gives a breakdown of question: 'How well informed about Radon do you think you are?' as judged against a 4 point scale 'very well informed', 'quite well informed', 'a little informed', 'not at all informed'. The y axis represents the number of respondents [N=76].

### 7.6.4 COMPARISONS BETWEEN ATTITUDES, KNOWLEDGE PERCEPTIONS AND LEVEL OF FORMAL QUALIFICATIONS

There is no doubt that the relationships between formal qualifications and these three self-perception measurements are complex. There are likely to be a number of additional influential inter-correlated factors (e.g. socio-economic background, gender and age) which are not explored in this analysis. When making comparisons a number of the cross-tab cells had an expected frequency of less than 5, as a consequence of the small number of 'very' and 'quite' responses. To perform $\chi^2$ association tests, it was necessary to amalgamate a number of categories and two of the categories in each of the variables were combined:

1. 'very well informed' and 'quite well informed' were amalgamated to form 'informed' in both the informed-about-Science and the informed-about-Radon questions;
2. 'very interested' and 'quite well interested' were combined and labeled 'interested'.

After this adjustment the variables become 3 point scales. Similarly, the list of qualifications was amalgamated into 3 categories; 'no formal qualification', 'school
qualifications up to age 16' and 'higher qualification'. These adjusted variables are used in all future \( \chi^2 \) association calculations.

Comparisons between the variables qualifications, interest and informed-about-science were performed and the results and \( \chi^2 \) calculations are summarised in figure 7.1 over leaf.

**Figure 7.1** Depicts the \( \chi^2 \) associations between the variables Qualification, Informed, and Interest in science. Each of this measurements are against a 3 point scale, adjusted from an initial 4 point scale. \([N=76]\]

A significant association, at the 5% level, was found between the variables qualifications and informed-about-Science \((\chi^2=20, 4\text{df.}, p<0.001)\). Respondents with higher levels of formal qualifications felt they were more informed.

A relationship was found between the variables informed-about-Science and qualifications \((\chi^2=20, 4\text{df.}, p<0.001)\). Respondents who were more interested in science also tended to be more highly qualified. A significant association was also found between interest and qualifications \((\chi^2=16, 4\text{df.}, p<0.005)\). As might be expected, the higher the level of formal qualification the more interested in science respondents were.
While these results are, perhaps, unsurprising, the results of how respondents feel about their knowledge of Radon are more revealing and unexpected. Intuitively, one might expect a correlation between how informed respondents feel they are about science and about Radon. This makes the plausible assumption that feelings about knowledge of science are a good indicator of feelings about a knowledge of Radon. However, in this survey this appears not to be the case because no association was found between: informed-about-Radon and informed-about-Science ($\chi^2=11.3$, 4df., p> 0.02).

To obtain a clearer picture of this lack of association, table 7.3 displays the number of respondents who judge themselves to be ‘informed’ ‘a little informed’ and ‘not at all’ informed-about-science (column 1) and Radon (column 2). The third column shows the number of respondents with identical perceptions for both science and Radon (A and B). Column four and five calculate the differences and relative differences between columns 1 and 3 respectively.

<table>
<thead>
<tr>
<th>informed</th>
<th>A: Science</th>
<th>B: Radon</th>
<th>C: Science and Radon</th>
<th>Difference (A-C)</th>
<th>Relative Difference (A-C)/A (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>informed</td>
<td>17</td>
<td>18</td>
<td>5</td>
<td>12</td>
<td>71</td>
</tr>
<tr>
<td>a little</td>
<td>47</td>
<td>44</td>
<td>32</td>
<td>15</td>
<td>31</td>
</tr>
<tr>
<td>not at all</td>
<td>12</td>
<td>13</td>
<td>4</td>
<td>9</td>
<td>70</td>
</tr>
</tbody>
</table>

Table 7.3 shows the numbers of respondents who judge themselves against a 3 point Likert scale: ‘informed’, ‘a little informed’ and ‘not at all informed’ for both science (A), Radon (B) and Science and Radon (C). It also displays the differences (A-C) and relative differences of these results [N=76].

Table 7.3 reveals a contrast between how respondents feel about their knowledge of science compared with their knowledge of Radon. Significant differences are found in the ‘informed’ and ‘not at all informed’ categories. Referring to table 7.3 column 5, 71% of respondents who feel informed’ about science do not feel ‘informed’ about Radon. Whereas, 70% of those who judge themselves as ‘not at all informed about science’ feel they are either ‘informed’ or ‘a little informed’ about Radon.
This suggests that the majority of these respondents feel quite differently about their general science knowledge than their Radon knowledge. Similarly, no clear association was found between the variables informed-about-Radon, interest ($\chi^2=8, 4\text{df.}, p>0.09$) and qualifications ($\chi^2=3.6, 4\text{df.}, p>0.46$).

Perhaps the most striking feature of this comparison is that a higher percentage of respondents with ‘no formal qualification’ (90%) judge themselves as ‘informed’ about Radon compared to respondents with ‘higher qualifications’ (66%). One possible interpretation of this trend is that respondents with higher qualifications are more critical about their understandings of Radon.

### 7.6.5 SCIENCE AND THE MEDIA

This is the first of two questions about sources of information. Respondents were asked how frequently they read science articles in newspapers; watch science TV programs and read science magazines. The results are shown in chart 7.4.

![Chart 7.4](image)

**Chart 7.4:** displays a breakdown of responses to the question: ‘How often do you read or watch Science TV programs’, ‘Newspaper articles’ and ‘Science Magazines’ measured against the 3 point scale ‘frequently’, ‘occasionally’ or ‘never’. The y axis represents the number of respondents [N=76].

In this sample, television has the greatest popularity with over 80% ‘frequently’ or ‘occasionally’ watching science programs. Science magazines are the least popular as over 60% of respondents claim never to have read a scientific magazine.
Unsurprisingly, television and newspapers are popular and appear to appeal to participants with a range of 'qualifications' and 'interests' in science. For comparison, a recent survey of the UK public found that 22% claim to make a particular point of watching the television series 'Horizon' (Lucas 1987a, 1987b). Science magazines articles have a more selected and limited appeal. They are 'frequently' read by respondents with higher qualification and respondents with no formal science qualifications claimed 'never' to read these magazines.

7.6.6 SOURCES OF INFORMATION ABOUT RADON GAS

The second media question focused on Radon gas. Respondents were asked how they had found out about Radon gas and were offered, 'TV', 'newspapers', 'magazines' as tick boxes and in addition a space was left for 'other', where multiple choices were made an average over the choices was recorded. The results are shown in chart 7.5.

How did you find out about Radon?

![Chart 7.5, breakdown of answers to question: 'How did you find out about Radon?'. Y axis represents the numbers of respondents [N=76].]

The largest response group was 'other' (55%) followed by 'TV' (35%). The 'other' sources of information are included in table 7.4. (percentages are in brackets).
In addition to the more conventional television, magazines and newspapers, a further 6 sources of information were added. This, amongst other factors, highlights the considerable diversity and wide-range of Radon information available to informal learners.

Television appears to act as both a main source of information about science and a significant source of information about Radon (35%). Radon leaflets also act as a major source of information (30% of the overall population). Of this group, 5 respondents claim the leaflet came from the NRPB, and 3 claimed it came from the government, others did not specify.

The DoE survey (DoE, 1994) found that approximately half of the residents of Cornwall and Devon recalled receiving an information leaflet. Just under a third of the sample claim to have found out about Radon through this means. The DoE survey found that only 7% of respondents claimed to have learned anything from the media, 4% from television and 2% for other sources (p22). In the present sample, a larger percentage claim to have found out about Radon from the television and newspapers. The efficacy of these learning sources was not considered.

Perhaps significantly, all those who claim they found about Radon from an information leaflet or circular judge themselves as either ‘informed’ or a ‘little
informed’ about Radon. This could suggest that leaflets and circulars have a significant role in the informal learning about Radon.

7.7 KNOWLEDGE OF RADIOACTIVITY AND RADON.

The survey contained a series of questions which aimed to assess the respondents’ levels of scientific understanding. These questions covered both general concepts of radioactivity and questions about Radon. These results are presented in two units:

- 7.7.1. Understanding of the general radioactivity concepts; half life and radioactive decay.
- 7.7.2. Understanding of Radon gas: background radiation; radiation from Radon; properties of Radon; and causal processes.

7.7.1 UNDERSTANDING OF GENERAL RADIOACTIVITY CONCEPTS

The questionnaire assessed understandings of two science concepts: ‘radioactive decay’ and ‘half-life’. These are fundamental concepts in radioactivity and frequently occur in the mass media where implicit assumptions are made about the readership’s understanding (see the analysis performed in Chapter 5).

The questions and results are provided on the following page (Charts 7.6 and 7.7). Both questions were of a multiple choice format and the available choices were derived from previously documented studies. The question probing the participants’ understanding of the term ‘radioactive decay’ was developed for a previously documented survey (Alsop, 1993). The ‘half life’ question is adapted from a question used by Eijkelhof (1990, p213). Eijkelhof’s original question had 5 options, while in this survey these are summarised, in a similar format, to 3 options.

Referring to chart 7.6, just under a half of respondents (46%) answered the radioactive decay question correctly - ‘when a radioactive substance gives off radiation’. A quarter claim that it is ‘when something is destroyed by radiation’ and 13% thought it was ‘when a radioactive substance stops being radioactive’. A larger percentage (67%)
answered the second question about half life correctly - 'when a radioactive substance emits radiation at half its original level'.

In an analysis of the press, Eijkelhof (1990, p138) found that newspapers commonly used the term half-life to mean the 'danger period'. In the present survey, only a minority of Radon confidants (13%) perceived this to be the case (i.e. they selected the 'how long a radioactive substance is dangerous' option). Eijkelhof (1990) has also documented a confusion between the terms 'fission' and 'radioactivity'. In the present survey, only a very small number of respondents (4%) thought that 'half-life' was 'how long it takes a radioactive material to split in half'.

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Chart 7.6 and 7.7 level of understandings of the terms: ‘radioactive decay’ and ‘half life’.

Which one of the following statements best explains what the term “radioactive decay” means. Is it:

a) when a radioactive substance stops being radioactive
b) when a radioactive substance gives off radiation
c) when something is destroyed by radiation
or other, please specify

![Meaning of radioactive decay graph]

Chart 7.6, breakdown of responses concern the best explanation of the word "radioactive decay". Y axis represents the number of respondents.

Which of the following statements best explains what the word “half life” means: is it:

a) how long a radioactive substance is dangerous
b) how long it takes radioactive materials to split in half
c) when a radioactive substance emits radiation at half its original level
or other, please comment:

What does the term "Half Life" mean?

![Chart 7.7 half life graph]

Chart 7.7, displays a breakdown of responses concerning the best explanation of the word, “Half Life”. The y axis represents the number of respondents [N=76].
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Taken separately, in traditional science-centred terms, these results are encouraging - the majority of respondents answer correct in each questions. However, when the two questions are combined, just over a third (36%) of respondents answer both correctly.

If scientific literacy is to be considered as a threshold concept, a traditional survey approach (Durant, 1989) - that is respondents can be judged to be literate (or not) according to whether they answer questions correct or incorrectly, 36% of the Radon confidants can be judged as 'scientifically literate' - or 64% illiterate with this result.

There appears to be a relationship between the correct responses and interest ($\chi^2= 8$, 2df., $p < 0.01$); qualifications ($\chi^2= 16.5$, 2df., $p < 0.003$) and informed-about-science ($\chi^2= 9.8$, 2df., $p < 0.010$). The associations for the qualifications and interest results are presented in table 7.5.

Referring to table 7.5, the column 'Totals' represents the total number of respondents with the particular 'qualifications' and 'interest' [N=76]. A greater percentage of respondents (89%) with higher qualifications answer both questions correctly - as might be expected. Similarly, respondents showing interest in science were also more likely to answer both questions correctly - percentages are in brackets.

<table>
<thead>
<tr>
<th>Qualifications</th>
<th>Total</th>
<th>respondents giving correct answers to both questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>37</td>
<td>9 (24)</td>
</tr>
<tr>
<td>School Qualifications</td>
<td>18</td>
<td>4 (22)</td>
</tr>
<tr>
<td>Higher Qualifications</td>
<td>9</td>
<td>8 (89)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Interest</th>
<th>Totals</th>
<th>respondents giving correct answers to both questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very interested</td>
<td>11</td>
<td>6 (55)</td>
</tr>
<tr>
<td>Quite interested</td>
<td>21</td>
<td>9 (43)</td>
</tr>
<tr>
<td>A little interested</td>
<td>34</td>
<td>11 (32)</td>
</tr>
<tr>
<td>Not at all interested</td>
<td>9</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

Table 7.5, shows the relationship between correct answers on a knowledge test and qualifications and interest in science.
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Perhaps what is surprising here is the small percentage of participants with school qualifications (22%) answering both questions correctly. Indeed, a greater percentage of respondents with no formal qualifications (24%) give correct answers. This is unexpected because traditionally the concepts half-life and radioactive decay are covered in school science courses (for example, DfE 1995).

No significant association was found between the correct responses and the variable informed-about-Radon ($\chi^2=0.35$, 2df., $p > 0.84$). This is discussed in future sections.

7.7.2 UNDERSTANDING OF RADON GAS

The first reported question considers the respondents’ understanding of ‘background radiation’. The survey question and results are provided in chart 7.8.

- There is a small amount of radioactivity around us all the time. This is called background radiation. In Devon and Cornwall this type of radiation is:
  1. Mostly from leaks from nuclear power stations
  2. Most from naturally occurring radiation
  3. Mostly from cosmic rays
  4. Mostly from nuclear waste
  Other, please specify

Chart 7.8, provides a breakdown of responses to the question: ‘In Devon and Cornwall background radiation is mostly from...’ The responses are to a 3 point scale: True, False, Unsure. The y axis represents the number of respondents [N=76].
The majority of respondents (91%) considered the radiation in Devon and Cornwall to be mostly background radiation - an orthodox response. In a comparative study, Durant et al. (1989) found that just under three quarters (74%) of their representative sample of the UK public acknowledged that not all radioactive is man made and some occurs naturally. Given so much regional publicity, it is to be expected that a greater percentage of Devon and Cornwall residents are aware of naturally occurring radiation. Perhaps, what is surprising are the small number [4] who are unsure.

The majority of the respondents thought that 'cosmic rays' were not a major source of background radiation (52%). A small percentage considered nuclear waste (4%) and nuclear power (3%) as a major sources of background radiation. Whilst this is only a small number of respondents, it is again surprising given the sample composition.

A nuclear conspiracy theory was mentioned by a couple of participants in the previous IAS study, Chapter Six. At the end of the present survey a space was provided for comments and one confidant also mentioned this theory:

I suspect that there might be a more sinister motive such as authorities or governmental conditioning for nuclear waste dumping (RS12).

In the next question, respondents were asked to indicate examples of radiation given off by Radon gas. This is a slightly more demanding questions as it requires an understanding of quite abstract nuclear physics particles. However, the information is contained within the NRPB leaflet (NRPB, 1995), previously analysed in Chapter Five and features in GCSE syllabuses (for example, DfE, 1995). Radon decays by alpha emission.

Respondents were expected to comment either 'true', or 'false', 'or unsure' for each item presented, a space was left at the end of the question for additional suggestions. The list of options presented were generated in a previous study (Alsop, 1993).
Radioactive materials give off radiation. Which of the following are examples of the radiation given off by Radon gas?

![Chart 7.9](image)

**Chart 7.9** depicts the totals for the question: 'Radioactive materials give off radiation. Which of the following which are examples of radiation given off by Radon gas?'. The responses are to a 3 point scale: True, False, Unsure. The y axis represents the number of respondents \([N=76]\).

A minority of respondents (28%) answer correctly that 'alpha particles' are given off by Radon. Of these, 56% hold 'higher qualifications', 17% hold 'school qualifications' and 19% have 'no formal qualifications'. The majority response was 'unsure' in this case (53%). Again, this is surprising given that a leaflet was sent to all houses in the area containing this information (NRPB, 1995).

Perhaps what is even more surprising is that just over a third of respondents (35%) thought microwaves an example of radiation given off by Radon gas. Microwaves are a familiar, everyday form of radiation which have been associated with health risks (for example eye cataracts) - this may have led to a confusion. X-rays (26%) and Beta particles (28%) are the other significant 'true' responses, although in both cases they are the minority responses. A majority of respondents were aware that sound waves are not given off by Radon gas (57%).

Throughout this question a large number of responses were 'unsure' and this would appear to indicate uncertainty. These, of course, should not be interpreted as incorrect (a cognitive deficit assumption). A space was left at the end of the question for other
responses; four response groups were made; gamma rays [4]; granite[1]; 'Radon gas given off from granite'[6]; and a 'colourless, odourless gas' [4]. The last three of these responses are consistent with an undifferentiated radioactivity concept - discussed in previous chapters.

Turning next to the properties of Radon gas two questions were used to explore understanding. The first considered the mechanism of transportation of radiation, the second the origins of Radon. These questions and results are presented in chart 7.10.

Which of the following are True or False?:
1. The radiation given off by Radon gas floats in the air like a cloud.
2. Radon gas comes from uranium.

Properties of radon gas.

![Chart 7.10](image)

Chart 7.10, provides a breakdown of responses to questions about the properties of Radon gas. Responses are judged against a 3 point scale: True, False, Unsure. The y axis represents the number of respondents [N=76].

About half of the confidants thought that the radiation from Radon gas floats in the air like a cloud - an incorrect response. This would appear to support an undifferentiated model and is commensurate with the results presented in Chapter Six.
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Just over a quarter of participants (26%) thought that Radon comes from uranium - the correct response. However, interestingly, this is a minority response with about half of the respondents being 'unsure' (49%) and (18%) answered incorrectly.

The large 'unsure' response is a feature of the more theoretical questions and it is impossible to deduce if this represents a lack of knowledge or a tentative response from a lack of confidence. Significantly, only one respondent answered both questions correctly - which could be considered surprising given the sample composition.

There appears to be a relationship between the variable informed-about-science ($\chi^2=5.9$, 2df., $p < 0.05$) and correct responses. In contrast, there appears to be no association between the variable informed-about-Radon and the correct answers ($\chi^2=4.3$, 2df., $p = 0.8$).

It is important to be cautious because the numbers involved are small [19]. Nevertheless this trend is exemplified in the table 7.6. Referring to the table, all the respondents (100%) who judge themselves ‘very well informed’ and 31% who are quite ‘informed’ about science answer correctly. This sharply contrasts with only 25% of those who feel they are ‘very well informed’ about Radon.

<table>
<thead>
<tr>
<th>Informed about Science</th>
<th>Totals</th>
<th>respondents giving correct answers to uranium questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very informed</td>
<td>2</td>
<td>2 (100)</td>
</tr>
<tr>
<td>Quite informed</td>
<td>16</td>
<td>5 (31)</td>
</tr>
<tr>
<td>A little informed</td>
<td>44</td>
<td>4 (9)</td>
</tr>
<tr>
<td>Not at all informed</td>
<td>13</td>
<td>0 (0)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Informed about Radon</th>
<th>Totals</th>
<th>respondents giving correct answers to uranium questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very informed</td>
<td>4</td>
<td>1 (25)</td>
</tr>
<tr>
<td>Quite informed</td>
<td>13</td>
<td>4 (31)</td>
</tr>
<tr>
<td>A little informed</td>
<td>47</td>
<td>7 (15)</td>
</tr>
<tr>
<td>Not at all informed</td>
<td>13</td>
<td>1 (8)</td>
</tr>
</tbody>
</table>

Table 7.6 shows the number of respondents answering the uranium question correctly against the two variables: informed-about-science and informed-about-Radon.
The final section presents the results of two questions about the potential harmful effects of Radon gas. The first question asked:

- Which of the following are True or False about the radiation given off from Radon gas?

The radiation from Radon gas:

- i.) it causes cancer
- ii.) it causes sterility
- iii.) it is potential explosive
- iv.) it is not harmful

Chart 7.11, contains the question and a breakdown of the responses. In the chart the y-axis represents the number of respondents [N=76]. The bars represent True, False and Unsure in each question.

The majority of the respondents thought that the radiation from Radon: causes cancer (77%), is harmful (79%) and is not explosive (53%) - correct responses. 50% thought that radiation from Radon gas causes sterility - taken as an incorrect response.

Once more, in traditional survey terms (Durant, 1989), this would appear encouraging - the majority of responses are correct in three of the four questions set. However, only one respondent answered all 4 questions correctly.

The sterility question is perhaps the more demanding question, radioactivity is often associated with genetic deformations and sterility and the results to this question appear distinctive - a significant percentage of respondents (41%) answer ‘unsure’. These respondents tend to have answered the other three questions correctly. Ignoring
this question, 32 respondents (42%) answered the other 3 questions correctly. No respondent answers all these three questions incorrectly.

A comparison between those giving correct responses and the variables informed-about-science, informed-about-Radon and qualifications is shown in table 7.7. Once more, there appear to be associations between correct answers and, qualifications ($\chi^2=8$, 3df., $p < 0.04$), interest ($\chi^2= 7.8$, 2df., $p < 0.05$) and the perception variable, informed-about-science ($\chi^2= 11$, 2df., $p < 0.004$). Whereas, in contrast, no clear association would appear to exist between the correct responses and the variable informed about Radon ($\chi^2= 0.54$, 2df., $p = 0.76$).

To elaborate, referring to table 7.7, the percentage of respondents in each category who answer the three questions correctly decreases with the perception variable informed-about-science, as might be expected. A similar, perhaps more distinctive, pattern emerges when considering the respondents' qualifications, table 3. However, in the second table, the pattern still exists but is not nearly so distinctive - i.e. a smaller percentage of respondents who judge themselves as 'informed' and a larger percentage of those who judge themselves as 'a little' or 'not at all informed' about Radon give correct answers. In this case, a higher percentage of respondents with 'school qualifications'(44%) than 'no qualifications' (30%) answered these three questions correctly.
Chapter Seven: A Survey of Radon Confidants

<table>
<thead>
<tr>
<th>Informed-about-science</th>
<th>Totals</th>
<th>respondents giving correct answers to three questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very informed</td>
<td>2</td>
<td>2 (100)</td>
</tr>
<tr>
<td>Quite informed</td>
<td>16</td>
<td>11 (69)</td>
</tr>
<tr>
<td>A little informed</td>
<td>44</td>
<td>15 (34)</td>
</tr>
<tr>
<td>Not at all informed</td>
<td>13</td>
<td>3 (23)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Informed-about-Radon</th>
<th>Totals</th>
<th>respondents giving correct answers to three questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very informed</td>
<td>4</td>
<td>2 (50)</td>
</tr>
<tr>
<td>Quite informed</td>
<td>13</td>
<td>6 (46)</td>
</tr>
<tr>
<td>A little informed</td>
<td>47</td>
<td>20 (43)</td>
</tr>
<tr>
<td>Not at all informed</td>
<td>13</td>
<td>4 (31)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qualifications</th>
<th>Totals</th>
<th>respondents giving correct answers to three questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>37</td>
<td>11 (30)</td>
</tr>
<tr>
<td>School</td>
<td>18</td>
<td>8 (44)</td>
</tr>
<tr>
<td>Higher</td>
<td>9</td>
<td>6 (67)</td>
</tr>
</tbody>
</table>

Table 7.7, contains 3 tables displaying the qualifications, informed about science and informed about Radon for respondents who answered 3 questions correctly [32].

In the final reported knowledge question, respondents were asked to consider if Radon gas would contaminate food. During the previous IAS study a number of participants saw organic objects as somehow 'attracting' radioactivity (see Chapter Six). This property was incorporated into a two-part question in this survey.

The respondents were initially asked: 'In a house with a high Radon levels could this radioactivity contaminate food?', and they were provided with 'Yes', 'No', 'Unsure' choices. If they responded 'Yes', they were asked: 'which of the following measures would reduce the level of contamination of a piece of meat and offered 'wash it', 'cook it', 'freeze it', 'boil it'. A space was provided to enter other reduction measures if deemed necessary. The results are presented in charts 7.12 and 7.13 respectively.
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Does radon contaminate food?

Chart 7.12, shows a breakdown of responses to the question does Radon contaminate food. Y-axis represents the number of respondents [N=76].

Ways of reducing the level of contamination of meat

Chart 7.13, displays the breakdown of responses to the question: 'which of the following would reduce the level of contamination of a piece of meat?'[N= 34]. The bars represent: Yes, No, Unsure for each reduction mechanism.

A large percentage thought that high Radon levels would contaminate food (45%), a slightly smaller percentage were unsure (42%) and a minority thought that no contamination would take place (10%). This is broadly compares with the previous IAS study where contamination was considered as a sole mechanism of radiation transfer. Whilst contamination of food is possible, it would not be a significant health risk and the main health risk is through inhalation. Given that just under a half of participants thought that contamination was possible, it is perhaps a concern that food contamination is not covered by Radon circulars.
The second part of the question covered the potential ways of reducing contamination in a piece of meat and a majority thought the act of ‘washing’, ‘cooking’, ‘freezing’ or ‘boiling’ would not reduce contamination. For comparison, In Durant et. al.’s (1992) UK survey participants were asked if ‘radioactive milk can be made safe by boiling it?’, 13% answered ‘true’, 65% ‘false’ and 22% ‘don’t know’. A much smaller percentage (8%) thought that boiling would reduce contamination levels in the survey.

In the previous IAS study, a germ analogy was used to explain how radiation affects humans. As many of the cited reduction ‘mechanisms’ are commonly known to be effective in reducing ‘germs’ it could suggest that this analogy is not being used to answer this question. A space was left for other reduction suggestions and 5 respondents replied. They all suggested, the eminently practical measure of throwing the meat away!

In summary, this survey aimed to judge the level of the sample of participants’ knowledge of radioactivity and Radon concepts. It suggests that, as measured, the participants are more familiar with some traditional radioactivity concepts and constructs than others. Table 7.8 displays a list of concepts explored arranged in descending order of their familiarity.

<table>
<thead>
<tr>
<th>Correct responses, (%)</th>
<th>Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>91</td>
<td>background radiation is mostly naturally occurring</td>
</tr>
<tr>
<td>79</td>
<td>Radon is harmful</td>
</tr>
<tr>
<td>77</td>
<td>Radon causes cancer</td>
</tr>
<tr>
<td>53</td>
<td>Radon is not explosive</td>
</tr>
<tr>
<td>28</td>
<td>Radon gives off alpha particles</td>
</tr>
<tr>
<td>26</td>
<td>Radon comes from uranium</td>
</tr>
</tbody>
</table>

*Table 7.8 displays a list the percentages of correct responses to questions about Radon gas. The list is arranged in descending correct responses.*

*If scientific literacy is judged as an ability to answer all these questions correctly, the majority of these confidants would not be judged as scientifically literate. As might be*
expected, levels of formal qualifications and the self-perception variables informed-about-science, and interest are associated with performance. Respondents with higher levels of formal qualification, greater interest and judge themselves more informed-about-science seem to answer more knowledge questions correctly. How well informed respondents perceive they are about Radon, informed-about-Radon, appears not to associate with knowledge performance.

7.8 KNOWLEDGE IN SOCIETY

The focus of the last section of the survey was the practicalities of living with Radon. This section document questions about Radon locations, measurements, reduction levels and techniques, as well as, any advice and guidance the respondents would offer a neighbour and any questions they raised about Radon.

7.8.1 WHERE DOES RADON COME FROM?

In an open format question, the respondents were asked to write down where they thought Radon comes from. Responses were wide ranging (11 different response types were recorded) and, in places, very detailed. The range and frequencies are shown in table 7.9.

<table>
<thead>
<tr>
<th>Response type</th>
<th>Frequency</th>
<th>(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granite</td>
<td>44</td>
<td>(57)</td>
</tr>
<tr>
<td>Rocks</td>
<td>7</td>
<td>(9.1)</td>
</tr>
<tr>
<td>Underground</td>
<td>5</td>
<td>(6.5)</td>
</tr>
<tr>
<td>Naturally occurring</td>
<td>4</td>
<td>(5.2)</td>
</tr>
<tr>
<td>Earth</td>
<td>3</td>
<td>(3.9)</td>
</tr>
<tr>
<td>Radium</td>
<td>2</td>
<td>(2.6)</td>
</tr>
<tr>
<td>Uranium</td>
<td>2</td>
<td>(2.6)</td>
</tr>
<tr>
<td>Sea</td>
<td>1</td>
<td>(1.3)</td>
</tr>
<tr>
<td>Atmosphere</td>
<td>1</td>
<td>(1.3)</td>
</tr>
<tr>
<td>Chemical reactions</td>
<td>1</td>
<td>(1.3)</td>
</tr>
<tr>
<td>Unsure</td>
<td>4</td>
<td>(5.2)</td>
</tr>
<tr>
<td>No response</td>
<td>2</td>
<td>(2.6)</td>
</tr>
</tbody>
</table>

Table 7.9, contains a list of the responses, and frequencies, to the question: “Where does Radon come from?” [N=76].

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The respondents' responses have different degrees of specificity. The most popular reply was 'granite' (57%) other responses were scattered. Some of the confidants appear well versed in the language of radioactivity and radiation and gave quite detailed answers. To illustrate, responses coded as granite, include:

It is a natural product of a metamorphic change i.e. granite has a high level of Radon (RS 49);

decaying granite gives off a gas which collects in contained spaces. (RS 53)

The majority of responses were geological in form. In an earlier question, a minority of the respondents (26%) agreed with the statement 'Radon comes from uranium'. This percentage sharply contrasts with the 57% in this question who state that Radon comes from granite. It appears that more respondents are aware of Radon’s geological origins (granite) than its radioactive origins (uranium).

7.8.2 HOW WOULD YOU ADVISE A NEIGHBOUR ABOUT RADON?

The next reported question explores the advice that the confidants would offer a neighbour. The participants were asked the question: 'If a neighbour of yours has a high level of Radon in their house how would you advise them to reduce their Radon level?'. This question lies a the heart of the use of the term confidant. The results are presented in table 7.10 over leaf.

A wide-range of responses were derived, 8 in total. The largest group (31%) would advise a neighbour to contact a specialist; a quarter of respondents would advise neighbours to increase ventilation and only 13% would not know what advice to give.
Chapter Seven: A Survey of Radon Confidants

Table 7.10, breakdown for answers given to the question: ‘If a neighbour of yours has a high level of Radon in their house how would you advise them to reduce their Radon level?’ [N=76]

<table>
<thead>
<tr>
<th>Advice</th>
<th>Response (%)</th>
<th>Supplementary Coding</th>
</tr>
</thead>
<tbody>
<tr>
<td>contact specialist</td>
<td>24 (31.2)</td>
<td>seek advice [24]</td>
</tr>
<tr>
<td>increase ventilation</td>
<td>19 (26)</td>
<td></td>
</tr>
<tr>
<td>seal floor</td>
<td>2 (2.6)</td>
<td></td>
</tr>
<tr>
<td>fit a Radon sump</td>
<td>5 (6.5)</td>
<td>offer advice [30]</td>
</tr>
<tr>
<td>ventilate and seal floor</td>
<td>3 (3.9)</td>
<td></td>
</tr>
<tr>
<td>move house</td>
<td>1 (1.3)</td>
<td></td>
</tr>
<tr>
<td>don’t know</td>
<td>10 (13)</td>
<td></td>
</tr>
<tr>
<td>no advice</td>
<td>2 (2.6)</td>
<td>offer no advice [22]</td>
</tr>
<tr>
<td>no response</td>
<td>10 (13)</td>
<td></td>
</tr>
</tbody>
</table>

When advice was offered, in the majority of cases [27; 36% of the sample] it was both detailed and agreed with the reduction techniques recommended by the DoE and the NRPB - i.e. forms of increasing ventilation.

The results have been divided into three categories: ‘seeking advice’ 32%; ‘offering advice 40%’ and ‘offering no advice’ 29%. Using these categories a potentially interesting pattern emerges when comparisons are made with the variables informed-about-science, informed-about-Radon and qualifications.

A significant association is found between the ‘advice’ offered and how informed respondents feel they are about Radon - the variable, informed-about-Radon ($\chi^2 = 18$, 4df, p =0.0009). It appears that the confidants who judge themselves to be informed are more likely to offer advice to a neighbour and those who feel uninformed about Radon are more likely to offer no advice. In contrast, no association is found between respondents level of formal qualifications and advice ($\chi^2 = 4$, 4df, p=0.36) and informed-about-science and advice ($\chi^2 = 6.4$, 4df, p=0.17). This pattern exemplified in table 7.11.
### Table 7.11 shows the number and percentages of respondents who offer advice or direct a neighbour to seek advice for each of the variables: informed-about-science, informed-about-Radon and qualifications. Percentages are calculated over the totals shown. These totals are the number of respondents in each of the categories of the aforementioned variables.

In the second table; respondents who judge themselves as 'informed about Radon' are more likely to offer advice (65%) and respondents who feel they are 'not at all informed' about Radon do not offer advice (62%). However, no clear pattern exists in the other two tables (level of qualifications and informed-about-science).

In other words, a response to the probe 'how well informed about Radon are you?' is associated with the respondents willingness to offer advice. Whereas, in contrast, qualifications and informed-about-science are not clearly associated with 'advice'.

### Table 7.11

<table>
<thead>
<tr>
<th>Informed-about-science</th>
<th>Totals</th>
<th>respondents giving advice</th>
<th>respondents seeking advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>informed</td>
<td>18</td>
<td>10 (56)</td>
<td>6 (33)</td>
</tr>
<tr>
<td>A little informed</td>
<td>44</td>
<td>17 (39)</td>
<td>12 (27)</td>
</tr>
<tr>
<td>Not at all informed</td>
<td>13</td>
<td>2 (15)</td>
<td>6 (46)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Informed-about-Radon</th>
<th>Totals</th>
<th>respondents giving advice</th>
<th>respondents seeking advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>informed</td>
<td>17</td>
<td>11 (65)</td>
<td>3 (18)</td>
</tr>
<tr>
<td>A little informed</td>
<td>47</td>
<td>19 (40)</td>
<td>17 (36)</td>
</tr>
<tr>
<td>Not at all informed</td>
<td>13</td>
<td>0 (0)</td>
<td>5 (38)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Qualifications</th>
<th>Totals</th>
<th>respondents giving advice</th>
<th>respondents seeking advice</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>37</td>
<td>11 (30)</td>
<td>16 (30)</td>
</tr>
<tr>
<td>School</td>
<td>18</td>
<td>9 (50)</td>
<td>4 (22)</td>
</tr>
<tr>
<td>Higher</td>
<td>9</td>
<td>5 (56)</td>
<td>3 (33)</td>
</tr>
</tbody>
</table>
7.8.3 THE ACTION LEVEL

The *action level* is the level of Radon at which householders are advised to take remedial action. In the UK this figure is set at 200 becquerels per cubic metre (NRPB 1995). On of survey questions explored the respondents' understanding of this term. They were asked:

For levels of radioactivity in the home the Department of the Environment and the National Radiological Protection Board have set an Action Level. What does this Action Level mean?

Three different viewpoints were identified, listed in table 7.12.

<table>
<thead>
<tr>
<th>The 'Action Level'</th>
<th>Descriptions</th>
<th>Totals (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>An action viewpoint</td>
<td>the level when action must be taken or when the authorities will act</td>
<td>29 (38)</td>
</tr>
<tr>
<td>A financial viewpoint</td>
<td>the level when grants are available</td>
<td>2 (3)</td>
</tr>
<tr>
<td>A threshold viewpoint</td>
<td>the level when Radon becomes dangerous</td>
<td>11 (15)</td>
</tr>
</tbody>
</table>

Table 7.12, contains a description of the three viewpoints which were expressed in response to the question ‘what does the Action Level mean? [N=76], there were a large number of no responses 35 in total (46%).

Just under a third of the participants (29%) defined the *action level* as the level where action must be taken, a typical response was: ‘Above this level you should have work done’ (RS6). The majority of these responses either did not specify or thought that they would have to take action, however, 5 respondents (17%) thought that the authorities would act on their behalf. For example one respondent claimed: ‘When Radon goes above this level then the DoE or NRPB will act and arrange for it to be reduced’ (RS9). Although this is only a small percentage, it is still a source of concern because within current legislation it is left to householders to arrange for their own
reduction work. Two respondents associated the action level with grants (a financial viewpoint).

A significant percentage of participants (15%) consider the action level to be the threshold when Radon becomes dangerous. This type of response is typified by the following four quotations:

1. When Radon levels go above this level they become dangerous (RS31)
2. Below this level you are completely safe (RS16)
3. It means whether it [Radon] is at a safe level (RS50)
4. It is the minimum safety level currently known (RS63)

This accords with responses made in the previous IAS study, where a significant number of participants thought that radioactivity only becomes dangerous when it is concentrated or high doses are received (Chapter Six). These results are also similar to research conducted by Eijkelhof (1994, p212) who found that students associate different meaning with the term 'radiation standard'.

Associations were noted between the correct action response and informed-about-Radon ($\chi^2 = 7.4$, 2df, $p=0.027$), less significant associations were found between qualifications ($\chi^2 = 7.0$, 2df, $p=0.068$) and informed-about-science ($\chi^2 = 4.7$, 2df, $p=0.06$).

This suggests that this sample of participants perceive their knowledge of science and Radon in different ways. This is elaborated in the summary at the end of this chapter.

**7.8.4 HAVE YOU ANY QUESTIONS ABOUT RADIOACTIVITY AND RADON YOU WOULD LIKE ANSWERED?**

The final question reported in this section was opened ended and it provided the participants with the opportunity to list any questions they would like answered. Questions can reveal limits of current understanding as well as areas which the questioner wishes to know more, as we demonstrate in Watts and Alsop (1996). In
total, 23 responses were received [30% of the sample]. The questions covered both general topics of radiation safety and more specific issues about Radon levels.

The majority of questions about radiation safety focused on the action level. For example, one question was posed about international differences between action levels:

*Why do different countries have different harmful and non-harmful levels set? (R22)*

Here, the questioner refers to a harmful level. Another respondent questioned the existence of a minimum level all together:

*Is there an acceptable minimum level? (RS61)*

Another respondent appeared concerned about different levels from different sources:

*Why are Greenpeace's safety levels different to scientists levels? (R37)*

Several respondents [4] were concerned about the information they had received, which appeared contradictory - as one respondent put it:

*I would like to know who is telling the truth? People have safely lived in this area for years and yet scientists had no idea what the background level was before the nuclear age? (RS22)*

Everyday experiences of healthy living with Radon seem to contradict the risks it poses. As Radon has existed in Cornwall for a long time, an older respondent saw little point in worrying about it now, unless the levels have increased:

*I've been living in Cornwall all my life, so why should I start worrying about it now? Have the original levels been upgraded? (RS28)*

This respondent appears to have resigned herself to the dangers involved. She is unaware that recent changes in house insulation have increased Radon levels. Home
insulation can act to both draw Radon in to houses and cut down ventilation (see Chapter Five).

Other respondents actively questioned all the information available:

*We will never know if it's all been exaggerated, how much of the fuss is hype? (RS31)*  
*Is Radon a cover up for government authorities nuclear waste dumping? (RS12)*

The extent to which it should be considered an issue was the focus of some questions [3]. For example:

*It is not really an issue, so why does the government pump so much money into it? (RS29)*

In this case, the expense of the high profile publicity campaign is questioned. A number of respondents [4] were concerned about their local Radon levels, for example:

*How much of a risk do I have to my health in my area? (RS77).*

Information about Action Levels in specific areas (e.g. streets or villages) is not available, much of the information is at the general level of the county. This can lack detail that some people would want.

Radon has become strongly linked with granite rock and one respondent asked about Radon in other granite areas.

*Why is there not a similar problem in Scotland, there is lots of granite in Scotland (R2)*

In fact, recent research indicates that there are high levels of Radon in Scotland (NRPB, 1996).
Many of the confidants are willing to offer detailed advice to neighbours and a series of astute questions are posed. The majority of these questions are not directly covered by the leaflets and circulars available in 'Radon areas' (see Chapter Five).

7.9 RADON AND FEELINGS

Phase two of the data collection suggests that 'everyday' knowledge about Radon is a complex blend of cognitive and affective knowledge. This last section considers the feelings which the survey respondents' associate with Radon. The survey asked: 'How would you feel if your house had Radon in it?'. The results are presented in table 7.13 below.

<table>
<thead>
<tr>
<th>Feelings</th>
<th>Frequency of responses, (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>concerned (Hot)</td>
<td>52 (68)</td>
</tr>
<tr>
<td>no concern (Cold)</td>
<td>13 (17)</td>
</tr>
<tr>
<td>conditional concern</td>
<td>2 (3)</td>
</tr>
<tr>
<td>don't know</td>
<td>4 (5)</td>
</tr>
<tr>
<td>no response</td>
<td>5 (6)</td>
</tr>
</tbody>
</table>

Table 7.13, displays a breakdown of responses to the question: 'How would you feel if your house had Radon in it?' \[N=76\].

A range of emotional responses were received, categorised into 5 response groups: concerned, no concern, conditional concern, don’t know and no responses.

While the majority of respondents (52%) stated showed concern, this category includes a wide range of emotional responses. The more emotional, hot, responses include the adjectives: 'terrified', 'furious', 'panic', 'frightened' and 'very alarmed'. The less emotional or cooler responses include: 'dismayed', 'disturbed', 'worried', 'concerned' and 'not happy'.

A significant number of respondents (13: 17%) were unconcerned. This category includes responses of the nature: 'it is quite safe' (RS12); 'fine, its been around for a long time' (RS30); 'I have and it doesn’t bother me' (RS63) and 'I would not know,
so I am not concerned’ (RS69). A small number of respondents (7: 3%) indicated a conditional response; their emotions would depend on the level of Radon concentration: ‘it would depend on the level’ (RS48); or who is exposed ‘I am more worried about my children than myself’ (RS76).

Calculations were performed to compare the emotional responses with: i) the advice offered ($\chi^2= 7, 8\text{df }p=0.18$) and ii) levels of qualifications ($\chi^2= 11, 8\text{df }p=0.18$) and no significant associations were found. A stronger association, though not significant at the 5% level, was found between informed-about-Radon ($\chi^2= 11, 8\text{df }p=0.06$) and emotional response. (Care should be taken when interpreting these results as the expected frequency was less than 5 for a number of the tabulation cells).

Level of qualifications and ‘advice’ appear not to be related to feeling about Radon. For some of the participants there may be a connection between how informed they perceive they are about Radon (informed-about-Radon) and the emotions they associate with the gas. The emotional response interest has already been associated with informed-about-science, qualifications and performance in knowledge questions in the previous section.

7.10 SUMMARY

It is important to be cautious when drawing inferences from the data collected in this survey. The sample size is small [N=76] and there are likely to be other intercorrelated variables that are not accounted.

The respondents recall finding about Radon from a variety of different sources. Television, newspapers and Radon leaflets appear to be more popular sources of information.

The knowledge questions explored acquaintance with ‘traditional’ science concepts of radioactivity. Concepts that are covered in the mass media and circulars’ and are readily available to residents of Devon and Cornwall. In traditional survey approaches, scientific literacy is considered as a threshold concept, and if this approach were
adopted here the majority of the confidants would be judged as scientifically illiterate on the answers they provided. Levels of formal qualifications, interest, and how informed respondents feel they are about science (informed-about-science) were found to be good indicators of performance. In general, respondents with higher qualifications are more interested in science judge themselves as more informed and answer more knowledge questions correctly.

At one level, a lack of knowledge about science is unsurprising in that previous surveys have demonstrated similar patterns with broadly similar associations (see for example: Miller 1987, Lucas 1987a; Durant 1992). However, given these participants are living in a potentially life threatening situation, have been the focus of considerable media attention, have received information about Radon and have been chosen as confidants, this result may stand out as surprising. Moreover, unexpectedly, how well informed participants feel they are about Radon (informed-about-Radon) turns out to be a poor indicator of knowledge performance and considerable disparity exists between this variable and the other self perception variables.

However, a judgment of scientific illiteracy in traditional terms (Durant, 1992) would mask the fact that many of these respondents show considerable competence in individual knowledge questions, are able to offer advice and give advice about Radon-reduction techniques that is both detailed and embellished, are knowledgeable about the action level and pose a series of astute questions. This would seem to challenge the manner in which traditional scientific literacy measurements over generalise and limit themselves to traditional ‘school based’ science concepts.

These results suggest that those who may have been judged as illiterate in traditional terms can show considerable competence with a measurement that is different in emphasis.

For these confidants, informed-about-science and qualifications are good indicators of traditional knowledge performance, whereas in contrast, informed-about-Radon is a good indicator of a willingness to offer advice. This contrast is significant and may indicate that these confidants view their knowledge of science and Radon in different
ways and for different purposes. One possible inference of this is that, for this sample, to feel informed about Radon necessitates a practical or actionable understanding (c.f. Layton, 1991) whereas to feel informed about science requires a familiarity with concepts and constructs of formal science (which in this context is concepts and construct of radioactivity - previously labeled as Radon-in-general - see Chapter Six).

This survey also considered two emotional factors, interest in science and feelings about Radon. Interest in science was found to associate with performance in the knowledge questions, and a degree of association was recorded between the variables informed about Radon and feelings about Radon. Although this is not conclusive, it seems to indicate a connection between cognitive and affective factors. This relationship is clarified as the thesis progresses.

The thesis now enters the second stage of the research. In this stage, the focus is more closely on learning. To start, the following chapter proposes a model for informal conceptual change learning and this provides the research tools to analyse conceptual change learning in the following chapters.
8.0 INTRODUCTION

This chapter has a pivotal role in the thesis. Here, the arguments presented in the previous chapters are used to propose a model for informal learning - the extended conceptual change model (ECCM). This model is then used as a theoretical framework to describe conceptual change in the studies documented in Chapters Nine and Ten. The ECCM is an extension of Treagust's (1996) multi-dimensional model of conceptual change and has three components: the cognitive, affective and conative. It is hypothesised that the relative status which the learner associates with a conception can be influenced by these three perspectives. The cognitive perspective uses the CCM (Strike, Posner et. al. 1982). In the original conceptual change model a conception's status is determined by its *intelligibility*, *plausibility* and *fruitfulness*. In this chapter the conditions which determine a conception's affective and conative status are proposed. These conditions are supported by drawing upon both empirical and theoretical evidence.

8.1 BUILDING THE MODEL

In the tradition of Grounded Theory, the model proposed was constructed through an iterative process (Glaser and Strauss, 1967). As such, it is difficult to fully present the processes involved in its derivation. The empirical evidence for the model is drawn from all 5 phases of the data collection while only 3 of these phases have been documented so far - data yet to be presented, in Chapter Nine and Ten (phases 4 and 5 of the data collection), have also played an instrumental role in refining the model's design. The model is introduced at this point in the thesis because the multi-dimensional framework both drew upon and shaped the design of the next two phases.
of data collection. The model was refined, enhanced and validated during this application phase. The next two chapters illustrate its application, elaborate definitions and explore the model's limitations in a number empirical case studies.

Chapters Three and Five embrace reviews of research which have challenged the notion of public ignorance. Rather than assuming a simple and negative cognitive deficit model of understanding, the conclusion has been drawn that the public learning of science is largely constructive and complex. There is evidence that the public spends considerable time and effort studying science and, in many cases, any perceived shortcomings in 'uptake' are thought to be because of a rationalised rejection of scientific knowledge rather than a wholesale lack of capacity. This rejection appears to be influenced by a number of social-institutional factors, which include the sources and types of information available.

Chapters Six and Seven have presented empirical evidence to suggest that learners have wide-ranging conceptions of radioactivity and Radon. These conceptions have cognitive and affective components. It also emerged that learners faced with a potentially life threatening situation, i.e. the effects of accumulations of Radon gas, can lack awareness of the science associated with this phenomena (Radon-in-general). However, these same members of the public appear more knowledgeable about the practicalities associated with living with Radon (Radon-in-practice). This research highlights the significance of a conative perspective - It may be that learners have selected or rejected information based on its potential practical value.

As has been demonstrated in earlier chapters, radioactivity is a remote entity commonly contextualised by danger and fear. The potential hazards it presents are constantly reinforced and embellished by mass media reports. It is a particularly salient issue, with close associations with destruction and death (see Chapter Five).

The research discussed in Chapter Six explores the rich array of conceptions which recent school leavers associate with radioactivity. Everyday knowledge and reasoning about radioactivity have been shown to be situated in, and influenced by, a broad range of cognitive and affective factors. Everyday conceptions do not conveniently
separate the cognitive from the affective. For learners, radioactivity is a complex and abstract subject which evokes 'hot' emotions; feelings of danger and fear. The analysis performed in Chapter Six used emotional responses to infer differences between two potentially different types of emotional learners 'fearers' and 'non-fearers'.

Taken together, this evidence suggests that a purely rational cognitive model of cognition is inadequate to describe the informal learning of radioactivity. Whether or not it is able to adequately describe formal learning is a point returned to in the final chapter. The research literature suggests that how information is selected, processed and retained can be influenced and shaped by complex social and affective factors (for example, see Gardner, 1983). In this chapter, the aim is to extend the Strike and Posner et. al. (1982) and Treagust (1996) models of conceptual change to include these conative and affective factors.

The additions to the CCM are documented in the following sections. First, the CCM is briefly revisited to provide a platform upon which to build. This extends the literature review documented in Chapter Three.

8.2 CONCEPTUAL CHANGE REVISITED

The original theory of Strike and Posner et. al. (1982) has received considerable attention and undergone several subsequent revisions. Over the last few years the term conceptual change has been used by researchers and educators to refer to a 'theoretical position' and a number of alternative theories of conceptual change have emerged. Many of these theories (for example, Scott et al. 1991 and Chi, Slotta and de Leeuw, 1994) study the manner in which knowledge changes without explicitly considering the conditions for change.

Along with the proliferation of alternative theories, theorists have also developed their own terminology to describe the processes involved. Even theories which remain closely allied to the original model CCM (Strike and Posner et. al. 1982) have used different terminology and have applied the model to explore different magnitudes of
conceptual change. For example, the CCM of Strike and Posner (1992) uses the Piagetian terms ‘assimilation’ and ‘accommodation’ to describe conceptual change, whereas Hewson and Hewson (1991) use the same basic model but describe conceptual change in terms of ‘conceptual capture’ and ‘conceptual exchange’. Contrasting these two popular theoretical positions is revealing because it enables a distinction to be made between large and small scale changes.

Strike and Posner restrict the use of their model to an ‘accommodation’ - by which they mean a large scale shift in thinking. They maintain that learners have central organising conceptions and that these need to be modified in order to register change. In contrast, Hewson and Hewson (1988, 1991), and later Thorley and Stofflett (1996), argue that the conceptual change theory can be applied to smaller revisions, revisions of a less revolutionary nature which involve the modification of existing, less central, conceptions. They refer to this type of revision as ‘conceptual capture’ (Hewson and Hewson 1991).

These two positions have common ground in so far as they view conceptual change as more than just the addition of knowledge - it involves some kind of revision or modification to a conceptual structure, although they differ in the degree of revision required. The distinction between strong and weak revisions has been used as a framework to unite the descriptors found in the field (see Tyson et. al. 1997, Dagher, 1994). To illustrate, this distinction can be been used to make a comparison between Hewson and Hewson’s (1991) and Strike, Posner et. al.’s (1982) terminology and revisions, contained within table 8.1 below. The shaded areas indicate the type of conceptual change which the theorists have explored with the CCM.

<table>
<thead>
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<tbody>
<tr>
<td>Addition</td>
<td>Accretion</td>
<td>Conceptual Addition</td>
</tr>
<tr>
<td>Weak revision</td>
<td>Assimilation</td>
<td>Conceptual Capture</td>
</tr>
<tr>
<td>Strong revision</td>
<td>Accommodation</td>
<td>Conceptual Exchange</td>
</tr>
</tbody>
</table>

Table 8.1, compares the terminology of conceptual change researchers. The shaded areas represent the applicability of the CCM.
In this thesis, the approach of Hewson and Hewson (1991) is adopted and the CCM is used to explore ‘conceptual capture’ as well as ‘conceptual exchange’. These weak and strong conceptual revisions are referred to generically as conceptual change. The advantage of this approach is that the conditions which influence all types of conceptual change can then be explored. Support for such position may be found in Dagher (1994) who states that ‘restricting worthwhile conceptual change to the radical type is equivalent to restricting worthwhile science to revolutionary science’ (p609).

A further difference between these two positions concerns the destiny of existing knowledge. Strike, Posner et. al. (1982) imply that conceptual change is a full-scale replacement of an existing conception. In this case, the incoming conception subsumes and extinguishes the old conception. In comparison, Hewson and Hewson’s (1991) conceptual capture, is the type of change which ‘involves the increasing or decreasing of a conception’ (Hewson and Hewson, 1991 p61) - a type of conceptual alteration, where cognitive restructuring occurs without the necessary extinction of the original conception.

Many researchers are now of the view that, even when considering strong revisions (conceptual exchange or accommodation), new conceptions can co-exist alongside older conceptions - typically conceptual extinction does not occur (for a review this research see, Taber, 1998). In particular, research documents that conceptions are context or domain specific - i.e. two versions of an identical concept label can co-exist but be related to different contexts (see for example, Bliss, 1995 and Taber, 1998). Duit makes this point clearly when he states:

There is no single study listed in the leading bibliographies of research on student’s conceptions . . . in which a particular students’ conception of the above deep rooted kind could be extinguished and replaced by a new idea . . . old ideas basically stay ‘alive’ in particular contexts (Duit, 1993. p392).

As previously noted, the CCM remains popular with researchers. Tyson et. al. (1997) suggest that this is that because it provides the researcher with tools to analyse explicitly the learner’s epistemological commitments, the condition for conceptual
change (dissatisfaction, intelligibility, plausibility and fruitfulness). The majority of studies of learning in science do not consider the epistemological status of the learners knowledge, and consider only changes in knowledge. In these studies successful conceptual change is measured by changes in knowledge often assessed before and after some educational intervention.

Studying changes in learner’s conceptions, is fundamental when considering conceptual change learning. However this is only one component of conceptual change. This study will consider both changes in status and knowledge. The advantage of this approach is that it enables an exploration of how learners evaluate new ideas and the links they make between existing conceptions and new conceptions. This can be used to distinguish between learning by rote and the more meaningful conceptual change learning - a distinction between memorising and understanding.

In Chapter Three, it has been argued that conceptual change research has largely remained committed to only one theoretical perspective, the cognitive. Recently, Treagust (1996) has extended this and his model of conceptual change incorporates ontological, and social-affective dimensions. In Treagust’s model, conceptual change is viewed from three different perspectives: the epistemological, the ontological and the affective-social. For the epistemological perspective, Treagust uses the CCM and Perry’s theory of intellectual development. In the ontological perspective he examines the learners’ beliefs about the ‘fundamental categories and properties of the world’ (c.f. Chinn and Brewer 1993) and in the affective perspective he examines the social and affective conditions necessary for conceptual change.

These modification are important since they re-emphasise that learning is not simply a cognitive act and offer new research directions for science education. However, the affective/social framework which Treagust proposes appears to limit itself to motivational commitments and fails to articulate clearly how these affective factors mediate the processes of conceptual change other than in terms of very general learner characteristics.
In the model proposed here, Treagust's modifications are extended to consider informal learning from three perspectives: the cognitive, the affective and the conative. Hewson and Hewson's (1991) interpretation of the Strike and Posner (1992) model of conceptual change is used to explore the cognitive domain. Furthermore, conditions are proposed which enable the researcher to explore the learner's epistemological commitments from these additional perspectives domains.

8.3 THE MULTI-DIMENSIONAL FRAMEWORK

To consider the informal conceptual change learning of radioactivity a model of conceptual change has been constructed to incorporate three perspectives, depicted in figure 8.1.

![Diagram](image)

**Figure 8.1**, depicts the model of conceptual change which is composed of three dimensions the cognitive, the affective and the conative. Each dimension determines the status of knowledge and mediates conceptual change.

In this model, the cognitive status concerns the way in which the learner views his or her own knowledge, its epistemological status. The affective status concerns the way learners feel about their knowledge. It determines the emotional conditions necessary
for conceptual change to occur. The conative status determines the way the learner views this knowledge as practical and empowering.

Following Treagust (1996 and later in Tyson et al. 1997) conceptual change is considered to be a dynamic process that takes place over a period of time, in this instance t1 and t2 as depicted in figure 8.2 below. Referring to the diagram, 'knowledge 1' represents pre-instructional conceptions and the revision of these conceptions (exchange or capture) is represented by 'knowledge 2'. As proposed in the original CCM (Strike and Posner et al. 1982), conceptual change always involves a concomitant change in the conceptual status of the conceptual knowledge involved.

![Figure 8.2](image)

*Figure 8.2*, a model representing conceptual change as a dynamic process as it occurs over a period of time t1 to t2 (adapted from Treagust 1996). The status of a conception is determined by the learners cognitive, affective and conative commitments.

In this manner, conceptual change depends upon the learners' current conceptions (knowledge 1) as well as the cognitive, affective and conative status attributed to this and the new revised conception (knowledge 2). In accordance with the original CCM, conceptual change will not occur without concomitant changes of conceptual status,
which involves the lowering of an existing conception’s status and the raising of the new conception before it can be accommodated.

It is suggested that the addition of affective and conative influences offers a much more holistic and fertile way of modelling conceptual change learning - this is particularly suited to the study of informal learning. The following 3 sections elaborate each of these learning perspectives.

8.4 THE COGNITIVE PERSPECTIVE

The cognitive perspective concerns the ‘intellectual status’ of a conception. It is a judgement of not only how intelligible the conception is but also its intellectual worth. It embodies a conception’s intellectual credibility and benefits - its usefulness in solving ‘academic’ problems. The CCM of Strike, Posner et. al (1982) is particularly well suited for a cognitive analysis of conceptual change, since it was derived from a study of the epistemology of science and as such has a wholly ‘intellectual’ emphasis.

A key criticism has been that this is the only perspective detailed by Strike and Posner. The CCM uses three conditions to determine conceptual status: intelligibility (I), plausibility (P) and fruitfulness (F) and a definition of these terms is provided in table 8.2, adapted from Hewson and Hewson (1991, p.60)

<table>
<thead>
<tr>
<th>Condition</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Intelligibility (I)</td>
<td>Does the learner know what the new conception means? Is the learner able to find a way of representing this conception?</td>
</tr>
<tr>
<td>Plausibility (P)</td>
<td>Does the learner believe the new conception to be true? Is it consistent with other conceptions accepted by the learner? For example, the sentence ‘the moon consists of green cheese’(p.60) is one which is intelligible but not plausible.</td>
</tr>
<tr>
<td>Fruitfulness (F)</td>
<td>Does the new conception achieve something of value to the learner, does it suggest new possibilities, directions, ideas? ‘For example, the sentence ‘matter consists of small particles’ is intelligible and its fruitfulness in science is enormous’ (p.60)</td>
</tr>
</tbody>
</table>

Table 8.2, defines the conditions I, P and F of the CCM adapted from Hewson and Hewson (1991)
Thorley and Stofflett (1996) have developed a framework for analysing the content of science classrooms which elaborates the meaning of these terms further. The most significant aspect of this framework is the emphasis given to the multi-dimensional nature of I, P, F. Thorley and Stofflett define:

i.) *Intelligibility* as ‘the mode of representation’ (Thorley and Stofflett 1996, p319). To illustrate, a conception can be made *intelligible* in a number of different ways through, for example: linguistic expressions, analogies and metaphors, images and kinaesthetic or tactile representations (p.321);

ii.) *Plausibility* as the grounds the learner uses to justify his or her explanation, for example, is it consistent with other accepted ideas? and

iii.) *Fruitfulness* as ‘the motivation (of a rather cognitive kind) for learners to cling to old ideas, or be prepared to struggle to understand new ones’ (p.322).

These elaborations are important because they suggest that instead of considering each of the conditions I, P and F directly, it is necessary to consider - in a less direct manner - the ways in which learners use these conditions. As an illustration, a learner’s sense of plausibility may be grounded on a number of different factors, for example: his or her past experiences, beliefs about the nature of the world or about cause and effect, hence it is the learner who decides the plausibility of the conception (or indeed how implausible) and the justifications for this can be wide-ranging. In a similar way, each of the conditions I, P, F is potentially multifaceted and can map onto different components of a learner’s conceptual ecology.

This elaboration re-emphasises that conceptual status is determined by the learner and interpreted by the researcher. Research methods which can be used to explore conceptual status are discussed in the following case studies (Chapter Ten and Eleven). In summation, descriptors for the cognitive conditions are presented in table 8.3 over leaf.
INTELLIGIBLE to me

- I must know what the concept means
- the way it is represented must be understandable
- I must be able to find ways of representing it to others (e.g. drawings, explanations, gestures ...)

COGNITIVE PLAUSIBLE to me

- it must be intelligible
- it must fit in with other ideas and concepts
- it should make sense
- it needs to represent the way I believe things work

FRUITFUL to me

- it must be intelligible
- it needs to be is useful - I can use it to explain ideas in a new way
- It can be applied to other ideas and concepts
- It provides me with new ideas for further investigations or explorations

Table 8.3, summarised the descriptors for the conditions of the cognitive perspective, adapted from Hewson and Hennessey 1991 (p177).

8.5 THE AFFECTIVE PERSPECTIVE

The Collins Dictionary defines affect as the emotions associated with an idea or set of ideas. This clearly covers a vast array of feelings, beliefs, motivations, attitudes, interests and anxieties and illustrates that research into the affective domain can be extremely wide-ranging. It is generally recognised that the cognitive cannot be separated from the affective although the extent to which these two domains are coterminous is debatable. Piaget unites cognition and affect through the role that energetics (specifically interest) plays in intellectual functioning (Hidi, 1990). Kelly (1955) saw the need for an individual to make sense of their world as the major motivating force in learning. He deliberately used the term construct (and the verb to construe) rather than concept (and conceptualise) to emphasise the unity of knowing and feeling. However, given this alliance it is perhaps surprising that little progress
has been made in linking cognitive factors with affective factors in most theories of learning (Pintrich et. al. 1993).

The research focus for this thesis is clear, it explores the influences that affect has on cognition i.e. affect as the independent variable and cognition is the dependent variable. To illustrate, it is likely that ‘cognition’ will influence ‘confidence’ and also that ‘confidence’ will influence ‘cognition’. This thesis, whilst acknowledging this symbiosis, explores the latter rather than the former.

It is well documented that learning itself is an emotional experience, as Claxton (1991) writes:

Learning is generally a risky business because it means moving out from the safety of the known into the unknown and uncontrolled. [...] The involvement of emotion in learning, especially any that involves personal risk of the kinds described, is inevitable (p99).

Conceptual change learning is a type of learning that involves the learner attending to new information, activating prior conceptual knowledge and monitoring comprehension. These process are active and require cognitive engagement - normally embracing concentration and persistence. A superficial engagement is thought unlikely to engender meaning full learning, as Claxton highlights when he continues:

Without choice and responsibility students are always likely to disengage from the learning challenge; and without the engagement of their existing stock of mini-theories, there is nothing that will evolve as a result of experience. [...] When learning is required without engagement, it occurs in a different manner: new knowledge is hoarded alongside old, or one laminates the other, without affecting it. The evolutionary quality is lost, and without it, mental coherence and the intuitive appreciation of the value of what is being discovered are lost as well (p101).

Emotions are likely to affect a learner’s engagement. Such views are fostered by contemporary work such as Gardner’s (1983) discussions of multiple intelligence
(including emotional development) and Greenhalgh’s (1994) explorations of emotional growth and learning.

However, the role that affect has on the learning of science is significantly under-researched. Several years ago, at an international conference, Head (1989) highlighted the importance of addressing this research agenda:

> Often the major problem is that the pupils do not like science. It is their feelings, rather than their thoughts, which we need to consider... My argument is that the affective area will prove to be crucial, in research and curriculum planning, in the next decade. There is overwhelming evidence that, despite the last twenty-five years of curriculum reform, pupils are voting with their feet, away from science (p.163).

The research community has failed to address these concerns and, unfortunately, Head’s statements are as relevant today as they were a decade ago. Indeed, concerns about the popularity of science are perhaps now even more acute as the uptake of science continues to decline (Breithaupt 1997).

When discussing the affective domain, in science education, it is important to draw a distinction between two different types of attitudinal research, namely: ‘attitudes towards science’ and ‘scientific attitude’ (Simpson et al. 1995). Customarily, scientific attitudes have come to mean the ways in which scientists conduct their work. A scientific attitude has become a methodological approach: questioning, collecting data, practical reasoning and making inferences. In this respect, the UK National Curriculum’s first attainment target ‘Experimental and Investigative Science’ is a statement of the scientific attitude expected in pre-16 education. Somewhat paradoxically, scientific attitudes are often portrayed as emotion free, although there is considerable debate in the field (for example, Knorr-Cetina 1981).

Scientific attitudes should not be confused with ‘attitudes towards science’. Attitudes towards science involve the emotional responses which science invokes. Some of the liveliest research in the area has concerned the differences between boys and girls attitudes towards science (e.g. Kelly 1987). This research agenda was initially driven
by girls' under-achievement and under-representation in science - it is a field of research which is both rich and diverse. Analyses have been drawn from sociological and feminists perspectives (see for example, Harding 1991; Bentley and Watts 1987; Harding 1986, and Whyte 1986). Perhaps the most significant result of this research is the challenge it offers to the epistemology of science. However, perhaps surprisingly, this has not lead to an analysis of the influences that attitudes have on the learning of science.

In direct contrast, research in the 1970's that sought to explore gender participation and performance in mathematics has more recently been used to account for blocks in mathematical problem solving. Extreme negative feelings towards the study of mathematics have become labelled as 'mathematical anxiety' (Evans, 1991; 1996). This research emphasises the need to step beyond the cognitive when considering learning. However, 'science anxiety' has yet to receive wide-spread attention.

In his model, Treagust (1996) uses the analysis of Pintrich, Marx and Boyle (1993) in order to explore the affective/social domain. This analysis draws together research on motivation, interest and classroom contextual factors and explores the influences that they have on cognition. This article stands alone in conceptual change research as an attempt to present 'a conceptual analysis of the relationship between motivational factors and student cognition' (Pintrich et. al. 1993 p169). They use empirical evidence to link motivational factors (mastery goals, epistemic beliefs, interest, utility value, importance, self-efficacy and control beliefs) with learner's choice of task, level of engagement and their willingness to persist at a task. They maintain that the conditions necessary for conceptual change (dissatisfaction, intelligibility, plausibility and fruitfulness) are each influenced by motivational factors. To expand, a learner's personal interest has been found to influence the learners satisfaction or dissatisfaction with a conception, the first stage of the CCM. Students who lack interest are not so concerned with conceptual discrepancies that then may lead to conceptual dissatisfaction (see Hidi 1990). Furthermore, a learner's level of cognitive engagement is influenced by motivation - if a learner lacks motivation they may fail to cognitively engage with a task thoroughly, and as a consequence may pay insufficient attention to judge a conception as intelligible, plausible or fruitful (Hidi, 1990).
Venville and Treagust (1996) use this motivational perspective to analyse a teaching scheme and found that a simple analogical model of the heart, and the teaching approach used, succeeded in motivating students and raised their self-efficacy both of which contributed to conceptual change. They use the term ‘motivator’ to refer to the conceptual change influences of this classroom model.

It is proposed that the nature of the content being studied also influences conceptual change. The need for a ‘theory of content’ has been widely recognised (e.g. White 1994). White distinguishes between types of science content, which he suggests may best be taught and learned in different ways. He identifies 10 properties of content: openness to common experience, abstraction, complexity, presence of alternative models with explanatory power, presence of common words, mix of types of knowledge, demonstrable or arbitrary, social acceptance, extent of links and emotive power. There is little doubt that many of these apply to the concepts within radioactivity which, in White's terms, are abstract, complex and arbitrary. Nevertheless, a theory which involves the learning of radioactivity also should consider the important emotive power and social acceptance related to this area of science.

The main assumption made is that the emotional nature of radioactivity, particularly for people living in areas of potential radiation hazards, acts as a mediator in their processes of conceptual change. Radioactivity is a subject often linked with 'hot' emotions and here, it is proposed that the status which a learner attributes to a particular conception is influenced by these emotions.

8.6 SALIENT, PALATABLE AND GERMANE

This part of the research is driven by the question “How do people’s feelings about radioactivity influence their learning?”. Venville (1996) suggests that students engage positively with a topic because they find it interesting, important and useful. Undeniably, Radon is a subject which is important and useful to learners within areas of Radon concern.
However, here it is argued that the reverse is also true - that learners will detach from a topic, will lose interest and attention when a subject lacks personal relevance. They will also reject and disengage with a topic when they view it as distasteful and disagreeable. This thesis explores these reactions in epistemological terms: in terms of the affective status which the learner attributes to a conception.

In the proposed conceptual change model, a conception which is interesting, agreeable and useful has a high status: whereas a conception which lacks personal relevance or, is distasteful and disagreeable has a lower status.

For the purposes of this thesis, the conditions which determine a conception’s affective status are driven by three particular expressions: Salient, Palatable and Germane. Elsewhere, these expressions have been used to explore the teaching and learning of radiation and radioactivity in schools (Alsop and Watts, 1997; Watts and Alsop, 1997; Watts, Alsop and Hanson, 1997). These conditions are summarised in Figure 8.3 and, when combined, they form the affective dimension of the proposed conceptual change model.

![Salient, Palatable, Germane](example_diagram)

**Figure 8.3** depicts the three factors which compose the affective dimension of conceptual change model: salient (S), palatable (P) and germane (G). The hypothesis is that each of these factors can influence, enhance, or hinder the process of conceptual change.
8.6.1 SALIENT

In the model, for something to be Salient means that it is prominent, conspicuous, striking or important in some way to a learner. Salience can be applied to an individual’s perspective: what a learner finds conspicuous or astounding or, more widely, to what a group finds to be eye-catching or stunning. It can have both positive and negative connotations - a sensational issue can be both engaging and disturbing and so might, in different circumstances either, stimulate conceptual change or inhibit it. In terms of status, it is conjectured that salience can either increase or lower a conception’s status.

The need for content to be salient is widely recognised by informal science educators (for a review see Crane et al, 1994). The press and television make use of eye-catching images and headlines to capture learner attention. Informal science research highlights the importance of attracting and maintaining a learner’s attention. For example, Csikensentmihalyi and Hermanson (1995) maintain that the most essential ingredient of a successful science centre is to have exhibits that ‘trap’ the learner’s interest and imagination. Indeed, it is often the lack of salience of the more traditional teaching approaches which is the source of concern (Claxton, 1991). Lock (1996) makes the point well when he compares the salience of informal and formal learning environments:

There is a major mismatch between the world of science in school and that available to pupils through the media. Consider a terms work for year 10 students focusing on gases, gas laws, the structure of elements, the periodic table, emulsions and foams, radioactivity and oxidation. Now contrast that with the output of terrestrial television in a single week of over twenty five science related topics including urban foxes, the third sex, chemical warfare, DNA from pharaohs, information war on battlefields and greyhound euthanasia; and that was without the relevant science-based issues in soaps. No contest! (p32).

In describing the CCM conditions, Hewson and Hewson (1991) use the phrase ‘the moon is made of green cheese’ to illustrate the differences between a conception’s
intelligibility and plausibility. This is a widely quoted example, here it is suggested that a reason why this statement is memorable is because it is salient.

Watts, Alsop et. al. (1997) have developed a pedagogical approach called ‘Event-Centred-Learning’ (ECL). The essence of this approach is the choice of contemporary events or occurrences upon which the teaching materials are based. Events are chosen which are salient and evocative; that is, incidents and episodes which are arresting, rich in human interest, stimulating of discussion and debate. They report finding this approach successful in promoting conceptual change in school settings.

8.6.2 PALATABLE

For the purposes of this thesis, the term Palatable is used to explore learners’ reactions to science content: the particular suggestion is that the concepts that are being learned need to be ‘agreeable to the mind’, or acceptable.

Eijkelhof (1994) notes that few approaches to the teaching and learning of radioactivity manage to dispel the distaste and resistance students feel about these issues. My previous studies of learners’ understandings of radioactivity and radiation, set within formal educational contexts (Watts and Alsop 1997), suggest that learners can ignore, or undergo a type of ‘conceptual avoidance’ when confronted with conceptions which they find unpalatable or unsavoury. This can amount to a simple ‘ostrich principle’ or the ‘ignorance is bliss orientation’ (Kruglanski 1989). Soloman (1993a, p115) has referred to this process as the ‘affective blocking out the cognitive’. Elsewhere, I have called this ‘the personal construction of ignorance’, where learners seem actively to contrive to block acceptance of unappetising or unpalatable concepts (see Alsop and Watts 1997; Watts and Alsop 1997).

In the previous empirically-focused chapters, many learners’ responses have raised this kind of issue, for example, in the IAS study, Martin comments on his understanding of the effects of radioactivity when it is swallowed (see Chapter Six):
Interviewer: Somebody swallows a radioactive substance. What happens?
Martin: The same as before, it will enter the body and into the blood.
Interviewer: What do you think would happen then?
Martin: I don't know - to be honest - I am not sure I really want to know. Sometimes is better not to know about these things.

(Martin, S13, Group A)

This response may be taken as evidence of the affective overriding the cognitive - for Martin, the subject is unpalatable and displeasing and this influences his learning. He prefers not to know about the harmful affects of radiation.

In a passionate analysis of his own work, Rose (1993) reflects upon his research into aspects of memory. Part of this research involves taking transections of chick brains; and he writes:

This is killing business. It is not easy or pleasant to reduce a bundle of yellow fluff to brain and body [...] Yes, the brain has a beauty, its cells an elegance of structure that catches my breath whenever I look down a microscope even now, thirty-plus years since I first observed them. But I have destroyed life. (p.27)

This aspect of his work evokes strong emotions and to a certain extent he is able to reconcile these with the aims of his research. It is likely that many learners may find this aspect of science 'unpalatable'. The point to be made here is that this type of emotional response has a direct impact on learning. Learners reach a balance in their digestion of science not just in terms of its intellectual worth, its plausibility and fruitfulness, but also in terms of its palatability. In terms of a conception's status, it is suggested that a conception which is 'unpalatable' has a lower status than one which is 'palatable'.

8.6.3 GERMANE

In this context, germane is a measure of emotional relevance, it is a measure of how a learner views a conception in terms of its personal applicability and appropriateness.

To some extent this is a personal response to questions of the nature “Do I need to know this?”, “Do I want to know this?”, “Just how important is this to me, anyway?”. This has a degree of commensurability with Strike, Posner et. al.’s (1982) fruitfulness. Thorley and Stofflett (1996) describe fruitfulness as the ‘motivation to stick with an idea, or give it up for another one’ (p.321).

In the ECCM, germane goes beyond a simple relevance to a greater sense of need and pertinence. It is a measure of how important the conceptions are to the learner, a type of conceptual value rating. Value ratings can be studied as personal characteristics (see Hidi and Anderson, 1992), however, in this case, the focus of attention is directed away from the individual and is epistemological in nature. In this model the researcher considers the status that a particular conception holds for the learner, a ‘situational response’ (Pintrich et. al. 1993, pp 169). In ECCM terms, it is argued that a conception will have a higher status if it is considered germane by the learner and a lower status where a conception fails to be germane. The proposed descriptors for the conditions of the affective perspective of the extended conceptual change model are summarised in table 8.4 below.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>For an idea/conception to be:</th>
<th>Descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td>SALIENT to me</td>
<td>• It must stand out.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• I must find it arresting or eye-catching or challenging.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It needs to be surprising or unusual.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• I could find it interesting or curious.</td>
<td></td>
</tr>
<tr>
<td>AFFECTIVE GERMANE to me</td>
<td>• I should feel that it is important.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• I must feel it is relevant.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• I want to understand it.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It strikes a chord with me.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It is an idea I can relate to.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It is an idea I need to bother about.</td>
<td></td>
</tr>
<tr>
<td>PALATABLE to me</td>
<td>• It is an idea I can deal with</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It resonates well with how I feel</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• I must find it appealing and tasteful</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• It must not be cold and alien.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• I must feel that it is better to know or think about it than not.</td>
<td></td>
</tr>
</tbody>
</table>

Table 8.4, summarises the descriptors for the conditions in the affective perspective.
8.7 THE CONATIVE PERSPECTIVE

The third component of the model is the conative perspective. This considers knowledge and its usefulness in a practical context. Specifically, it considers the degree to which scientific knowledge can be linked with practical action in the social and physical worlds. Dewey (1897) saw the need throughout his writings to link knowledge with practical action as axiomatic. He held a particular social agenda; the ability to harness knowledge for democratic progress and humankind. The following quote from Dewey captures the theme which the conative perspective explores:

In order to ascertain the meaning of an intellectual conception one should consider what practical consequences might conceivably result from the truth of that conception; and the sum of these consequences will constitute the entire meaning of the conception

(Dewey 1897 quoted by Garforth 1966, p.16)

Practical consequences - a conative perspective - have a key role in learning. The CCM uses the condition *fruitfulness* to relate to the intellectual advantages of a particular conception. In these terms, the conative perspective explores the *practical advantages* that a conception holds. It answers learner’s questions, such as: “Can I use this knowledge?”, “Does it empower me to act?”, “Is it practical?”, “Does it meet my practical needs?”.

It is hypothesised that informal learning about Radon is more than just intellectual or idle curiosity, but embodies the need to act - it has an empowering agenda. In this sense, conceptions which are readily applicable are likely to be of a higher status to a learner than those that are more general and less applicable. The conative perspective manifests the conception’s practical worth attributed by the learner.

In order to explore this, three conative elements are delineated: the level to which learners are able to *Trust* their understandings; how *Actionable* or readily applicable the information is, and how much *Control* their understandings allows them. During
Chapters Six and Seven, a distinction was made between: Radon-in-general and Radon-in-practice. The conative perspective builds on this distinction and suggests that in general Radon-in-practice has a higher conative worth than Radon-in-general. In contrast, the latter may have a higher cognitive worth than the former. A conception’s worth (its status) is judged by the learner.

The conative conditions are summarised in figure 8.4 over-leaf.

![Diagram: Trust, Conative Factors, Determining Conceptual Status, Actionable, Control]

Figure 8.4, depicts the three factors which compose the conative dimension of the conceptual change model. Each of these factors can influence, enhance, or hinder the process of conceptual change.

8.7.1 ACTIONABLE

The concept of actionable knowledge is derived from the compelling writings of David Layton (Layton 1975, 1986, 1991). Layton uses empirical evidence (reviewed in Chapters Three and Five) to highlight the argument that scientific knowledge is offered to the public is rarely accessible in a form that is ‘use-able’ in everyday situations, without being reworked and recontextualised. This reworking involves the addition of situation-specific knowledge, as well as other knowledge, beliefs and values. Layton (1991, p. 62) refers to this in two stages, as the processes of ‘deconstruction and re-construction’ (see Chapter Three).
Of particular significance here is the degree of translation or reworking that is required in order to fit scientific knowledge with everyday praxis. This can be considered at two extremes, knowledge which is readily applicable (knowledge which requires little or no transformation) and knowledge which is more abstract and theoretical and requires considerable transformation. The proposed extended conceptual change model uses the term ‘actionable’ to indicate the degree of applicability of conceptions - i.e. how well suited learners feel conceptions are to meet their everyday needs.

As an illustration, in teacher education a popular distinction is drawn between ‘content knowledge’ and ‘pedagogical content knowledge’ (Shulman 1987). Pedagogical content knowledge is closely allied with professional practice - it is knowledge which can be immediately applied in the classroom context, whereas content knowledge is removed and remote from practice. In terms of the proposed theory, in the context of the classroom, pedagogical content knowledge is more actionable than content knowledge.

It is argued, therefore, that the conative status of a conception can, in part, be determined by how actionable a conception is. For an informal learner, knowledge which is actionable may be of a higher status than knowledge which is removed from practice. The term actionable is an expression of the conception’s ability to meet the learner’s practical need.

8.7.2 TRUST

Trust has become the point of convergence of a number of different research perspectives. Studies of the public understanding of science have accentuated the importance of trust as a mediator in learning. Members of the public are found to judge the value of a piece of information in terms of its institutional source (see Chapter Three). It appears that where experts come from is as important to acceptability as the validity of science they profess (Layton et. al. 1993, Wynne 1991).
A similar conclusion has been drawn in studies of social risk perception (see for example, Krimsky and Golding 1992). Within this research, the public acceptance or rejection of a risk is found to be influenced by their trust in the institutional source of risk estimation. However, having emphasized its importance, in my view, this research has then fallen short of providing a detailed analysis of trust and its relationship to risk. As Slovic (1993) writes:

As I contemplate the current problems most in need of research, the issue of trust leaps to the top of the list. The massive discrepancies between expert risk perceptions and the acrimonious conflicts over risk management issues can be seen as reflecting a 'crisis in confidence', a profound breakdown of trust in the scientific, government, and industrial managers of radiation and chemical technologies. There is a great need to understand the nature of trust in order to develop social and institutional processes for decision making that restore and maintain this vital but fragile quality (p152).

This thesis builds trust into a model of informal learning. The concept of trust is also re-emphasized, at a more general level, in the sociological accounts of Giddens (1994) and Beck (1992). Both these authors independently reinforce the importance of the social dimension of trust in relation to late modernity and its problems. Giddens (1994) uses the term 'active trust' to investigate the role that expertise plays in social life. He describes how modern society has become dependent on expertise - founded on trust, Giddens writes:

The increasing role that expertise plays in social life intertwines with reflexivity; expertise is no longer the sole prerogative of experts. No one can be an expert in more than a very narrow area [...] All forms of expertise presume active trust, since every claim to authority is made alongside those of other authorities, and experts themselves often disagree with one another. (p95)

It is suggested here that the conative worth of a conception depends upon the extent it can be trusted by a learner. A conception which can be trusted will have a higher conceptual status to a learner than one which can not. The mechanisms by which individuals decide to trust a conception are likely to be complex. However, recent
research suggests that the particular source with which the information is associated has a role to play in these judgements (Wynne, 1991).

8.7.3 CONTROL

In this context, control manifests itself in two ways. The first concerns the extent to which a learner feels their knowledge can be used to control a particular situation. The second considers the control which the learner feels they have over particular knowledge within this situation. These two aspects are often closely related.

Over a decade ago, Rowe (1983) introduced a powerful concept called ‘fate control’ which has been largely ignored. Fate control, Rowe suggests, can be used to explore an individuals’ interaction with their physical and social world. Fate control refers to a pattern of beliefs about influences. Rowe separates people into two groups: those with low and high fate control. People with a low sense of fate control feel powerless to influence the world around them. She writes:

[they] act as if the world were a collage of happenings with few connections between them, as though each event has sprung uninvited into their lives. The world for them is unpredictable, like a game of chance. As a rule their knowledge and understanding of science tends to be rather primitive, if not totally absent. This lack of knowledge gives licence to their belief that nothing is worth any sustained planning, since the world is in the grip of forces and people beyond influence. (p.135)

Rowe contrasts this with people with a high sense of fate control, who are:

more keenly attuned to cause and effect and the structure of relationships and ideas because they believe that the future grows out of what one does in the present, they are more disposed to long term plans and projects. (p136)

This is an analysis of a learner’s personal empowerment and, as such, is an essential component of a conative perspective. Here, the concept of fate control is subsumed within the general notion of ‘control’ which a learner associates with particular knowledge.
The analysis distinguishes between conceptions which learners feel are empowering and those which they feel render them impotent. In the ECCM it is proposed that a conception with which a learner feels unable to use to control a personal situation is of a lower status than a conception that is enabling for them.

In summary, the three conditions for the conative perspective are presented in table 8.5 below.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>For an idea/conception to be:</th>
<th>Descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TRUSTWORTHY</strong> to me</td>
<td></td>
<td>• I need to trust the source of the knowledge.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• It must ring true to me.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• It must be reliable.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I must feel it to be good information.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I need to perceive it as true and accurate.</td>
</tr>
<tr>
<td><strong>CONATIVE</strong></td>
<td><strong>ACTIONABLE</strong> to me</td>
<td>• It needs to be useful in solving my practical problems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• It must be easily applicable in my everyday environment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I can understand how things work better.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I can offer other people explanations and advice</td>
</tr>
<tr>
<td><strong>CONTROLLABLE</strong> to me</td>
<td></td>
<td>• I can make decisions using this knowledge.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I feel I can use it in my situation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I must feel I am able to influence my surroundings with it.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• I feel I can adapt it to meet my needs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• It allows me to 'go forward' in things.</td>
</tr>
</tbody>
</table>

Table 8.5, summarises the descriptors which are used to describe the ECCM's conative perspective.
8.8 THE EXTENDED CONCEPTUAL CHANGE MODEL (ECCM).

In this chapter, the CCM has been extended to include conative and affective perspectives and 6 additional conditions have been delineated. The hypothesis has been that these conditions influence conceptual change. A summary of the Extended Conceptual Change model is presented in figure 8.5 below and an amalgamation of the descriptors for each of the conditions is presented in table 8.6 over-leaf.

The ECCM is not a theory of cognitive development but is an attempt to describe and use the evidence which is relevant to generating conceptual revision. It maintains that the conditions necessary for conceptual change to occur are dissatisfaction with a current conception and a new conception must be intelligible, plausible and fruitful. Strike and Posner (1985, p221) do acknowledge that the process (i.e. dissatisfaction $\Rightarrow$ intelligible $\Rightarrow$ plausible $\Rightarrow$ fruitful $\Rightarrow$ accommodation) is oversimplified because, as they admit, certain conceptions are complex and at a particular time learners are likely to accommodate aspects, or fragments of conceptions.
Table 8.6, Descriptors for the technical terms of the Extended Conceptual Change Model.

<table>
<thead>
<tr>
<th>Perspective</th>
<th>For an idea/conception to be:</th>
<th>Descriptors</th>
</tr>
</thead>
<tbody>
<tr>
<td>INTelligible to me</td>
<td>I must know what the concept means</td>
<td>-the way the it is represented must be understandable</td>
</tr>
<tr>
<td></td>
<td>I must be able to find ways of representing it to others (e.g. drawings, explanations, gestures ...)</td>
<td></td>
</tr>
</tbody>
</table>

**COGNITIVE**

<table>
<thead>
<tr>
<th>PLausible to me</th>
<th>I must be intelligible</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>it must fit in with other ideas and concepts</td>
</tr>
<tr>
<td></td>
<td>it should make sense</td>
</tr>
<tr>
<td>FRUitable to me</td>
<td>it needs to represent the way I believe things work</td>
</tr>
<tr>
<td></td>
<td>it must be intelligible</td>
</tr>
<tr>
<td></td>
<td>it needs to be useful -I can use it to explain ideas in a new way</td>
</tr>
<tr>
<td></td>
<td>It can be applied to other ideas and concepts</td>
</tr>
<tr>
<td></td>
<td>It provides me with new ideas for further investigations or explorations</td>
</tr>
</tbody>
</table>

| SALient to me | I must find it arresting or eye-catching or challenging. |
|               | It needs to be surprising or unusual. |
|               | I could find it interesting or curious. |

**AFFective**

| GERMANe to me | I should feel that it is important. |
|               | I must feel it is relevant. |
|               | I want to understand it. |
|               | It strikes a chord with me. |
|               | It is an idea I can relate to. |
|               | It is an idea I need to bother about. |

<table>
<thead>
<tr>
<th>PALATABLE to me</th>
<th>It is an idea I can deal with</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It resonates well with how I feel</td>
</tr>
<tr>
<td></td>
<td>I must find it appealing and tasteful</td>
</tr>
<tr>
<td></td>
<td>It must not be cold and alien.</td>
</tr>
<tr>
<td></td>
<td>I must feel that it is better to know or think about it than not.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TRUSTWORTHY to me</th>
<th>I need to trust the source of the knowledge.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It must ring true to me.</td>
</tr>
<tr>
<td></td>
<td>It must be reliable.</td>
</tr>
<tr>
<td></td>
<td>I must feel it to be good information.</td>
</tr>
<tr>
<td></td>
<td>I need to perceive it as true and accurate.</td>
</tr>
</tbody>
</table>

**CONATIVE**

<table>
<thead>
<tr>
<th>ACTIONABLE to me</th>
<th>It needs to be useful in solving my practical problems</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>It must be easily applicable in my everyday environment</td>
</tr>
<tr>
<td></td>
<td>I can understand how things work better.</td>
</tr>
<tr>
<td></td>
<td>I can offer other people explanations and advice</td>
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<table>
<thead>
<tr>
<th>CONTROLLABLE to me</th>
<th>I can make decisions using this knowledge</th>
</tr>
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<tr>
<td></td>
<td>I feel I can use it in my situation</td>
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<td>I must feel I am able to influence my surroundings with it.</td>
</tr>
<tr>
<td></td>
<td>I feel I can adapt it to meet my needs</td>
</tr>
<tr>
<td></td>
<td>It allows me to 'go forward' in things.</td>
</tr>
</tbody>
</table>

*The descriptors for the cognitive conditions are adapted from Hewson and Hennessey (1991, p177)
Throughout their writings, Strike and Posner display the processes of conceptual change as linear, starting with dissatisfaction and ending with fruitful accommodation. In contrast, Hewson (1981) maintains that intelligibility and plausibility in a new conception can lead to dissatisfaction in an existing conception.

The focus of the ECCM is still cognitive, the proposed conative and affective perspectives contain conditions which influence cognitive conceptual change - i.e. it is not intended that the model should provide a framework to consider emotional change or decision making. There is great need to develop the model in these directions but this lies outside the immediate scope of the thesis and must wait for further research, see final chapter. In the ECCM, intelligibility and dissatisfaction remain fundamental conditions of conceptual change. Although, it is accepted that these conditions can occur in any order - i.e. dissatisfaction may come before or after intelligibility as Hewson proposes.

In some respects, the proposed affective and conative conditions are similar to the CCM’s conditions plausible and fruitful. However, distinctively, these conditions can both increase and decrease conceptual status - plausible and fruitful only raise conceptual status. The research model maintains that if a learner finds something emotionally unappealing (it is perhaps unpalatable and not germane), such emotions can hinder conceptual change. Similarly if a conception is considered not practical and not suited to a particular need, it can also hinder conceptual change. The reverse is also obviously possible, i.e. conceptions which are considered appealing and suited to a specific need are more likely to be acquired by a learner.

The affective and conative conditions proposed can operate in any order. For example, if a subject is unappealing a learner may prefer to persist with an existing conception and reject a new conception entirely - the affective mitigating against the cognitive. This can occur before dissatisfaction or intelligibility. Similarly, if a learner does not trust a conception, the conative dominating, or overriding, the cognitive, they may not engage sufficiently in order to find it intelligible and may be satisfied with a current conception because it is an idea they can trust. These are both
illustrations of a process the author have labelled elsewhere as ‘the personal construction of ignorance’ (Alsop and Watts, 1997).

There are many possible interactions of the proposed conditions. To illustrate, a single scenario, consider an hypothetical learner, Mike. Mike is faced with understanding a concept about the interaction of radiation on organic matter. He is able to understand, and represent, a differentiated model of radioactivity. He can distinguish between the processes involved in ‘irradiation’ and ‘contamination’. This conception is *intelligible*, it is also a conception which is *plausible* - it makes sense to him when he recalls his school science knowledge. However, he is concerned about the source of the information, it is contained within a leaflet from nuclear industry. He finds it difficult to *trust* the information presented and sees little practical benefit from knowing about this aspect of radioactivity (it is not *actionable*). Furthermore, as he lives near a nuclear power station and is very concerned that it might make him worry unnecessarily (it is *unpalatable*). He argues to himself ‘What is the point in knowing about radioactivity anyway, its not a subject which I can do anything about’ (it is neither *germane* or *controllable*). He decides he is generally *satisfied* with his current understanding: distinct *dissatisfaction* has not occurred and consequently conceptual change does not proceed.

This is a very rational and perhaps over-simplistic representation of Mike’s learning. However, as an illustration, it serves a purpose to illuminate the various components of the model and the potential influences they have. It is not to be suggested that each condition always carries an equal weighting; it may not be possible to add up the positives and negatives to arrive at an overall status. To do so could require very specific research tools, for example rating scales or repertory grid techniques - see final chapter. In the end, the importance, influence and definitions of each of these conditions is determined by the learner, Mike. However, as with the CCM, it is suggested that a new conception of radioactivity needs to be of a higher overall status than an existing conception before conceptual change will occur. Table 8.6 represents Mike’s possible epistemological influences as judged against the proposed extended conceptual change model.
Table 8.7, represents some of Mike’s epistemological commitments when learning about radioactivity in the context of nuclear power: the conditions influencing conceptual change with reference to the ECCM.

The interaction of these perspectives can be represented graphically, see figure 8.6. In this representation, the Y-axis represents the cognitive perspectives, the X-axis the affective and the Z-axis conative. Using this representation, each of the perspectives can be plotted and combined to form a vector of epistemological status.

![Diagram]

Figure 8.6, diagrammatic representation of a conception’s status including the cognitive affective and conative influences. Status can be raised or lowered from each of the three perspectives proposed.

This vector representation can be thought of as representing ‘personal science space’ and Mike’s epistemological commitments could be represented in this format as drawn in figure 8.7, over leaf.
The fact that the model proposed has symmetry may be a cause of concern. There is nothing magical about the number three, a model has been generated which deliberately tries to give similar weighting to the affective and conative as to the cognitive. Arguably, a model of informal learning must pay every bit as much attention to the feelings, emotions and empowerment of knowledge as to the purely intellectual. The distinctions made are intended to be distinctive but not exhaustive - principally to act as heuristics in exploring the informal learning of science.

8.9 SUMMARY

Earlier in this chapter, several key interpretations of the CCM were documented. Weak and strong revisions were included and both are accepted as representing conceptual change. Conceptual change may be an abrupt, radical shift in thinking or a more gentle, less brusque and gradual process. It can involve a re-organisation of central conceptions or an adjustment of conceptions which are less influential. Indeed, it can be any combination of these, or any position between these extremes. During conceptual change it is not necessary for pre-change conceptions to be automatically extinguished.

The CCM argues that conceptual change is determined by conceptual status. In the new proposed model, a conception's status is linked to its empowerment in a particular context and to associated emotions. Everyday conceptions work, are profitable and hold explanatory power in everyday contexts. These conceptions differ in form and status to the more orthodox scientific concepts which may hold a higher
status in a different context. The context this study considers is the informal learning of radioactivity, specifically Radon. This raises the more general question: to what extent is the type of conceptual change context specific - or does it have relevance across a number of contexts? This question is considered in the concluding chapter.

An assumption has been made that the nature of content is an important determinant in conceptual change. The nature of content it is suggested includes the content's academic worth, its ability to meet practical situations and the emotions it evokes.

It is proposed that by creating a more holistic, multi-perspective picture of conceptual change it is possible to commence exploration of the complex world of informal learning. Earlier chapters have identified learner's alternative conceptions of radioactivity and Radon as well as their feelings. The following chapters build on this work and explore conceptual change from the cognitive, affective and conative perspectives. The strength of the model proposed is that it provides the researcher with tools to explore the influences of these perspective - how they facilitate, enhance or hinder the conceptual change process.

8.10 APPLYING THE MODEL

The following two chapters use the Extended Conceptual Change Model (ECCM) both to explore informal learning and test the robustness of the model.

The first, Chapter 9, reports an investigation of learning from a source of informal information - a Radon leaflet. The sample of learners are drawn from the participants involved in the interview-about-scenario study, documented in Chapter 6. This enables a comparison to be made between the participant's conceptions pre- and post-Radon leaflet.

The second, Chapter 10, reports a visits to a Somerset village in the South West of England to explore informal learning in-situ. It documents interviews which investigate how the villagers learn about Radon. The village has been recently targeted by the government as an area of potential Radon concern and information about
Radon has been widely circulated. Together these chapters provide different contexts to apply and evaluate the efficacy of the proposed ECCM as ways of describing informal learning.
9.0 INTRODUCTION

This chapter presents the results of phase four of the data collection. The aim of this part of the thesis is to use the extended conceptual change model (ECCM) as a theoretical framework to describe how the participants learn from informal information sources, in this case a Radon leaflet. The research here is driven primarily by the question:

- Can the proposed Extended Conceptual Change Model be used to describe learning from an informal information source?

The method of data capture is semi-structured interviews which focus on the participants' conceptions and the status they attributed to these conceptions. The ten interviewees were drawn from members of a previous sample. The Radon leaflet acts as an educational intervention and the analysis documents conceptual change both before and after this intervention.

9.1 THE INFORMAL LEARNING SOURCE

An analysis of sources of Radon information has been reported in an earlier chapter of this thesis (Chapter Five). In the Information context of this thesis, the Radon leaflet by the National Radiological Protection Board (NRPB, 1995) has been a particularly significant source of public information (Chapter Seven). The focus of this part of the study is to describe learning from this informal information source using the proposed ECCM. A copy of the leaflet is contained in Appendix I. The
NRPB were contacted and written permission was granted to use their leaflet for this study. Information on the leaflet is divided into six main sections, entitled:

i) Our biggest radiation dose  ii) What is Radon  iii) Radon in homes
iv) Radon risks  v) Radon areas  vi) Radon reduction

The leaflet is the main source of information about Radon issued to householders by the NRPB and a copy has been circulated to all homes in Radon areas.

The leaflet forms part of the NRPB ‘At-a-Glance’ publication series (NRPB, 1995). A conceptual analysis of the leaflet is reported in Chapter Five, showing that the leaflet contains a wide number of science concepts and requires the reader to understand graphical information. It has an emphasis upon informatory discourse (Rowan, 1990).

9.2 THE SAMPLE

The sample was drawn from the participants of phase two of the data collection, from members of the interviews-about-scenarios (see Chapter Six). Ten of the previous 30 participants volunteered to be interviewed for this part of the study. The other 20 were either unable to be contacted or had other commitments during this data collection phase. The names and qualifications of those interviewed are listed within the table 9.1 over-leaf.

The majority of the sample [7] have a home address in a geographic area associated with high Radon concentration, 5 in Cornwall and 2 in Devon. The other 3 participants do not reside in areas associated with Radon or the nuclear industry. Further details about the participants has been provided in Chapter Six.
9.3 THE APPROACH

Traditionally, studies of conceptual change involve an analysis of conceptions both before and after a series of controlled and structured interventions, are long term and usually focus on a single conception. For example Demastes et. al. (1996) have recently performed a year-long study that focuses on the concept of evolution.

This study is slightly different - it is short-term and considers a number of science concepts. These concepts are contained with the Radon leaflet and include; radioactive decay, risk statistics and Radon reduction techniques. The present study has similarities with traditional studies of informal learning which tend to be short term and evaluative (see Crane et. al. 1994 and the arguments in Chapter Three). However, the focus here is the learner rather than the educational stimulus.

In preparation, the participants were given a copy of the Radon leaflet and were asked to “read the leaflet and make a note of anything which occurred to them about it’s content”. An appointment was then made for an interview. The participants were provided with a reassurance that the interview would not be a test of the leaflet’s

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Table 9.1. Characteristics of those interviewed. The sample consists of 5 women and 5 men [N=10]. They are all aged between 20 and 30 years and are students in higher education studying non science degrees.
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contents and that they would be able to refer to the leaflet at any time. Typically the interviews were arranged within three days of issuing the leaflet.

This part of the research took place nine months after the 'interview-about-scenario' study. When viewed longitudinally, the NRPB Radon leaflet can be considered an educational intervention in a two-stage study, represented in figure 9.1. From this view-point, phase three and five of the data collection provide a 'snap shot' of the learners before and after the intervention. It is possible to document conceptual changes by comparing the participants' conceptions in phase three (T1) and five (T2) of the data collection. Though, it should be borne in mind that a lapse of time has occurred between these stages and consequently any conceptual change cannot necessarily be attributed to this particular intervention.

Figure 9.1, provides a longitudinal representation of the two studies, interviews-about-scenarios (Chapter Six) and the learning from informal sources (Chapter Nine).

9.4 CLINICAL NON-TECHNICAL SEMI-STRUCTURED INTERVIEWS

Semi-structured interviews (Powney and Watts, 1987) were used as the method of data capture. A study of conceptual change learning requires an analysis of learners' conceptions and, in the case of the ECCM, the cognitive, conative and affective status that they attribute to these conceptions as well. Hewson and Hewson (1991, p.63) suggest that this type of study can be conducted in 4 different ways:
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1. *The non-technical interview* - in this approach the interviewees are not aware of the technical language of the CCM and another person infers the conceptual status.

2. *Non-technical classroom discourse* - in this approach the interviewees are unaware of the language of the CCM, as in 1 above. There may be many students involved the discourse and so it is likely to contain fewer comments about individual students’ conceptions - which can be used to determine conceptual status.

3. *The technical interview* - in this approach the interviewees are required to be aware of the CCM conditions. The interviewer then asks directly about conceptual status - e.g. “Do you find this idea fruitful?” or “Is this idea plausible?”. In this process the interviewees become collaborators in the research.

4. *Technical classroom discourse* - in this approach method 3 is used in a classroom setting. This approach has similar methodological difficulties as method 2 - the classroom setting can dilute the number of individual comments which refer to conceptual status.

The focus of Hewson and Hewson’s review is the difficulties associated with a reliable determination of conceptual status. The current study also has a developmental agenda - it sought both to *refine* and *categorise* conditions influencing conceptual status. A *non-technical* approach was adopted because it enabled a series of broad questions to be used to elicit comments *about* conceptions from each of the perspectives: concerning the cognitive, conative and affective. These comments were then used to infer epistemological commitments and categorise the conditions influencing these commitments. The *technical interview* explicitly uses the status conditions. It was not possible to use this approach in this study because not all the conditions were fully defined at the outset of the research.

*Non-technical interviews* place particular demands on the researcher who has to interpret the interviewee’s statements and then assign conceptual status. A *clinical* approach was adopted because it was then possible to elicit comments explicitly about
conceptions and then explore these comments in depth. This made the task of status determination less interpretative and therefore easier and potentially more reliable.

9.5 THE METHOD

The Radon Leaflet (NRPB, 1995) was opened and placed in front of the participants and provided the stimulus and structure for the interview discussions. As already noted, the interviews focused on:

1. The content of the Radon leaflet - the leaflet contains a number of science concepts and the aim of the interview was to explore the conceptions which the participants’ associate with these concepts.

2. The epistemological commitments that the learners associate with these conceptions and the status that they attribute to these commitments.

One key concept was selected from each section of the leaflet as an initial focus. After an exploration of the understandings of this concept, the participant were free to explore other aspects of the section if they considered them important. The key concepts chosen are listed in the table 9.2 below.

<table>
<thead>
<tr>
<th>Section</th>
<th>Key Concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>i) Our biggest radiation dose</td>
<td>Radiation is naturally occurring</td>
</tr>
<tr>
<td>ii) What is Radon?</td>
<td>Radioactive decay</td>
</tr>
<tr>
<td></td>
<td>The causal affects of Radon.</td>
</tr>
<tr>
<td>iii) Radon in homes</td>
<td>Transport mechanisms - how Radon enters homes</td>
</tr>
<tr>
<td>iv) Radon risks</td>
<td>The risks associated with Radon</td>
</tr>
<tr>
<td>v) Radon areas</td>
<td>The Action Level</td>
</tr>
<tr>
<td>vi) Radon reduction</td>
<td>The mechanisms of Radon reduction</td>
</tr>
</tbody>
</table>

Table 9.2, presents the concept focus of the interview when referring to each of the sections of the NRPB Radon leaflet (NRPB 1995).
With the leaflet open, a series of questions were used to elicit the participant’s understanding of the leaflet’s content. General questions asked the participants to explain the content of the leaflet, for example: ‘Can you describe this section to me?’, ‘What does this mean?’, whereas more specific questions explored particular aspects of the content in more detail, for example: “What do these graphs represent?”, “Can you explain these arrows to me?”, “What did you mean when you said ...”.

A list of indicative general and specific questions are provided in figure 9.2 over-leaf alongside a section of the leaflet.

Following some discussion about each conception the interviewees were asked a series of questions about the status they attributed to this conception. Questions about i) cognitive status explored the conception’s intellectual worth; ii) affective status explored the conception’s emotional value; and iii) conative status explored the conception’s practical value. A list of indicative questions is provided in table 9.3.

<table>
<thead>
<tr>
<th>Focus</th>
<th>Questions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cognitive status.</td>
<td>• What do you think about this?</td>
</tr>
<tr>
<td></td>
<td>• Was it easy to understand?</td>
</tr>
<tr>
<td></td>
<td>• Does it make sense?</td>
</tr>
<tr>
<td></td>
<td>• Why does it make sense?</td>
</tr>
<tr>
<td></td>
<td>• How does it make sense?</td>
</tr>
<tr>
<td>Affective status.</td>
<td>• What do you feel about this?</td>
</tr>
<tr>
<td></td>
<td>• Do you feel it is important?</td>
</tr>
<tr>
<td></td>
<td>• Why do you feel this way?</td>
</tr>
<tr>
<td></td>
<td>• Did any of this content stand out?</td>
</tr>
<tr>
<td>Conative status.</td>
<td>• Did you find this content useful? Why?</td>
</tr>
<tr>
<td></td>
<td>• Do you believe this content?</td>
</tr>
<tr>
<td></td>
<td>• Is it suited to your needs?</td>
</tr>
</tbody>
</table>

Table 9.3. A list of indicative questions used to probe cognitive, affective and conative conceptual status.
Section Two of the NRPB Radon Leaflet.

What is Radon?

Radon is a natural radioactive gas. It comes from uranium that occurs naturally in all rocks and soils and is given off at the surface of the ground. We all breathe it throughout our lives. Out of doors, it disperses in air so levels are very low.

Radon-222

Radon is created when uranium undergoes radioactive decay through a number of stages. Radon itself decays to form short-lived radioactive particles which remain suspended in the air.

When inhaled, these particles expose the lung to alpha radiation and increase the risk of developing lung cancer. This risk rises as the level of radon and the duration of exposure increases.

Initiating Interview Protocol:

- What did you understand by this section?
- Did you learn anything new from this section?
- Can you tell me what Radon is and where it comes from?
- What do you understand by this radioactive decay chain?
- What do the arrows represent?
- How does Radon enter the body and what damage can it do?

Figure 9.2, illustrates how the leaflet was used to stimulate responses. The first two questions are more general, the others are more specific.
The research method was piloted with 5 non-scientific adults separate from the main sample. The pilot was used to trial the interview protocol and a number of small adjustments were made. In particular, the need became apparent to focus on a limited number of science concepts and to explore these in greater depth.

The final interviews were undertaken over a two-week period and each interview lasted about 45 minutes. All conversations were audio-taped and then transcribed verbatim using standard conventions (Powney and Watts, 1987).

9.6 THE ANALYSIS

The data analysis was an iterative process which involved 4 stages:

1. Identifying and categorising statements representing conceptions and comparing these with conceptions elicited in phase 3 of the data collection;
2. Identifying statements about conceptions;
3. Categorising statements about conceptions (conditions) and assigning conceptual status.
4. Revisiting the data several times to check, harden and saturate the conceptual and conceptual status categories in a continuous and iterative process.

Methods of determining conceptions and conceptual status have been considered in some detail in the CCM literature. Hewson and Hewson (1991), in a seminal review, rationalise this as a three step process (ibid. p62). Their approach was used to guide the analysis here which has four steps:

- **Step 1:** identifying statements which represent conceptions (this type of analysis has been previously performed in Chapter Six). To illustrate, in the following excerpt of her transcription, Lorraine describes the causal processes of Radon.

  *Interviewer:* Looking at section two, can you tell me what this picture represents [a picture of how Radon enters the lungs].

  *Lorraine:* Yes, its showing you that when you breathe in the gas it gets inside the lungs.
Interviewer: And then what happens?
Lorraine: I know the picture is only of the lungs, but, I think the Radon gas will get inside the blood stream and travel all the way around the body.

Interviewer: Would it effect other parts of the body?
Lorraine: Yes it would, but I think it might particularly affect the liver or the food tracks.

(Lorraine, Group B)

Lorraine describes the harmful affects of Radon with out reference to radiation: an undifferentiated conception (T2). She also conceptualises the harmful affects of Radon in terms of contamination. During this process Radon enters the blood stream through the lungs. This conception was then compared with the results of the interviews-about-scenario study (T2) where Lorraine displayed a similar undifferentiated conception, hence, this is evidence that conceptual change has not occurred in the time between the two surveys.

• Step 2: identifying comments about conceptions. These comments can be cognitive, affective or conative in perspective. To illustrate, in the following example, Fiona explains why she believes that Radon, a natural gas, can also be dangerous.

Interviewer: Could we now focus on ‘the biggest dose’, there is a pie chart here, could you explain it to me?
Fiona: Yes, this was the information that I found the most surprising, because it uses the word ‘natural’ [Natural Radiation]. Although the fact that its naturally occurring doesn't mean to say it's any better for you. I mean, ‘natural’ you get this all over cereal packets. Natural ingredients, and the natural ingredients are brown sugar - but it doesn't say it's good for you. It's the same sort of thing when you talk about natural radiation.

(Fiona, Group A)

Fiona is considering how something ‘natural’ can also be dangerous - she is commenting about her understanding of natural radiation. This is a statement of her cognitive commitments - she is rehearsing why this content makes sense to her. In addition, Fiona states that she finds this idea surprising. This is an emotional comment about this content - an affective status comment. Hence this
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extract of Fiona’s interview provides cognitive and affective status data for coding.

- **Step 3:** interpreting and categorising statements extracted in step two and then assigning conceptual status. These processes can be illustrated using the above extract of Fiona’s transcript. Fiona understands that natural radiation can be harmful, she can represent this concept-idea and hence there is evidence of *intelligibility*. The extract contains evidence that Fiona is able to *make sense* of her ideas by comparing them to other natural cooking ingredients - there is evidence for *plausibility*. Furthermore, as Fiona comments that she finds it surprising that something natural can also be harmful there is evidence that she considers this concept prominent, striking or eye-catching - this is taken as evidence for the condition *salience*.

Similarly, the analysis considered the conative aspects of the transcriptions. In the following extract of his interview, Paul considers the conative worth of the information presented. The interview focuses on the risks of Radon. Paul’s responses are prompted by the interviewer asking him to reflect upon how useful he finds the information.

*Interviewer:* Could we now focus on the ‘Radon Risk’ section, what does this section mean?

*Paul:* It explains, the life time risks involved when living with different Radon levels [...] 

*Interviewer:* Do you find this information useful?

*Paul:* I don’t really, it is actually quite difficult to understand and very general. It would be better if it told you how many deaths will result from Radon exposure and what can be done about it. You need information which you can use to reduce Radon levels. There is no information about grants or funding to reduce Radon in the home. This information appears vital to me. The information is too technical in places and the average householder who I think would simply not bother to read it, let alone take action.

*(Paul, Group B)*

From his responses, Paul appears to view the risk information presented as having a low *actionable* status. He sees the information presented (life-time risks) as less
important than information which is more closely linked with practice, such as grants and specific casualty details - information which are perceived to be of practical use. Paul considers the more general concepts of risk expressed in terms of lifetime risk per radiation level as less useful and subsequently for him they have a lower actionable status. This extract provides evidence of conative epistemological commitments - the ECCM condition actionable.

These examples are indicative of the coding processes. Extracts were not analysed in isolation but whole interviews were coded. Where an interviewee offered no explanation of a particular section of the leaflet or displayed no evidence of conceptual status then their responses were classified as ‘no evidence’.

- **Step 4.** As the research progressed, the data gathered was used to harden, and saturate the conditions. In consonance with Grounded Theory, as discussed earlier, care was taken to be critical of the emergent theory and sensitive to the empirical data. In the final stage of the analysis, the data was revisited and checked independently by two researchers and over 80% reliability was achieved. Where disagreements were found it was due to a lack of clear evidence. In all cases, the analysis was agreed during consensus discussions. If data was considered to be ambiguous it was not coded. On occasions the ECCM conditions were found to overlap. For example, the affective condition germane and the conative condition actionable can overlap. A conception can be considered relevant and important because it is actionable [i.e. a conception is considered germane because it is actionable]. In these cases, the statements were coded as providing evidence for both of the conditions.

### 9.7 PRESENTATION OF THE RESULTS

An ECCM analysis is particularly ‘rich’ as a single interview contains a raft of conception and conceptual status statements. The data is considered to be broader than in traditional conceptual change studies because it incorporates affective and conative analyses.
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The results provide an abundance of data in support the ECCM, as previously defined in Chapter Eight. In each case study there was evidence of cognitive, affective and conative epistemological commitments. The data and analysis is represented here with an overview of all 10 studies and then 4 cases which are documented in more depth. These are selected because they are contrasting and can be used to illuminate particular features of the ECCM.

9.7.1 AN OVERVIEW OF THE DATA

Before commencing the interview, each participant was asked to estimate the amount of time they had spent reading the Radon leaflet (see table 9.4).

<table>
<thead>
<tr>
<th>Time spent</th>
<th>frequency (N=10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>up to 15 minutes</td>
<td>2</td>
</tr>
<tr>
<td>15 -30 minutes</td>
<td>4</td>
</tr>
<tr>
<td>30 minutes</td>
<td>3</td>
</tr>
<tr>
<td>50 minutes</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 9.4. Participant responses to the question “How long did you spend reading the leaflet?”

These figures vary significantly and range from estimations of 10 minutes to 50 minutes. The point here is that the leaflet covers a large number of concepts, albeit superficially and, in general, the more time the learners estimate the spent reading the leaflet, the more familiar they might be with its content. The participants who had spent a shorter time did not appear to lack commitment or to find the leaflet demanding but, rather, had chosen to focus on only those particular aspects of the leaflet that they felt were important. Significantly, what emerged seemed to be two different and quite distinctive learning approaches. Two participants [Cathy and Liam] were eager to understand all aspects of the leaflet and had persisted with many concepts that they found initially confusing. Liam, for example, articulates his approach in this extract of his transcript:

Interviewer: How long did you spend reading the leaflet?
Liam: About half an hour or so [pause] well I needed to read some parts of it over and over.
Interviewer: Why was that?
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Liam: Well, some bits I found quite difficult to understand the first time, that section about the radiation doses was particularly difficult... [pause...thinking aloud] and any other difficult sections which I need to study in depth. But I think what slowed me up was the wording of the leaflet rather than the concepts.

Interviewer: You spent time considering all the concepts of the leaflet?
Liam: Yes, I studied it in depth, I wanted to understand what the leaflet contained.

(Liam, Group A)

Here, Liam appears driven by a sense of academic completeness, his goal is mastery of the leaflet’s content - an approach to learning which was also evident in Cathy’s interview.

In contrast, the majority of the participants [8] were more selective in their reading. These learners spent less time reading the leaflet and focused on particular sections. They avoided, ignored or relegated in importance other sections of the leaflet. The reasons behind these learners’ selection of content are revealing and provide data to support the ECCM. To illustrate this, in the following extract of her interview, Lorraine describes her learning:

Lorraine: It [the leaflet] uses a lot of graphs, for example, this pie chart. This makes the leaflet difficult to understand and it seems to be very scientific. I tended to avoid these bits, but I feel it is important to know about the Radon levels and how you can lower them - I concentrated on these bits. I suppose it depends what we should know for our homes.

(Lorraine, Group B)

In her report, Lorraine reflects that she approached the leaflet with a clear goal, ‘what we should know for our homes’ and avoids the ‘very scientific bits’. She states she has a goal of knowledge for everyday life rather than academic mastery and, as a consequence, she concentrates on the areas of the leaflet which she perceives match this goal. This extract provides evidence that Lorraine approached this information with a conative agenda. She considers information suited to her practical needs (Radon-in-practice) to be of a high status. In the proposed ECCM terms, this knowledge has a high status because it is actionable.
This analysis of learning approaches provides evidence of how epistemological commitments can influence learning. In Lorraine's case, her epistemological commitments appear to be at a more general level - a preference for a type of content - and the influence this has on her learning is explicit. Similarly, in the following extract, Anna explains how an emotional response, that of being surprised, has influenced her learning:

*Interviewer:* What did you feel about this section? [Radon risks]
*Anne:* well I was quite surprised really. You know, exactly how high the levels can be. This caught my attention and made me want to find out more.

(Anne, Group A)

Anne acknowledges that risk details have 'caught her attention' - which is taken as evidence for the ECCM condition salient. Her subsequent comment '[it] made me want to find out more' provides evidence that the condition salience could have influenced her learning. Although, in direct contrast, Melody appears to find the same information inconsequential (or lacking salience).

*Interviewer:* What did you feel about this section? [Radon risks]
*Melody:* Not much really, I didn't bother with it. The risks of Radon are not something I really think about.

(Melody, Group B)

Radon risks is not a subject which Melody is bothered about - it is not a topic that is germane. This attitude appears to influence her learning when she says '[this is] not something I really think about'. This extract provides evidence that an affective condition can influence learning, but in this case in a negative way. In the proposed ECCM terms, Melody seems to have attributed Radon a low status subject and this has hindered her learning.

During the analysis, epistemological commitments were recorded at both the more general level, a preference for a type of content and at a more traditional conceptual level, the status associated with a conception, further illustrations of this are documented in the following case studies.
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The ten cases drawn on here have been extremely wide ranging in the ways that learners focus on different sections of the leaflet and attribute different status to the concepts covered. A comparison of responses to particular concepts is ‘patchy’ because several learners had not considered all the concepts prior to interview. As the analysis has three perspectives, there is a strong inclination to group learners under a particular perspective - i.e. as being a learner with a current bias in relation to the particular Radon leaflet that is cognitive, conative or affective. However, this type of representation is misleading because it fails to show that each learner displayed epistemological commitments in all of the perspectives. That is, their transcripts all illustrated cognitive, affective and conative dimensions. Nevertheless, as the status attributed to these commitments was variable, it is possible to provide an overview of the case studies by highlighting the perspectives which appeared to be prominent for each learner, see table 9.5. The learners in bold are those documented in the following sections.

<table>
<thead>
<tr>
<th></th>
<th>Cognitive</th>
<th>Affective</th>
<th>Conative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anne</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Liam</td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Fiona</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cathy</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lorraine</td>
<td></td>
<td>✓</td>
<td></td>
</tr>
<tr>
<td>Mark</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>David</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melody</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melika</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Paul</td>
<td>✓</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Table 9.5. An overview of the ten case studies representing the prominent epistemological commitments of each learner.*

To explore these prominent commitments the following sections document the results of 4 case studies: *Cathy, David, Mark* and *Fiona*. These four studies are selected because they embrace most possible combinations of the cognitive, affective and conative perspectives. In each documented case, the cognitive, affective and conative perspectives are outlined using extracts of the participants’ interviews. The cognitive perspective focuses on the concept radioactive decay and the affective and conative perspectives focus on aspects of the participant’s interviews which illuminate these
perspectives. In each case, evidence for the ECCM conditions are documented which appears to be particularly influential to the learner.

9.7.2 CASE STUDY ONE: CATHY

Cathy judges herself to be very interested in science and quite well informed. She frequently watches science on television and is particularly interested in medical programs. She has no formal qualifications in science. Cathy is currently studying music at an institute of higher education. She lives in Devon and has heard about Radon from television. The Radon levels in her house have not been measured.

Cathy estimates she spent over 30 minutes studying the leaflet. She appears interested in the leaflet’s content and was eager to understand all aspects of the information presented. She was enthusiastic during the interview.

• The Cognitive Perspective

In the previous IAS study (T1), Cathy displayed a differentiated conception of radioactivity. She described radioactive decay as a ‘decomposition’ of a radioactive source and perceived that the source would remain the same element but shrinks in size during the emission of radiation (extracts of Cathy’s IAS are set out in Chapter Six). The following excerpt of Cathy’s interview transcript (T2) focuses on the discussions about the second section of the Radon leaflet, ‘What is Radon’. Her comments are elicited with a general question as she considers radioactive decay:

Interviewer: What did you find out about Radon from this leaflet?
Cathy: Well, Radon gas and radioactive substances, in general, don't just breakdown and that's the end of it - they breakdown further and release more radioactivity as they break down, which is demonstrated by the picture with the circles on it. Umm, yeah, it sort of makes sense because that's how Radon comes from uranium... It changes substance [element] when it breaks down.

(Cathy, Group B)
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Cathy finds the radioactive decay chain being depicted as *intelligible* - she is able to represent the processes involved in her own words. The processes make sense to her - they are *plausible* because they fit with something she already knows - Radon comes from uranium. This idea is also *fruitful* because she can use it to explain the generation of Radon. This is interpreted to be a conception with a high cognitive status.

When a comparison is made with her responses in the previous interview-about-Scenario study (T1), Cathy appears to have undergone a change in her thinking. She now conceptualises radioactive decay as involving transmutation (i.e. a change in the substance [element] occurs). She is also aware that radioactive decay is a multi-stage process (i.e. there is a decay chain).

A particular issue here is the magnitude, or extent, of the change. This type of change is recognised as an illustration of Hewson and Hewson’s (1991) ‘conceptual addition’ which they describe as an ‘*increase or decrease*’ (*ibid.* p.61) in learning. This involves the learner making sense of something by making *connections* to what they already know. In this current example, Cathy has *increased* her conception of radioactive decay to include transmutation and multiple stages. She has made *connections* between her previous ideas about radioactive decay and the information presented in the Radon leaflet.

Cathy continues at a later point in her interview to reflect upon her new conception:

*Interviewer:* How does Radon breakdown?
*Cathy:* The radioactive substance breaks down in this little string [decay chain] of polonium, lead, bismuth and polonium, which - I dunno - I guess lead is sort of is unstable in some way!

*Interviewer:* You sound surprised?
*Cathy:* Yes, well I mean, lead isn't a radioactive substance is it?

(*Cathy, Group B*)

Cathy recognises that uranium eventually decays into lead, this information is represented pictorially on the Radon leaflet, however this raises an anomaly as she finds it difficult to accept that lead can be radioactive. This is something she finds
implausible. Currently, Cathy’s revised conception of radioactive decay lacks consistency (parts of her revised conception are plausible whereas other parts are implausible). There is no discernible evidence in Cathy’s transcript to suggest that she feels it necessary to reconcile this conceptual ambiguity.

• The Affective Perspective

Affect appears not to be a strong feature at this point in Cathy’s learning. She tends to have a factual style and her responses can be classified as ‘cold’. She does appear surprised by some aspects of the information contained within the leaflet so that, for example, in the following excerpt of her transcription she appears puzzled by the information about Radon reduction. One of the reduction mechanisms suggested by the leaflet is to install a fan in a house’s loft. She finds this surprising:

Cathy: I think that it would be of greater concentration higher up - but - the leaflet says that by blowing air from your loft back into the house you can disperse it.

Interviewer: hum [Yes]

Cathy: I actually find that surprising - yes - because I thought it would only leak into the loft and that would be okay.

(Cathy, Group B)

Cathy’s reaction to the information presented suggests she finds it interesting or arresting. This provides some evidence for the ECCM condition salience. This raises an interesting point as this information appears salient because it lacks sense - it is implausible. The ECCM proposes that conceptions which are implausible have a lower status than those which are plausible and conceptions which are salient have a higher status than conceptions which are not. In this instance, it would appear that the revised model’s cognitive and affective conditions are opposing.

In the following extract, Cathy is asked directly about how she feels about the information presented, and she chooses to focus on her instrumental learning goals and the importance for information to be widely available.

Interviewer: What do you feel about this information?
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Cathy: Well, it’s a very important subject, it is a subject which we all need to know something about. If you know something more about it you can do something like reduce the levels in your home.

(Cathy, Group B)

Knowledge with a conative dimension is *germane* for Cathy, illustrated in another excerpt of her interview:

*Cathy:* Well, the most important thing for me is that you can measure the amount of Radon in your home and do something about it

(Cathy, Group B)

From the affective perspective, knowledge that one can measure and control is *germane* and, as a consequence, Cathy accords it high status.

- **The Conative Perspective**

A series of conative issues are raised when Cathy is asked if she believes the information presented about the risks Radon presents:

*Interviewer:* Do you believe this knowledge?
*Cathy:* I don’t think it’s false, because I think it’s a government leaflet but as far as I can tell they are trying to sort of play it all down.

*Interviewer:* How are they playing it down?
*Cathy:* Yes, well I feel that the presentation is such that they’re trying to, not lie, but be being economical with the truth- that’s the way of putting it. It definitely leaves you with the impression of wanting to know more

(Cathy, Group B)

Cathy finds it difficult to believe that the information given is a misrepresentation, but she accepts that it may offer a particular view point. She uses her image of the source of the information, the government, to judge the information’s validity. Her image of the government suggests that they may wish to minimise the Radon issue, but are unlikely to tell an outright lie. Cathy *trusts* the information with certain reservations. *Trust* provides the information with the status that it ought to be believed.
Interestingly, Cathy doubts information when it is over-simplified. In the following extract of her transcription she expresses these doubts:

**Interviewer:** What do you think about this information?

**Cathy:** Well at first glance it is informative, but - then upon closer inspection you notice that apart from this lifetime chart there aren't actually any, you know, it doesn't actually tell you what the Radon concentrations are. I mean this is all rather vague and pretty wishy-washy-really.

**Interviewer:** What sort of thing would you have liked?

**Cathy:** It would have been nice to have equal scales and perhaps even put the becquerels, or whatever they are called, up the sides. And with this, you know, add a scale so that you can judge. The information presented is very misleading.

(Cathy, Group B)

In this case, it is the style of presentation which causes Cathy to doubt the information provided and this lowers its status.

### 9.7.3 CASE STUDY TWO: MARK

Mark judges himself to be quite interested and a little informed about science. He frequently watches science television programmes (including *Tomorrow's World*, *BBC TV*) and occasionally reads about science in the newspapers. He never reads specialist science magazines. Mark has an A-level in Biology and is currently studying social policy to degree level. He found out about Radon from the local news on television and in a regional newspaper. He lives in Devon and the Radon levels in his house have not been measured.

Mark estimates that he spent 20 minutes reading the leaflet and admits that he tended to skip over some parts because he feels sufficiently informed already about Radon. He was enthusiastic and animated during his interview.

- **The Cognitive Perspective**

In his previous interview (T1), Mark displayed an undifferentiated conception of radioactivity. He described the harmful affects of radioactivity in terms of
contamination. In the following extract of his interview (T2) he articulates how his conceptions have changed:

_Interviewer:_ What did you find out about Radon from reading the leaflet?

_Mark:_ Well, I've changed the actual chemical structure, the way I look at it from the previous interview

_Interviewer:_ What in particular?

_Mark:_ Well it [the leaflet section 2] says about the alpha particles which come from the Radon and can cause the damage [...] It explains about lung cancer and how Radon can cause or give you lung cancer. It basically explains that it is the alpha particles which affect the inside of the lungs and not directly the gas [Radon].

(Mark, Group B)

Mark, now, associates the harmful effects of Radon with alpha particles - a differentiated conception of radioactivity. Clearly this conception is _intelligible_ to him. His transcript contains no direct evidence to judge if he finds this differentiated conception _plausible_, although a positive inference can be made in that he appears to believe and use this conception. He is able to use his undifferentiated conception of radioactivity to explain the effects of Radon on the lungs. This provides evidence that the conception is _fruitful_.

This is an example of conceptual change, although a point of debate might be the extent of change. Mark now displays a differentiated conception about Radon [i.e. he separates the source, Radon gas, from the radiation, alpha particles]. This type of conceptual change would appear to be more radical than the kind of _conceptual addition_ presented in Cathy's interview. This compares with a shift in thinking about radioactivity of a more fundamental kind, a type of _'conceptual capture'_ as described by Hewson and Hewson (1991).

- _The Affective Perspective_

Mark has lived in a Radon area for a long time and does not consider Radon to be either a _salient_ or _germane_ issue. The following extracts of his interview illustrate his lack of interest in the subject:
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*Interviewer:* Did you find the information interesting?
*Mark:* Not really, I mean I have seen leaflets on Radon before and we’ve had some at our house - we don’t really bother reading them.

*Interviewer:* Have you changed your view after reading this one?
*Mark:* I haven’t changed my view because I am one of those people who realise it is not overly dangerous and its not in huge amounts. In the South West it has been rather over emphasised in the past.

(Mark, Group B)

Mark considers Radon information to be of low emotional status. At another point in his interview, when asked directly about his feelings, Mark appears ‘cold’, and contrasts his reaction with the hot reactions of others.

*Interviewer:* What are your feelings about Radon?
*Mark:* I am not too bothered about Radon, but when you mention it to the public they think “my God”, you know, “dangerous stuff”. I think this leaflet is good because it allays fears on the presence of radiation.

(Mark, Group B)

Radon information is not of a high affective status for Mark and does not generate further questions:

*Mark:* [the leaflet] It doesn't generate questions - I think some people may think that Radon is a major problem, especially in the South West, and they would see these peaks on graphs in areas like that. I think it would be slightly more that although there is a risk it is minimal and it's only in areas of very high concentration. Personally I am not that interested in find out any more about it.

(Mark, Group B)

Radon is not a subject that Mark currently attributes a priority. It is not a subject which is *germane* to him. In the proposed ECCM terms, the subject currently lacks relevance and this lowers the affective status he attributes to it at this time.
• The Conative Perspective

Because Radon is not a concern, Mark is not interested in the reduction techniques mentioned and he is unwilling to engage in a detailed consideration of these sections of the leaflet. He responds to a direct question which asks if he believes the information provided. He replies:

Mark: I believe most things, but that's just me, I'm very gullible. I do disbelieve statistics. It [the Radon leaflet] doesn't go into too much detail. It needs to explain how Radon can be reduced rather than just what is Radon and the risk and explain there is a low risk.

(Mark, Group B)

This extract shows evidence for trust, Mark has no reason for disbelieving the information presented. Nevertheless, he is concerned about the level of the information and would prefer information which is more detailed and covers other areas rather than just about Radon. This extract provides some evidence that Mark considers Radon reduction information as important, or higher status. When pressed, he refers to the need for knowledge to be practical (or actionable):

Interviewer: Why should it explain about Radon reduction?
Mark: Because its important to find out about how you can reduce your Radon levels if the need arises.
Interviewer: And what about the science of radioactivity, is it important to know about this?
Mark: No, I don’t think it really is, you can’t use this, so why bother?

(Mark, Group B)
9.7.4 CASE STUDY THREE: DAVID

David is very interested in science and perceives himself to be quite well informed. He frequently watches science television programs and reads scientific articles in newspapers. He occasionally reads specialist science magazines. David has 3 GCSEs in science. He found out about Radon from the television and this Radon leaflet. He judges himself to be a little informed about Radon. He is unsure but thinks that his house has been tested. His parents tend to deal with household matters. David has lived in Devon all his life.

David estimates he spent about 30 minutes reading the leaflet and appears interested in its content.

- The Cognitive Perspective:

David was unaware of how common and widely spread Radon is. He lives in Exeter and had not previously associated this area with high levels of Radon. In the interview-about-scenario study (T1), he displayed a differentiated conception of radioactivity. David is able to represent the radioactive decay chain which is depicted in the second section of the leaflet - it is an intelligible conception (T2).

Interviewer: Can you explain this picture to me?
David: Yes, it represents a radioactive decay chain for Radon [...] Radon decays into polonium and then eventually lead. I mean it's a typical radioactive decay chain, much the same way as other radioactive substances would also decay. I mean there are some parts here where it appears not to give out any type of radioactive particles - is that something that is unusual?

(David, Group B)

David finds the information 'fits' with his knowledge of radioactive decay. He believes the information; it makes sense to him. This provides evidence for the condition plausible. David makes comparisons with knowledge that he has of radioactive substances and this provides some evidence that the conception is fruitful. Radioactive decay is a conception with a high cognitive status. However, the decay
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chain presented is partially complete and only displays the alpha emissions and this causes him concern.

David explains the causal effects of Radon. He is also able to represent the information presented on the risks of exposure, however, he finds it difficult to accept this information. In the following excerpt of his transcription, he is rationalising these beliefs:

**Interviewer:** What do you think about the risks associated with Radon?
**David:** I'm not too bothered, it isn't an issue, we are probably exposed to more radiation within London, but it is in a different form - chemical smog and things like that. The air in the centre of London is horrible, at least in the South West you can breathe

**Interviewer:** The leaflet suggests that there is an increase in lung cancer in Devon and Cornwall, do you believe this?
**David:** I wouldn't have thought so.

**Interviewer:** Why not?
**David:** Well, although there is high levels of Radon radiation there's also lots of clean air which doesn't cling to your lungs so much. I think the leaflet needs to give a national picture and not just concentrate on the South West.

(David, Group B)

David is able to represent the risks but finds it difficult to accept them, suggesting that David finds the risks **intelligible** but **implausible**. His risk conception seems to have a low cognitive status.

- **The Affective Perspective**

David’s responses were factual in nature. He has known about Radon for a while and does not consider it to be a **salient** or **germane** issue. The following extract of his transcription illustrates his lack of concern (David, Group B):

**Interviewer:** How do you feel about this information?
**David:** I am not too bothered really, I knew a little about Radon before and I don’t really need to know any more

**Interviewer:** Why not?
**David:** Well... its not that important - I really don’t see it as an important issue.
This is evidence that Radon is not *germane*. In his interview, there is no evidence to suggest that David is unwilling to learn about the risks associated with Radon but rather, it is a subject which in ECCM terms has a low affective status. His phrase: 'I don't really need to know any more' suggests that this influences his learning. For David, the information about Radon is not considered to be of a high status, principally because it is not *germane*. He appears satisfied with his current conceptions and has temporarily frozen his learning.

* The Conative Perspective

Radon does not offer a health threat and consequently David does not feel that it is a subject which warrants practical solutions. His interview contains no evidence to suggest that he considers *actionable* or *controllable* knowledge to be of high status in this area. David's considerations of the subject tend to be of academic curiosity. However, he raises one issue about the source of information when discussing the Action Level (NRPB, 1995):

*Interviewer:* ... it mentions the Action Level here what does that mean?
*David:* I would have called it safe Becs. I think it is the maximum exposure without having any increased chances of lung cancer. But this all depend on who is defining it. To tell you the truth, I mean some people might define it higher.

*Interviewer:* Who might define it higher?
*David:* Anyone trying to cover it up like the government or the nuclear scientists.

*(David, Group B)*

David perceives the Action Level to be the level up to which Radon concentrations are safe. He recognises that this figure will depend upon the source of information and suspects that the *government* or the *nuclear scientists* might set a higher levels to cover the information up. David is judging the reliability of the figures presented by considering their institutional sources. His reasoning suggests that he perceives the government or the nuclear scientists are less *trustworthy*.
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9.7.5 **CASE STUDY FOUR: FIONA**

Fiona is quite interested in science and judges herself to be a little informed. She enjoys watching science television programmes, in particular nature programmes. Fiona has an O/A level in human biology and an O level in physics. She does not live in a Radon affected area, but visits Cornwall regularly on her holidays.

Fiona estimates she spent 20 minutes studying the leaflet. She appears very interested and surprised by the leaflet’s content. She had not heard about Radon before her participation in this study.

- *The Cognitive Perspective.*

In her previous interview (T1) Fiona displayed an un-differentiated conception of radioactive decay. She also displays this view in her present interview (T2). Fiona realises that Radon is a naturally occurring radioactive gas, but finds it difficult to understand the leaflet’s representation of the Radon decay chain.

*Interviewer:* What is Radon?
*Fiona:* Radon is the gas that's produced from uranium which is found either in the soil or in rocks.

*Interviewer:* Can you explain this picture to me? [the diagrammatic representation of radioactive decay chain]
*Fiona:* I must admit, that I didn't understand that to be honest. Yes, yes, it's obviously the different stages, I mean the numbers seem to have some importance - they are going down - which is probably indicates the stages of decomposition it goes through, maybe. I think it's probably something that's radioactive because they talk about Alpha and Alphas are rays and radioactivity is to do with rays, I think, but I mean it doesn't really make all that much sense.

(Fiona, Group A)

Fiona is attempting to make sense of the information presented, however, she finds it confusing. She is unable to represent her ideas meaningfully, radioactive decay is not presently intelligible.
In comparison, when asked to consider how Radon levels vary in homes Fiona is able to represent the information covered.

*Interviewer:* Can you explain this section of the leaflet to me please?
*Fiona:* Yes, this makes sense it's talking about [when] the pressures inside the house are less than the pressures outside then it draws it [Radon] into the house. This relates to all these charts which explain how the levels vary when the door's open. It's highest in the morning when the family gets up and obviously everythings tightly shut and nothing's been open and there is no air circulation. It is lowest in the summer months, which again rather implies the doors are open and the air is circulating round it [the house].

(Fiona, Group A)

The ways in which Radon levels vary with time of day Fiona finds intelligible. She is able to explain these ideas and is 'comfortable with' the different patterns of Radon levels. Evidence for plausibility comes from Fiona’s acceptance of these ideas, it 'makes sense'. Fiona uses her knowledge of how ventilation affects Radon concentrations to explore how the levels vary in different seasons - these ideas are fruitful to her. Fiona’s conception of how ventilation affects Radon appears to have a high cognitive status.

*The Affective Perspective*

During the interview (T2), Fiona makes numerous affective statements. In this context, she appears to have an emotional basis to learning - she is a 'hot' learner (Chapter Six). At the start of the interview, Fiona expresses some of the emotions which the leaflet raises:

*Interviewer:* Did the leaflet answer your questions?
*Fiona:* It did tend to answer my question and it led you on. In reading it you tended to find that it would raise a question in your mind and then bang the next paragraph was answering that question. You know it obviously raised issues of God this is awful what's being done about it, or what can I do!

(Fiona, Group A)
Fiona found the leaflet discomforting. In the following extract she refers to the average Radon levels in UK homes which is given as 20 Bq/m3.

Fiona: Yea, I honed in on that because I was surprised that we live and breathe this stuff every day - it's around us. There's twenty - whatever the equation is, around us the whole time it's only when it reaches two hundred that they're [The NRPB] talking panic.

(Fiona, Group A)

Although not living in an area associated with high levels, Fiona is concerned about the average levels provided. This information appears salient to her. By stating that she 'honed in' on this information she indicates how her feelings are influencing her learning. There is also evidence that she finds this information germane. Fiona's statement 'what can I do' implies that the information is both important and relevant to her (as well as actionable and controllable). Information about Radon levels seems to have a high emotional status for Fiona.

Later in the interview, Fiona places herself in the position of somebody living in an area with high Radon levels. She expresses an 'ignorance is bliss' viewpoint by suggesting that her reaction would be to 'block out' information about Radon.

Interviewer: The leaflet covers Radon reduction mechanisms, can you tell me about these?

Fiona: Yes, I mean, it talks about having the option of having somebody come out to assess your house and measure it [...] If I was living in a Radon area I would have stuck my head in the sand and forget about it - I can't see it, can't feel it, and don't feel poorly so it's all right - why bother about it?

(Fiona, Group A)

This type of response provides evidence for the ECCM condition palatable. It is also an illustration of how the affective can override the cognitive. A potentially threatening environment may cause learners to freeze their learning.

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• The Conative Perspective

Extracts of Fiona’s interview previously cited in the affective analysis also contain conative evidence. When Fiona states: ‘what’s being done about it, or what can I do?’ she is expressing a need for information which she can be used to ameliorate her situation. This shows evidence of the condition control. Trust is a particular issue for Fiona and occurs at several points in her interview. When considering the reduction techniques she is concerned that there may not be sufficient ‘facts’ to support the techniques suggested.

Interviewer: Do you believe this information?
Fiona: Not really, if I was living down there and I was offered to have a pump installed in my house, or air blown through the loft, I think I'd move. I think that if they'd go to that sort of extreme it obviously recognises there's a serious problem. I'd be worried whatever measures they took. I'd sort of feel well this is all well and good but do we have any facts to show this is actually working.

(Fiona, Group A)

Her comments, at a later point in the interview, consider the risk statistics provided:

Fiona: I think they'd probably been engineered for whoever this was made for. Being statistics you can read into anything you want. You know, I think there's an element of jigging figures. I mean I wouldn't say they were untruthful, but it's obvious they don't want to totally scaremonger people.

(Fiona, Group A)

In her final extract, she explains why it is important to be aware of the source of information. Statistics appear less trustworthy than other sorts of information. To have a balance, she maintains that, one needs to seek advise from contrasting points of view - sources of information with contrasting attitudes to the nuclear industry.

Fiona I think you’d have to establish whether or not the leaflet is linked with the company that had written it. If you want to have an unbiased approach you could take two extremes - you could go to Greenpeace who would give you facts for an anti nuclear view point or the government who will be pro-nuclear. I think they will both use figures to back up their arguments and you’d need
to go to these two extremes to get a balanced view point.

(Fiona, Group A)

9.8 SUMMARY AND DISCUSSION

Phase four of the data collection comprised 10 case studies. In each of these studies an abundance of data was collected and analysed. The data has two forms:

1. Evidence for an epistemological commitment - in consonance with the original CCM (Strike, Posner et al. 1982) the link between epistemological status and conceptual change learning is then taken as axiomatic.

2. Evidence for an epistemological commitment and evidence of how this commitment may have influenced learning.

In both forms the data provides rich evidence that learning can be meaningfully explored from a number of different perspectives.

This study has sought to refine conditions which influence conceptual status. In each of the case studies, evidence was collected in support of the ECCM conditions, as outlined in Chapter Eight.

The evidence assembled endorses the conditions intelligible, plausible and fruitful as originally proposed by Strike, Posner et al. (1982) and elaborated by Hewson (1991). When a comparison is made with the results of phase 2 of the data collection, the IAS interviews (T1), two examples of conceptual change are identified. The more radical conceptual capture and the less radical conceptual addition (Hewson and Hewson, 1991).

The original CCM is a cognitive model of conceptual change, it suggests that learners approach learning with the goal for new intelligible, plausible and fruitful ideas which add to their conceptual models. The evidence presented here suggests that, in addition,
learners have affective and conative epistemological commitments and these play a part in their learning.

Evidence where learners focus on specific parts of the leaflet has been presented, 'what we should know for our homes' (Lorraine), 'what can be done about it' (Melika), 'how you can reduce Radon levels if the need arises' (Mark). In these cases, learners actively and rationally seem to be selecting information which they consider empowering, practical or conative. In ECCM terms, these learners are displaying a conative epistemological commitment - they are selecting or rejecting information based on its conative status. The ECCM claims that conceptions with a high status are more likely to be acquired.

During the analysis a series of conditions were isolated that influence conative status, or conative worth. Evidence has been provided which supports the conditions actionable, controllable and trustworthy. An analysis of the judgement of trust appears to be influenced by three factors: 1) the institutional source of the information; 2) the type of information; and 3) the presentation and depth of the information.

Traditionally, studies of conceptual change conducted in formal educational settings use the question “Do you believe this?” as a probe for the condition plausible. In these cases, the focus is on the intellectual integrity of an idea (see for example Hewson and Hennesey 1991, p177). In comparison, in this study, the same probe “Do you believe this?” initiates discussions of trust. This highlights an important distinction between formal learning where trust is presumed and un-questioned and informal learning where trust is questioned and faltering.

In most cases, the conceptual change learners have been fairly factual and 'cold' in their discussions. This is perhaps to be expected because the majority of the participants have been living with Radon for a number of years. Nevertheless, in each case there was direct evidence of affective influences and the data presented supports the ECCM conditions salient, germane and palatable as documented in Chapter Eight.
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Particular aspects of the leaflet were surprising or eye-catching and this provided evidence for the ECCM condition *salient*. For some participants information about risks is *salient*, whereas, for others they are over-emphasised. The sense of relevance and the need to know more was acute in all cases. In the ECCM this is represented by the condition *germane*. In general, practical information was considered *germane*.

The leaflet was considered approachable - the content was *palatable*. Although, learners who were unfamiliar with Radon, those who were not from Radon areas, were markedly more emotional in their responses. Fiona’s comment ‘I would have stuck my head in the sand and forgot about it’ is a ‘hot response’ and an illustration of how the affective can dominate the cognitive. In ECCM terms, this is interpreted as the affective condition *palatable* lowering the status of new information and as a consequence learning is temporarily abandoned.

In summary, these results lend credibility to the idea of studying conceptual change from cognitive, affective and conative perspectives. The research documented has provided evidence for: a) the reaffirmation of the cognitive conditions *intelligible*, *plausible* and *fruitful*; b) the emergent conative conditions (*actionable*, *controllable* and *trust*) and affective conditions (*salient*, *germane* and *palatable*). A multi-perspective analysis is both data rich and revealing.

### 9.9 A CRITIQUE OF INTERPRETATIONS

Throughout the analysis it is important to maintain an appropriately critical perspective. Hewson and Thorley (1989) emphasise that evidence of conceptual status cannot be decided from conceptual comments but requires comments *about* conceptions. The researcher can then *infer* conceptual status by considering these second level comments. At times during the analysis the data is convincing and the learners’ descriptors are clear and abundant; for example using statements like ‘I don’t understand this...’, ‘to me, the most important information advice I can act on’ provide direct evidence for the conditions *intelligible* and *actionable*. However, at other times, there is only a limited amount of direct evidence and the analysis relies more heavily on interpretation.
In many cases of affect the evidence is in tone and emphasis used (disgust or surprise) or in body language (a frown or dismissive hand movement). Consequently the words used, when presented flat and unadorned on the page, give fewer clues to their emotional weighting. The interpretation here comes from the authors observations and readings of the interviewees as they made their comments. Understandably, this is indirect evidence - better to have respondents comment on their feelings - but has nevertheless influenced the analysis.

It is also possible to be critical of the extent to which this study is actually a study of informal learning. In this study the motivation to learn stems, in-part, from the research. Participants were requested to read the Radon leaflet. This motivation is likely to be different to that of an 'informal setting'. The extent to which this methodological compromise has 'tainted' the data will remain unknown. However, the fact that the majority of the participants were selective in their learning would seem to indicate that their motivations are more than simply complying with the instructions provided. However, this last point is worthy of further contemplation and in the next stage of the data collection learning is considered in a more naturalistic manner. In this final phase of the study, attention is given to learning in the informal setting of a Somerset village.
CHAPTER TEN
LEARNING IN A SOMERSET VILLAGE

10.0 INTRODUCTION

This chapter presents the results of the final phase of the data collection, phase 5. This phase represents a shift into a more informal arena as the Extended Conceptual Change Model (ECCM) is used to analyse informal learning for a sample of residents of a small rural village in a Radon area.

Within the context of an area with high Radon concentrations, the research is driven by the broad question:

- Can the Extended Conceptual Change Model be used to describe informal learning about Radon in this rural village?

The method of data capture employed is semi-structured interviews which engage the villagers in a discussion about their learning. This discussion explores sources of information, understandings and epistemological commitments.

10.1 THE VILLAGERS

The English county of Somerset is judged to have a 1% probability (or more) of houses having a Radon concentration above the 200 Bq/m³ action level (NRPB, 1996). This 'affected area' has been the location of the third phase of the NRPB's and DoE's Radon surveys (NRPB, 1997). The results of these surveys have already been presented in Chapter Two.

The interviewees are all adult residents of a small rural Somerset village located towards the east of the county. Radon has received considerable local publicity both as a consequence of recent circulars and offers of measurements and also because the
county is located next to Devon and Cornwall, geographic areas which have previously been the focus of Radon measurements.

The village has a close-knit community of approximately 50 adults. It is an attractive village in a sought-after location; the houses are constructed from local stone and many date back to the 18th century. The village is clustered around a small Norman church and a duck pond. All the houses are privately owned and the residents are mainly professional families, social groups A and B (airline pilots, company managers, nurses, farmers and a policeman). There is a local Airforce base which provides nearby employment and as the village is approximately 2-3 hours from London and many residents commute on a weekly basis.

The adult residents of the village were contacted through one member of the village who herself formed part of the interview sample. The self-selecting sample is formed from those who agreed to be interviewed and who were available during the data collection week in August 1996. In total, seventeen in-depth interviews were performed. The village contact kindly arranged the schedules for these interviews. A 'personal approach' was considered an advantage due to the potentially sensitive nature of the subject. The interviewees' names have been changed to allow anonymity and for similar reasons the location of the village is not provided.

Table 10.1, displays the villagers' personal details: ages, occupations and levels of formal science qualifications. The sample consists of 6 males and 11 females. More females were interviewed than males because they were available during the data capture week - several males were away on business. Five couples were interviewed and these are indicated by the brackets (see table 10.1). The participants span a wide range of ages although the majority are in their 30's. This is broadly representative of the adult population of the village.

The villagers' science qualifications range from 'none' to degree level: 7 [41%] have school level qualifications (GCSEs or O levels), 3 [18%] post 16 qualifications (A levels), 6 [35%] higher qualifications (degrees, vocational qualifications) and 1 [6%] has no science qualifications. These qualifications are higher than the UK average but
are broadly representative of qualification levels in the corresponding social groups (OfNS, 1996).

The forth column of table 10.1 documents whether the participants recall receiving the NRPB Radon ‘At-a-Glance’ leaflet (NRPB 1995) - ‘yes’ is represented by the symbol (√) and ‘no’ by the symbol (X). In total, 14 [88%] villagers recalled receiving the leaflet. This is higher than the results documented by the DoE (1994) who found that approximately half of the residents of Devon and Cornwall recalled receiving a Radon leaflet. However, this might be expected because, as the DoE report (1994, p29) notes, residents from social groups A & B, who own property tend to take greater interest in Radon.

The final column indicates whether the resident proceeded with a Radon measurement. The villagers live in 12 different houses, of these 7 have been surveyed, none recorded above the UK Action Level (200 Bq/m^3). That said, a number of the measurements were recorded above the US Action Level set at 150 Bq/m^3. 5 Houses have not been tested; 3 from conscious choice and 2 from a lack of awareness of the testing procedures.
TABLE 10.1 Personal details about the villagers.

<table>
<thead>
<tr>
<th>Name</th>
<th>Sex</th>
<th>Age</th>
<th>Occupation</th>
<th>Qualification in science</th>
<th>Radon leaflet*</th>
<th>Radon Test details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chris</td>
<td>M</td>
<td>36</td>
<td>Policeman</td>
<td>GCSE General Science</td>
<td>✔</td>
<td>Elected for test, level found below Action Level</td>
</tr>
<tr>
<td>June</td>
<td>F</td>
<td>35</td>
<td>Medical Secretary</td>
<td>GCSE in Biology</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Paul</td>
<td>M</td>
<td>38</td>
<td>Naval Officer</td>
<td>A level Physics</td>
<td>X</td>
<td>Unaware of the test.</td>
</tr>
<tr>
<td>Alan</td>
<td>M</td>
<td>37</td>
<td>Civil Pilot</td>
<td>A level Biology, Aeronautical Qualification</td>
<td>✔</td>
<td>Elected for test, level found below the Action Level</td>
</tr>
<tr>
<td>Claire</td>
<td>F</td>
<td>32</td>
<td>Home Keeper</td>
<td>O level Biology</td>
<td>✔</td>
<td>Elected for test, level found below the Action Level</td>
</tr>
<tr>
<td>Nigel</td>
<td>M</td>
<td>33</td>
<td>Company Director</td>
<td>O level Biology, O level Physics, Chemistry and Biology</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandra</td>
<td>F</td>
<td>36</td>
<td>Home Keeper</td>
<td>A level Biology and Chemistry</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>David</td>
<td>M</td>
<td>50+</td>
<td>Retired Naval Officer</td>
<td>A level Physics</td>
<td>✔</td>
<td>Aware but did not elect for a test</td>
</tr>
<tr>
<td>Deborah</td>
<td>F</td>
<td>50+</td>
<td>School Caretaker</td>
<td>Diploma in Domestic Science</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Linda</td>
<td>F</td>
<td>40</td>
<td>Home Keeper</td>
<td>None</td>
<td>✔</td>
<td>Elected for a test, level found below Action Level</td>
</tr>
<tr>
<td>Susan</td>
<td>F</td>
<td>33</td>
<td>Aerobic Instructor</td>
<td>O level Biology and Physics</td>
<td></td>
<td>Elected for test, did not return the detectors</td>
</tr>
<tr>
<td>John</td>
<td>M</td>
<td>38</td>
<td>Cabinet Maker</td>
<td>A level Chemistry and Biology</td>
<td>✔</td>
<td></td>
</tr>
<tr>
<td>Rachel</td>
<td>F</td>
<td>28</td>
<td>Home Keeper</td>
<td>GCSE General Science</td>
<td>X</td>
<td>Unaware of the test.</td>
</tr>
<tr>
<td>Helen</td>
<td>F</td>
<td>34</td>
<td>Nurse</td>
<td>A level Biology, SRN</td>
<td>✔</td>
<td>Elected for test level just under the Action Level</td>
</tr>
<tr>
<td>Mary</td>
<td>F</td>
<td>43</td>
<td>Chartered Accountant</td>
<td>O level Biology and Chemistry, Degree in Business Studies</td>
<td>✔</td>
<td>Aware, but did not elect for the test</td>
</tr>
<tr>
<td>Hannah</td>
<td>F</td>
<td>50+</td>
<td>Home keeper</td>
<td>O level General Science</td>
<td></td>
<td>Aware, but did not elect for a test</td>
</tr>
<tr>
<td>Liz</td>
<td>F</td>
<td>36</td>
<td>Farmer</td>
<td>A level Biology, Degree in Food Science</td>
<td>✔</td>
<td>Opted for test, level found below Action Level</td>
</tr>
</tbody>
</table>

* The NRPB 'Radon-at-a -Glance' leaflet (NRPB 1995): ✔ indicates that the participant recalls receiving the leaflet, X not.
10.2 METHODOLOGY

In Chapter Nine, the study of conceptual change involved an analysis of conceptions before and after a controlled and structured intervention. The extent to which this approach is truly representative of informal learning was raised. Informal learning is unlikely to consist of a series of structured, progressive and controlled educational interventions. It is much more likely to be opportunistic and un-structured (Layton et al., 1993). When considering informal learning it is difficult to define singular times of before and after because informal learning is essentially continuous. In this study, rather than imposing a structured learning intervention, resulting in a methodological compromise, the author decided to look at the participants after their recent informal learning experiences. The aim was to engage the participants in a discussion of their learning and the sources of their information. These discussions aimed to explore the understandings the villagers associated with Radon as well as the epistemological commitments they attribute to these understandings.

10.3 THE INTERVIEW QUESTIONS

The method of data capture was semi-structured interviews (Powney and Watts, 1987). These were usually about an hour in length and tape recorded onto audio cassette. The interviews are ‘non-technical’ (Hewson and Hewson 1991, see Chapter Nine) - i.e. the interviewees were not conversant with the language of the ECCM model, although the interviewer explicitly elicited comments about the participant’s learning from each of the cognitive, conative and affective perspectives.

A pilot study of 5 ‘non scientific’ adults (not included as part of the final research sample) was used to check and develop the interview protocol. This protocol can be divided into four phases, although these were not necessarily sequential. For illustration, Table 10.2 presents a list of the main questions used.
TABLE 10.2, Indicative interview protocol divided into conceptual and three ‘meta-conceptual’ perspectives.

<table>
<thead>
<tr>
<th>Conceptual</th>
<th>Cognitive Commitments</th>
<th>Affective Commitments</th>
<th>Conative Commitments</th>
</tr>
</thead>
<tbody>
<tr>
<td>• What is Radon?</td>
<td>♦ What do you think about this conception?</td>
<td>♦ How do you feel about this conception?</td>
<td>♦ How useful is this information/ conception?</td>
</tr>
<tr>
<td>• What does it look like?</td>
<td>♦ How understandable is it?</td>
<td>♦ How do you feel about learning about Radon?</td>
<td>♦ How practical was the advice offered? Why?</td>
</tr>
<tr>
<td>• Can you smell it; taste it; see it;</td>
<td>♦ Does it make sense, do you believe it?</td>
<td>♦ Why do you feel this way?</td>
<td>♦ Do you believe the information? Is it an accurate representation? Is it true?</td>
</tr>
<tr>
<td>• How does it travel?</td>
<td>♦ Does it fit with other ideas?</td>
<td>♦ Did any of the information stand out?</td>
<td>♦ Can you make decisions using this idea? Can you adapt it to meet your needs?</td>
</tr>
<tr>
<td>• What makes it radioactive? - what does it mean to be radioactive?</td>
<td>♦ Why does it make sense?</td>
<td>♦ Did you find any thing surprising?</td>
<td>♦ Can you offer people explanations and advice with this idea?</td>
</tr>
<tr>
<td>• How does Radon compare with, for example, the radioactive waste from a nuclear power plant?</td>
<td>♦ Can you apply these ideas to other science ideas?</td>
<td>♦ Was the information important and relevant?</td>
<td></td>
</tr>
<tr>
<td>• Where does Radon come from?</td>
<td></td>
<td>♦ Was it an idea you could relate to?</td>
<td></td>
</tr>
<tr>
<td>• How does it come out of the granite..</td>
<td></td>
<td>♦ Was it an idea you could deal with?</td>
<td></td>
</tr>
<tr>
<td>• Why is it potentially dangerous?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• The Department of the Environment and the National Radiological Protection Board have set an Action Level - what does the Action Level mean?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>• If a neighbour of yours has a high level of Radon in their house how would you advice them to find out about it?</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
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The conceptual questions explored the participants' understandings of Radon. The target concepts are those which are widely available and have been explored in previous chapters. Subdivided into *Radon-in-general* and *Radon-in-practice*, the areas explored were:

1. **Radon-in-general**: - *The entity*: its appearance and method of travel,  
   - *Causation*: the harmful affects of Radon.

2. **Radon-in-practice**: - Radon testing procedures,  
   - The Action Level,  
   - Practical advice offered to a neighbour.

Questions about conceptions sought to elicit comments about epistemological commitments. In accordance with the ECCM, these commitments were explored from cognitive, affective and conative perspectives. The interview questions are derived directly from the ECCM condition descriptors listed in Table 8.5.

### 10.4 THE APPROACH

Villagers were interviewed singularly in the comforting setting of their own homes. The pre-interview started by outlining the study and stressing its confidentiality and then collected general details about the participants and explored the sources of their Radon information. These data were entered on a pre-prepared sheet. This was followed by the main interview where each participant was asked a series of questions about their understanding of Radon. The question order was the same for each participant (as presented in Table 10.1) After each conceptual question the interviewer probed for epistemological commitments and throughout the interview, where necessary, clarification and elaboration was sought. The concluding stage of the interview was open-ended and discussed any questions the participants' raised.

Each respondent engaged with the study with enthusiasm and the interviews often lasted an hour and then continued informally for up to an hour after the tape recorder was switched off. The participants welcomed the opportunity to discuss their learning
as well as finding out more about Radon gas. Each interview was then transcribed in full, using standard conventions (Powey and Watts 1987).

10.5 THE ANALYSIS

The analysis consisted of 4 stages (these stages are identical to those described in more detail in Chapter Nine). The data was studied in depth to elicit the participant’s meaning and statements of conceptions and epistemological commitments were coded. The coded data was then used to infer conceptual status. Finally, each interview was revisited to check and harden the coding process.

This process was performed independently by two researchers and these results were then compared and discussed. In cases of discrepancy, either agreement was reached or the data was not considered reliable and as a consequence was not used.

10.6 PRESENTATION OF THE RESULTS

The analysis provided a raft of conceptual and conceptual commitment data. The data was extremely contrasting and idiosyncratic. Some villagers were very knowledgeable about Radon while others were extremely unsure of its properties other than the hazard is may present. The villagers’ comments about their epistemological commitments were heavily contextualised - different villagers associate different commitments to different understandings. Sometimes, in a single sentence a learner would slip between several ECCM’s status conditions.

In this chapter, the data is represented by; i) providing an overview of each learner and documenting significant epistemological commitments; and ii) exploring these commitments in more depth in 4 case studies.

Four case studies have been chosen because they broadly represent the 17 people interviewed - each study highlights a particular facet of the ECCM. Other cases from this study have been published elsewhere (see Alsop and Watts, 1997).
10.7 VILLAGERS AS INFORMAL CONCEPTUAL CHANGE LEARNERS

To provide an overview, in the following 17 paragraphs the key features of each learner are summarised. These descriptions are supplemented with a vector representation of the learner's epistemological commitments. In this representation, the y-axis represents cognitive status, the x-axis affective status (+ve and -ve) and the z-axis conative status (+ve and -ve) - (see figure 10.1 and Section 8.8)

The aim is to use the ECCM to provide an overview of each learner's cognitive, affective and conative epistemological commitments when learning about Radon gas. However, learners frequently attribute different epistemological status to different Radon understandings, for example, June displays a strong emotional commitment to knowledge about 'reduction mechanisms' but a weak emotional commitment to more general details about Radon. In these cases, the representations provide a summary of commitments as judged by the researcher.
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**Chris**

Chris is interested in science and concerned about Radon. He has read the information provided by the NRPB, appears knowledgeable about the reduction techniques and has had a Radon test performed. Chris displays high cognitive commitments, his interview displays a range of evidence for the conditions *plausibility* and *fruitfulness*. For Chris, a sense of relevance is acute. He considers Radon levels and the reduction techniques to have a high status because they are *actionable* and *controllable*. Chris feels able to act on the information he has been provided with, but is concerned that he may not have been given the whole picture (he lacks trust). In general, Chris is judged to be a learner with positive cognitive, affective and conative epistemological commitments.

**June**

June has an interest in medicine and she recalls studying the NRPB information in some detail to ascertain any risks involved. Primarily concerned with the health of her young children, June considers health information to be of high status because it is practical (*actionable* and *controllable*). She lacks knowledge about the general science of Radon because she does not consider it important (it is not *germane*). Practical empowerment appears an important driving force in her learning. In ECCM terms, she considers conative information to be of high epistemological status.

**Paul**

Paul appears to be a confident learner of science. He has an interest in the subject and a detailed understanding of radioactivity. Paul displays strong cognitive commitments, he engages with the information provided because he considers it *fruitful* - he can use it to develop and extend his knowledge.
of the subject. Paul does not consider Radon to be a health concern and his affective and conative epistemological commitments are minimal. It is the lack of intellectual consistency in the information provided which raises the question of trust.

Alan seems interested in science and has a good understanding of radioactivity. He displays a differentiated conception of radioactivity and describes the causal affects of Radon in irradiation terms. Alan displays a commitment to understanding as much as he can about Radon and appears knowledgeable about the subject. He is a learner who attributes all Radon information with positive cognitive, affective and conative status.

Clare is not interested in science but is anxious about the risks involved with Radon. She studied the information provided in an attempt to reduce her anxieties. Clare’s emotional commitments have made the subject a high priority (she finds Radon salient). In ECCM terms, she has a strong conative commitment and information which she considers actionable is attributed high status. Clare has positive conative and affective epistemological commitments, although it is her feelings which appear to drive her learning of Radon.

Nigel seems interested in science but initially did not link Radon with radioactivity. He displays an emotional commitment to the subject because of the link it has with cancer. His father died of cancer and he thinks he may be more susceptible to the disease as a consequence. Nigel finds the subject both salient and germane. However, he feels he
lacks information and wants to learn more so he can act. He is critical of the information which is widely available because he perceives it too abstract.

Sandra is an enthusiastic learner, she has a fear of radioactivity because she considers it 'un-natural'. Sandra has a low fate control and is contented to leave the subject with the local authorities. She trusts the local authorities and reasons that they would not let people live in areas of significant health concern. Her trust in the local authorities and, above all, her perceived lack of control result in her disengaging with the subject. In ECCM terms, Radon is a subject with a significant negative conative status.

David has an interest in science. He is a retired naval officer and his job required a level of scientific expertise. He has a good understanding of radioactivity: he displays a differentiated conception and can explain the processes involved in radioactive decay in some detail. In contrast, he appears uninformed about Radon. David has lived in areas associated with high Radon levels all his life and as a consequence feels that it is not a subject worth worrying about now - it is neither germane or salient. It is not a subject that he feels he can now control. For David, in ECCM terms, information about Radon has a negative affective and conative status that appears to have hindered his learning at this point in time.

Deborah finds science difficult and displays weak cognitive commitments. She links Radon with cancer and displays an undifferentiated germ model of radioactivity. Deborah has strong emotional commitments, she is a 'hot' learner and is
concerned about the dangers involved. Deborah finds the subject un-palatable. She feels powerless to act on any of the information provided (lack of control) and consequently feels helpless in the face of the information provided. Deborah’s negative affective and conative status appear to override her learning.

Linda has no formal qualification in science and lacks an interest in the subject. She is, however, interested in health matters and as a consequence wishes to find out more about Radon. She considers information about local Radon levels and grants to be important because it is actionable and ‘useful’. She trusts the information provided.

Susan is a motivated learner of science. She wishes to find out as much as she can about Radon to make a decision. Radon is a salient issue due to the recent publicity and germane because it is a health threat. Information about Radon has a high affective status. Susan uses several sources of information to find out about the gas. She is a confident learner who, in ECCM terms, attributes Radon with positive affective, conative and cognitive status. Her conative commitments appear particularly significant.

John has a detailed understanding of radioactivity, he can explain the processes involved in radioactive decay and the causal affects. He has an academic curiosity about Radon - It is a subject which he finds intelligible, plausible and fruitful. He does not consider it to be a threat and thinks the risks are over emphasised - It is the high cognitive status which he attributes to Radon which drives his learning.
Rachel

Cog. +ve
Aff. +ve
Con -ve

Rachel lacks confidence in science. She is aware of the recent publicity but is unsure if Radon is radioactive. Rachel has not read the leaflets provided, she is a single parent, is very busy and trusts that the authorities would relocate people if it was a significant risk. Here, a lack of control, and a trust in the authorities appear to have influenced learning.

Helen

Cog. +ve
Aff. +ve
Con +ve

Helen is intrigued to find out more about Radon. She has read the information provided and has visited the local library. She is anxious about the threat it poses, in particular, because she lives in a house with a paved floor. Helen has a thorough understanding of radioactivity, however her understanding of Radon has tended to concentrate on the practicalities. She is willing to cognitively engage with the subject and wishes to find out more about risks and reduction mechanisms. Information which is actionable and controllable she attributes high status.

Mary

Cog. +ve
Aff. -ve
Con +ve

Mary is an emotional Radon learner. She is worried about radioactivity and extremely anxious about Radon. Mary has lived in Somerset all her life. She detaches from the subject because it not palatable. Mary appears to have 'frozen' her learning and constructed ignorance because she is frightened about what she might find out.

Hannah

Cog. +ve
Aff. +ve
Con +ve

Hannah recalls receiving leaflets about Radon. Her husband is builder who is now required to fit reduction mechanisms. She tends to leave Radon issues up to her husband - he considers the risks to be over emphasised. Hannah feels it is important to learn about Radon so you can do something about if the need arises.
Liz has a higher qualification in science. She has studied the Radon leaflet provided in some detail - it was the main source of information. She has lived in a Radon area for a number of years and has not seen or experienced any negative effects. Liz is a farmer's wife and her recent experiences with BSE have caused her to doubt risk calculations. She feels that, like BSE, the risks associated with Radon may be exaggerated. She has not read too much about Radon because she lacks trust in the materials available.

During each interview illustrations of the ECCM conditions were elicited, coded and these were then used to assign conceptual status. Overall, 11 of the participants were judged to have a positive commitment to Radon information and 6 a negative commitment. The following sections document four of these informal learners (Chris, Paul, Deborah and Susan) in more detail. These are learner's with different epistemological commitments and are broadly representative of the other learners interviewed. For each learner, evidence which has been used to support the ECCM's cognitive, affective and conative conditions is presented.

10.7.1 CASE STUDY ONE: CHRIS

Using the ECCM, Chris is judged to be an informal learner of Radon with positive cognitive, conative and affective epistemological commitments. Chris judges himself to be quite interested in science and will learn science if the opportunity arises. He received the information about Radon and went ahead with a Radon test because he was concerned about his safety and safety at home. The measured levels were found to be beneath the UK Action Level. Chris contrasts his eagerness with the ambivalence of his friends in the village:
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*Chris:* It was talked about amongst our friends here in the village. Some of them have got quite antiquated views on various things like Radon, but we are a farming community and the attitude of “it never killed anybody before, it never will kill anybody in the future” is rife here - maybe, who knows, we probably won’t know until it is all too late.

Radon is a serious subject which he considers important: it is a subject which he wishes to find out more about. Chris explains how he found out about Radon:

*Chris:* The word Radon I’ve heard in the past prior to the publicity but probably through my own ignorance I didn’t know enough about it. But whether there would have been the opportunity to find out about it I don’t know. I started to find out about it when it was in the news and there was such a big publicity over it and then the leaflets started coming out and the newspaper reports and television etc. etc. Hopefully this information has educated us enough to deal with the situation.

He recalls the media coverage and the leaflet and hopes this has provided him with enough information. Chris relies on the general media for information, like the majority of those interviewed, he is not active in seeking information but his learning is passive and opportunistic.

*The Cognitive Perspective*

Chris describes Radon as an a-sensory gas. He strongly associates the gas with granite, but is unaware of its link with uranium. Chris is willing to cognitively engage with the subject, in the following excerpt, he describes the physical appearance of Radon:

*Chris:* I believe Radon is a gas which comes form the ground, yes-from granite. Its a substance we can’t hear, see, smell or taste. It travels like most gases, really, as particles through the air. These are just my own thoughts, put together from reflections from right back in school days. I think it needs a lot more explaining to make complete sense.
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Chris relates his ideas back to his formal studies, this provides some evidence for the conditions plausible and fruitful, however, he feels his knowledge is somehow incomplete.

Chris displays an undifferentiated conception of Radon. He associates the casual affects of the gas with Leukaemia, a link which provides evidence for the conditions intelligible and plausible:

*Interviewer:* Why is it [Radon] potentially dangerous.
*Chris:* I'm under the understanding that radioactivity which is within Radon gas causes major health problems long term.

*Interviewer:* Such as - what sort of?
*Chris:* Basically leukaemia - that is the first word that comes to mind. I'm sure it maybe the possible reason for many other illnesses, that we possibly don't know about at the moment. It won't surprise me in 25 years time, when I'm a lot older, that the results may turn round and say well that's the cause of asthma all the way from the minor common cold all the way up - in some way.

Chris has a detailed knowledge of Radon reduction mechanisms and displays a 'statistical representation' of the Action Level (see Chapter Seven). He would not advise his neighbours directly about Radon gas but would encourage them to seek advice from the NRPB.

**The Affective Perspective**

Viewed from the affective perspective, Radon is a particularly germane subject for Chris, he feels it is essential to find out as much as he can about the topic. This motivation stems from the potential health risk it poses to him and his family.

*Interviewer:* Were you interested to find out about Radon?
*Chris:* Yes, I am very interested, because, as it is our environment that we live in - the house we live in, it is important to find out as much as possible about Radon for the family's future health.
Chris, is concerned about the subject of Radon, although after finding out more about the subject he feels less anxious. However, it still remains an emotive subject for both him and his wife.

Chris: I think the leaflets available allayed some of my anxieties about Radon, whether they were designed to do that or not, who knows. But, it certainly took the edge off it, but we, my wife probably more than me, carried on the fear.

Radon is an emotive subject for Chris, these emotions have raised the status of information about Radon, it is an important subject because it is both *germane* and *salient*.

The Conative Perspective

Chris feels that he is personally able to act on information about Radon to *control* his present situation, however, he doubts, the *truth* of the information he has been presented.

*Interviewer:* How do you feel about your knowledge of Radon?

*Chris:* Whether this sounds paranoid or not I don’t know, but, I think there’s more to be told about it. I think we’re not being told everything.

*Interviewer:* What makes you think that?

*Chris:* I’m just going on pure history of this country. I won’t say ‘Government’ because it doesn’t really matter which Government it is - I don’t think this country, at times, tells you enough! We’re going through a similar situation now with BSE. We’re told a little bit to start with, a little bit more, a little bit more and eventually - when its too late - when we’ve all been affected, then we’ll get the truth.

In this case, Chris’ engagement with science appears to be limited, not so much by his inability to cognitively rationalise the subject, but rather by a socio-institutional image he holds of *trust*. It would appear that Chris feels dis-empowered, because he perceives the information he has available is only telling ‘half of the story’. The judgement of *trust*, which appears based on the source of information (the Government), plays a significant role in Chris’ informal learning.
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ECCM terms, Chris considers Radon to be a high status subject which needs to be intelligible. The affective conditions (germane and salience) and the conative conditions (control and action) raise the status of Radon information. However, he feels that information which he is presented may not be a represent a complete picture. Trust partially lowers the conceptual status. Overall, Chris’ eagerness to find out more about Radon indicates that new knowledge is of a high personal status.

10.7.2 CASE STUDY TWO: PAUL

In ECCM terms, Paul is judged to be a Radon learner with strong cognitive and low conative and affective epistemological commitments. Paul considers himself to be a confident learner of science, he keeps up to date by reading newspaper articles and engineering texts as part of his job - he is a civil airline pilot. Paul is very interested in science and judges himself to be very well informed. He has A levels in physics and mathematics. Paul did not opt for the Radon test because he associated Radon with granite and he knows the local area is not granite based. He is more confident in his knowledge about Radon-in-general rather than Radon-in-practice. Paul recalls hearing about Radon on the local news, his knowledge of radioactivity is from his formal training.

The Cognitive Perspective

Paul has a detailed understanding of radioactivity, his transcript presents evidence that he finds a differentiated conception of radioactivity intelligible.

Interviewer: What is radioactivity?
Paul: Well, its the emission of particles by certain elements or natural or man-made really.

Paul uses this conception throughout his interview, for example, during a discussion of the harmful effects of the Radon he describes the radiation emanated:
Interviewer: Why is it [Radon] potentially dangerous to humans?

Paul: I think its mainly because of the radiation aspect of it. It gives off alpha and beta particles. It has been proved statistically that high doses of radiation are not very helpful to the bodies. we think that above a certain level of exposure it is harmful.

His commitment to a differentiated conception suggests that he finds it believable, - (i.e. it is plausible). Paul uses, and distinguishes, between contamination and irradiation processes when explaining Radon hazards:

Interviewer: How is Radon dangerous?

Paul: I'm not even sure whether it is just the inhaling it because it obviously gives off particles and those can do damage. I am not sure whether the whole body gets a sort of a count just because it's in a Radon environment. But obviously if you're actually taking a radioactive gas within your body whether ingesting it or inhaling it, it gets to certain organs at a far more local level than perhaps just by being in a room whereby you might be immersed in it.

Paul has an academic fascination for the Radon. In his interview he comments that he enjoys learning about Radon because it 'fills gaps in his knowledge'. He finds the topic fruitful - it is useful in an academic way. He comments:

Interviewer: Did you find your knowledge about radioactivity helped you to find out about Radon?

Paul: Yes. I think associated subjects are important. I'm a great believer in if I know something about a particular subject then I see an associated subject I'll read about it because it fills gaps in my knowledge. I enjoy science and like to find out as much as I can about the subject.

Interviewer: Do you think this influenced your learning?

Paul: Yes, I am sure it did - I feel I should know about radioactivity because I have studied it at school. In some way I suppose it's a bit like completing pieces in a jigsaw puzzle - you want to find out as much as you can and complete the puzzle.

Finding out about Radon is like 'completing a puzzle' - it is a subject in which he seeks a detail understanding. For Paul, it is the intellectual worth of Radon information about which raises its status. He is a Radon learner with strong cognitive epistemological commitments.
Paul has a detailed understanding of the Radon-in-general but lacks understanding of Radon reduction mechanisms. He is, however, aware of the NRPB measurements and would urge a neighbour to have a measurement performed.

*Interviewer:* If a neighbour of yours had a high level of Radon in their house - what advice would you offer them about it?

*Paul:* Well, if they had a high level I would say, get it assessed so that they’ve got a definitive amount. It depends on what question they came to me with - but if they said, we think we’ve got a lot of Radon gas - I’d say well make sure you have or you haven’t there’s no good at being sort of grey about it, so define the problem.

*Interviewer:* Suppose your neighbour had the test and they came back and said it was slightly over the action level - what would your advice be?

*Paul:* I would probably, if it was slightly over the action level, offer them a little bit of reassurance and say, well don’t worry too much about radiation because we’ve been living with it for years. And if you’ve been here for 30/40 years and they’re in their early 70s/80s or in later years and they’re still in good health, I would sort of say well it’s obviously not that big a problem because here you are - you’ve lived here for a long period of time and it has not affected you, has it?

Paul would reassure a neighbour by drawing on their personal experiences of healthy living.

*The Affective Perspective*

Paul appears to be a factual learner. He considers radioactivity to be a ‘cold’ issue. In the following excerpt, he compares his reaction with others:

*Interviewer:* What do you feel about radioactivity?

*Paul:* Well, I do think there’s a tremendous amount of sensationalism that goes on, people are always scared of something that you can’t smell, that you can’t taste and that you can’t see. People would rather believe that it is more dangerous than something they can see. So that’s why I think that it is often exaggerated.

Paul feels that the a-sensory nature of the gas may be responsible for people’s reactions, although, in contrast, it is not a subject which he considers *palatable* and *salient*. Paul does not consider practical measures about Radon to be important:
Chapter Ten: Learning In A Somerset Village.

*Interviewer:* How practical was the advice offered?

*Paul:* I didn’t really relate to my own circumstances. I didn’t believe there was that much of granite type of rock in this area. In any case, the levels would be very low. I was more interested I finding out about it really.

Radon does not appear to be a particularly *germane* issue, nevertheless Paul maintains an interest in the subject because of his interest in radioactivity rather than its conative worth.

*The Conative Perspective*

The conative perspective appears not to be particularly influential in Paul’s learning. Paul has confidence in the nuclear industry and he discussed this in the following excerpt of his interview, where he is asked to compare ‘man-made’ radioactivity with Radon gas:

*Interviewer:* How does Radon compare with, for example, the radioactive waste from a nuclear power plant?

*Paul:* I would say they are different things. Anything that’s sort of man-made and controlled is better. Whilst historically probably some of the things that have gone on in nuclear industry haven’t been terribly well done but nowadays there is a tremendous amount of knowledge that we’ve built up about radiation and it is now something we can control.

Paul perceives radioactivity offers a low threat because it is something that can be *controlled*. In the following extract, Paul considers the credibility of the information available. Interestingly, it is the lack of academic consistency which raises questions of *trust* rather than the source of the information.

*Interviewer:* You have mentioned that you found out about Radon from newspaper articles, did you believe the information presented?

*Paul:* At the time I wouldn’t say I necessarily consciously thought about it because it was new information about something that I knew very little about generally. I probably tended to believe it in the early stages and then as my knowledge would grow I became more sceptic because I would be able to fill in certain bits in the report that weren’t quite so accurate with the knowledge that I’d already got. Quite often media tend to
glamorise science, but then don't bother, having glamorised it, to put in the amount of coverage or detail it deserves, this can make it misleading.

It is the lack of intellectual completeness, its cognitive worth, which revokes trust.

10.7.3 CASE STUDY THREE: DEBORAH

Overall, using the ECCM Deborah is judged to be a learner who attributes Radon a negative epistemological status. It is Deborah's affective and conative commitments which seem to override her learning.

Deborah judges herself to be quite interested in science and a little informed, she keeps up to date with science by reading newspapers and watching television. She has an ambivalent attitude to learning science and at times is 'daunted by its difficulty'. She received the information about the Radon test but chose not to have measurements taken. She and her husband have lived in 'Radon Areas' all their lives and she holds the view that 'any damage that might have happened must already have happened'.

The Cognitive Perspective

Deborah considers Radon to be an a-sensory gas with 'gas-like' properties. She associates Radon with granite and therefore granite areas. Deborah uses an undifferentiated conception of radioactivity to explain Radon. She associates the harmful affects of Radon with cancer and is aware of some of the reduction mechanisms.

The central issue of intelligibility is representation and within the following excerpt, Deborah is able to apply her knowledge of Radon gas to rationalise and represent the effects of Radon on the human body, and to make a story of radioactive 'contamination' intelligible to herself.
Interviewer: Is there a particular part of the human body which is susceptible to Radon gas?
Deborah: Now, I don't absolutely know, but I would think that as it is a blood related disorder it would probably get to the liver.
Interviewer: Why do you say...?
Deborah: (interrupts) Well, I just feel that as it's a gas, you breath it in so it will probably get to the lungs, and then into the blood, as well, wouldn't it? And then it will spread out and cause damage in the rest of the body. Yes, that's right, it will cause damage to the sort of soft organs of the body rather than the bones.

Deborah sees Radon as a 'disorder' in itself (much like a germ - see Chapter Six) which causes other disorders. She goes on to talk about her ideas. Previously she has acknowledged the harmful effects of Radon gas - that it can cause cancer. In the following passage, she is attempting to reconcile these conceptions with her understandings of nature. In fact she sees some warnings about the danger of Radon gas to be un-plausible and she is trying balance this hazard with her own experiences:

Deborah: I feel that Radon is a natural thing and we are meant to live on this earth and therefore we ought to be able to live with Radon. But, you know, its all very well saying that all these things cause cancer, but they have been there millions of years and we are all still alive.

Deborah’s metaphysical belief of nature, as essentially harmless, and her teleological commitments (components of her conceptual ecology) appear to contradict her knowledge of the harmful effects of Radon. While the effects of Radon are intelligible they appear implausible given the continuation of life on Earth.

The Affective Perspective

Deborah finds the topic of Radon an emotional subject - she is a 'hot' Radon learner. Throughout her interview she constantly refers to her feelings about the potential dangers of Radon. These feelings are exemplified in the following excerpt of her transcription.

Deborah: Deborah: I think everybody is scared of radioactivity, I suppose because you can't see it and because you don't really know what damage it is doing to you - you read all these dreadful things about radioactivity (...) And I feel that if you worry about
When asked directly about her learning, she explains why she failed to engage with the subject.

_Interviewer:_ Did you find out about Radon gas?

_Deborah:_ Well, of course I didn’t pursue it, I felt that I might find out something horrible, the fact that it causes cancer is enough to put anybody off.

This is a case of the 'affective' hindering the 'cognitive' or 'the personal construction of ignorance' (Alsop and Watts, 1997). Deborah finds the whole subject of Radon unpalatable and so chooses to 'freeze' or 'override' her learning in the face of the unknown and undesirable. New information about the hazards associated with Radon have a low conceptual status to Deborah.

This is illustrated, again, in a further excerpt, which this time focuses on the harmful effects of Radon.

_Interviewer:_ Have you any idea what harm Radon can do?

_Deborah:_ No I haven’t, and I don’t want to!

Deborah prefers not to find out about the harmful affects of Radon. Clearly, the affective perspective plays a significant part in Deborah’s learning about Radon gas.

**The Conative Perspective**

The conative perspective also plays a key role in Deborah’s learning. She believes that any knowledge she acquires concerning Radon will not actually place her in a position to alter her personal circumstances. Subsequently, she appears helpless in the face of this knowledge and so chooses not to follow the subject up, she comments:

_Deborah:_ Yes, I am interested in the effects of Radon and I don’t know why I didn’t investigate further, except that I felt that I was perhaps in a situation where if I was living in a dangerous area then what was I going to do about it? And therefore perhaps it’s better not to know! (...) I’m thinking back to the sitting room of
our old house and the fact that we had a huge big open fireplace at either side of the room which were made of solid granite. I used to think, I bet there’s a lot Radon in there and there’s nothing I can do about it!

In this case it is the lack of control which Deborah perceives that blocks her engagement as a learner. The lack of control lowers the status of new Radon information.

Viewed from the affective and conative perspectives, Deborah’s perception of lack of control and distaste (un-palatability) influence her learning about the affects of Radon. Using the terminology of the ECCM, the conditions control and palatable have lowered the status of any new information about the hazards of Radon. Deborah prefers her current understandings and brackets herself away from any new information.

10.7.4 CASE STUDY FOUR: SUSAN

Overall, using the ECCM, Susan has been judged to be a learner with positive cognitive, conative and affective epistemological commitments. Her conative commitments appear particularly influential. Susan is a motivated learner of science, she has a very positive attitude towards science and is keen to find out about Radon gas. She opted for a Radon test as she wanted the information to make an informed decision but other things got in her way and she failed to return the detection equipment. Something which she now regrets.

The Cognitive Perspective

Susan is willing and able to engage in the information available about Radon gas. She describes Radon as a ‘colourless odourless natural gas’ that is linked particularly with granite rock. Deborah uses an undifferentiated contamination model to describe the potential harmful affects of Radon. She doubts that there has been a ‘definite’ link established between Radon and cancer but feels that it is prudent to treat Radon
exposures with the link in mind. She has a statistical representation of the Action Level and would recommend a neighbour with Radon to install reduction mechanisms to ventilate their house.

Susan recalls receiving the Radon leaflet and the news items. She found the information both ‘understandable’ and on the whole ‘believable’ (plausible), although, much like Deborah, she found it initially difficult to reconcile that something which is ‘natural’ can also be radioactive as illustrated by this excerpt of her interview.

**Interviewer:** How well informed about Radon do you think you are?

**Susan:** I’d say just a little and I wish I knew more. I thought about the leaflet at the time that I did the test, but it’s only very recently that I read an article that was talking about the risks associated with Radon - and I realised I didn’t know very much and I wish I knew more (...) To be honest, until recently I didn’t connect Radon with it being a radioactive gas or a radioactive substance. Only retrospectively, because at the time, they talked about it being a naturally occurring substance and for some reason that didn’t trigger a connection.

Susan is willing and able to engage and rationalise the casual effects of radioactivity, and views science as something which is unable to provide answers to all her questions:

**Interviewer:** How is Radon dangerous?

**Susan:** I don’t have an image of it because I rest fairly heavy on the scientific aspects of this and I think that’s it’s not known yet enough how it effects us - I imagine it gets through the immune system in some way, but quite how - you don’t know. I suspect in a way that lots of radioactive things or other things can suppress the immune system.

**The Affective Perspective**

The significant media exposure appears to have influenced Susan’s learning, she feels it important to find out about Radon partly because it is something which is topical and Salient and partly because of a worry, generated by the large media presence. It appears a germane issue for her.
Susan: All the recent publicity motivated me to want to have the Radon test done. I felt that if I was being sent information about it, there was probably something that other people were researching therefore I wanted to know what this gas was and why it was being tested for.

In the following quotation, the source of the information appears to have motivated Susan to consider the subject further. Here, the availability of information, and the image she holds of the information provider, rather than the content of the information itself, has caused Susan to worry:

Susan: it was the way the information was presented that slightly worried me because the tone of it was - "there is this gas and we sort of feel we'd like to test for it but there's nothing to worry about". So, I immediately thought, if the Government or some sort of official agency is producing this information, there probably is something, someone worried about - so that's what first alerted me to it.

The Conative Perspective

Susan approaches the available information with a clear learning goal, she wants information which is specifically practical, i.e. something she can act upon (actionable knowledge). She judges that the information is not suited to her particular needs. In this sense, the failure of the 'science' to be responsive to the practical desires of the learner has caused Susan to disengage with the information available:

Interviewer: What did you think of the information which was available?
Susan: The focus of the information when it initially came round, didn't necessarily suit what I really wanted, I was looking for something which wasn't there.

Interviewer: What information did you want?
Susan: I wanted more practical things to do with, how I can act.

For Susan, information which is practical is of a high status. The conative worth of information provided appears as a mediator in Susan's learning.
10.8 DISCUSSION OF RESULTS

This has been a study of 17 informal learners. Each study provides contextualised data that supports the cognitive, affective and conative conditions documented in Chapter Eight. These conditions, research tools, have been used by the researcher to infer epistemological status - the status the learner attributes to Radon.

The analysis has been revealing because the learners' epistemological commitments were contrasting. For a minority, it is the cognitive worth, the intellectual worth attributed to Radon which raises its status. For the majority, however, it is Radon's conative worth - its ability to practically empower, to be useful - which is important. As one of the learners, Hannah, succinctly notes:

_Hannah:_ Learning about Radon is a bit like going to the doctors: you want to find out about how it affects you and what you can do about it but not necessarily the minute details of the disease.

In examples like this, the conditions _actionable_ and _controllable_ appear axiomatic. In a number of cases, learners took this a stage further and were dismissive of the information which they had been presented, as June remarks:

_June:_ I really wanted to find about how I can lower the levels of Radon for my family - I wasn't really interested in most of the information I was provided with. It reminded me of my school physics.

All the learners remained passive recipients of information - nobody had sought additional information and most relied heavily on the NRPB leaflet.

For other learners, the conative perspective had the reverse effect; it was the lack of _control_, the perceived inability to act, that lowered epistemological status. In this case, it is the conative that hinders the cognitive - Radon is not something the learner feels they can _control_ and subsequently it is not an area they need to find out about, knowledge becomes redundant.
The condition *trust* appears significant: learners judge the status of their knowledge on the sources of knowledge and the trustworthiness of these sources is acute. For some, the media were likely to overemphasise the risks involved, for others their was an keen sense of the government not telling the whole picture or playing down the risks to avoid anxieties. In both these cases there was an air of doubt and the need to read between the lines and be cautious was apparent. In complete contrast, a minority of learners placed their complete *trust* in the authorities and used this to bracket themselves away from the issue. A knowledge of Radon was not considered important, of high status (in ECCM terms), because the authorities would act if necessary, as Rachel recounts:

*Rachel:* To be honest, I didn't bother to find out much about it - I assumed that if it ever became a real issue then the authorities would act.

Here, *trust* would appear to hinder learning.

The affective perspective was found to be pivotal: for some learners it appeared a driving force, the health threat has made Radon both *salient* and *germane* - the affective enhancing the cognitive. For others, the reverse appears true, the threat results in avoidance. Older villagers, in particular, felt it was too late to start worrying about it now. A knowledge about Radon had become un *palatable*, it was better not to know about it - a case of the affective blocking out the cognitive. Through a fear of the unknown the learner prefers ignorance.

This discussion, once more illustrates the potential of a multi-dimensional framework to describe informal learning. For many of these learners conative and affective influences are not peripheral but are of central importance and this revokes a model of learning which is solely cognitive in outlook. The affective and conative conditions proposed appear as important instruments to describe learning in these perspectives.

For the majority of these learners, a purely cognitive description of their learning would portray ignorance and a lack of ability. Arguably, this would amount to a *cognitive deficit* model of their learning.
10.9 AN EMERGENT PERSPECTIVE: SELF ESTEEM

During the analysis, it was noticeable that the participants approached their learning in different ways. To elaborate, some of the participants displayed confidence and independence while others lacked confidence and the willingness to find out more. These characteristics appear to relate to issues of self perception and concern the learners' self-esteem: their confidence as learners, their self direction and autonomy, and their perceptions of themselves as learners of science. During the analysis, three ingredients emerged; image, confidence and autonomy. The following illustration comes from Susan’s interview, because of her role as an aerobics instructor she feels she can identify with Radon, as a learner of science, particular as it relates to health issues:

Susan I read a lot - I was reading about cancer and the environment. It was an article in a woman’s magazine about cancer and the ways that you could cut your risk. One of the things mentioned was Radon in the home. I guess I am generally motivated to know more, especially health issues, because that’s part of what I do, I'm quite into science like that.

Susan appears confident in her science learning, she is a learner with a positive image of herself as a science learner and she willing, time permitting, to find out more (autonomy). Elsewhere the author has incorporated self-esteem as another conceptual change learning perspective (see Alsop and Watts, 1997). In the concluding chapter this emergent perspective is proposed to form the basis of future work.

10.10 CRITIQUE OF RESULTS

Through out the analysis it is important to mindful of the interpretations made. The ECCM has provided tools to analyse and describe the informal learners. In this analysis, the author has assigned conceptual status from interpretations of the data collected. The principal focus has been epistemological status, the key ingredient, of the extensions in the proposed ECCM. The research methodology has been reflexive, to generate data each learner has been engaged in a discussion about their knowledge and epistemological commitments after their recent informal learning experiences.
The study is reliant on the participants’ comments as the basis to infer conceptual status - using the tools provided by the ECCM. As this study is at a singular point in time, it has not been possible to ‘observe’ and document changes in conceptions or epistemological status. The research has not directly observed how epistemological status influences conceptual change learning. In this respect, it is reliant on the assumptions made in the original CCM model, namely, that epistemological status is fundamental in the process of conceptual change.

The focus of the analysis has been cognitive and the research has explored how cognitive, affective and conative commitments affect epistemological status. It has not been a direct exploration of feelings or decision making.

In the final Chapter, the journey so far is reviewed and the implications of the proposed model are discussed.
CHAPTER ELEVEN
CONCLUSIONS AND IMPLICATIONS

11.0 INTRODUCTION

This final chapter brings together the central themes of the thesis. The thesis, up to now, has consisted of a series of generative studies and each of these studies has, in many respects, been self sustaining - they have included methodological issues, a summary of the results and a critique of the interpretations. The early studies lead to a model which has then been developed and tested in the later studies. This conclusion highlights the key features of these studies and the process of model making. It starts by reviewing the progress made so far and then addresses the research questions documented in Chapter One. The thesis was developed from an ‘interactive viewpoint’ of the Public Understanding of Science and the following sections consider this viewpoint and the challenge it offers the traditional science-centred approaches. A critique is then undertaken of the interpretations of data and the limitations and boundaries of the research performed are highlighted. This is followed by a series of recommendations for adult learning, and for formal and informal education provision. Finally, some suggestions for further research are presented and the thesis concludes with the words of one of the Somerset villagers.

11.1 A SUMMARY TO THIS POINT

There are a number of aspects which make the work reported here both challenging and far-reaching. First, the focus has deliberately moved away from the relatively well researched domain of formal instruction in school and undergraduate science, beyond the semi-structured science education within museums, galleries and science centres, in order to explore the complex and under-researched world of informal learning within the general population. This thesis has explored particular understandings of radiation hazards as these affect people’s daily lives. The focus has been on Radon gas. Recent research estimates that, in the UK alone, this significant health threat
causes over 4000 cancer deaths and 50 cases of motor-neurone disease per year (Edwards, 1996). UK policy is to support informed decisions rather than governmental regulations (NRPB, 1997), but this in turn requires an informed citizenry (Johnson et al., 1988). This study has been concerned with how this informed citizenship can come about.

Second, the arguments have cast aside the dominant paradigm of science-centred communication in favour of a richer, interactive approach. From the outset, the study has aimed to turn the traditional study of the PUS on its head and set about understanding informal learning in more complex terms than the customary simple 'cognitive-deficit models' (Irwin, 1995) This approach has challenged the one-dimensional representation of the public as ignorant, passive recipients of scientific guidance (see for example, Roberts, 1996).

Third, the thesis has sought to understand the processes of learning and the reasons why some learning outcomes are occurring and not others. The starting point has been a conceptual review of informal educational materials (newspapers, television programmes and circulars). This review provided a menu of target concepts which were then used as the basis of the exploration of the research participants' understandings. Conceptions of radioactivity and Radon have then been documented through both qualitative and quantitative research. In these studies the need was set up for a new way of modelling informal learning, a multi-dimensional framework using three theoretical perspectives: the cognitive, conative and affective.

Fourth, the thesis adopted and adapted a model of conceptual change which originated in formal science education, and tailored it in order to increase its range of applicability. The Conceptual Change Model of Posner, Strike et al. (1982) was fashioned to describe informal learning by adding affective and conative facets. These facets were delineated with additional ingredients, to provide the researcher with tools to explore epistemological status: the affective conditions; salient, germane and palatable, and the conative conditions; actionable, controllable and trust. In harmony with the methodological approach, that of Grounded Theory, the research returned
once more to the literature to theorise upon the conditions which are emergent in the data.

Fifth, and finally, the thesis has applied this model in the field in 27 case studies in two separate contexts. The first of these considered learning from an informal source and a second was a more naturalistic study of learning in a Somerset village.

11.2 BACK TO THE ORIGINAL QUESTIONS

This thesis has been located in a particular social context - that of living with Radon. The following three sections use the results, as previously documented, to address the research questions outlined in Chapter One. The first section considers the sources of information available to Radon learners (the information context); the second has a 'knowledge focus' and documents common understandings associated with radioactivity and Radon gas and the third considers informal learning about Radon. Sections two and three combine to form the personal context of the research.

11.2.1 SOURCES OF INFORMATION

The empirical starting point was a consideration of sources of Radon information which are readily available in the public domain. This research was driven by three questions:

- What sources of information are available about radioactivity & Radon gas?
- What information do these sources contain?
- In what ways do these sources communicate this information?

In the public domain there are a limited number of sources of Radon information. The analysis focused on seven UK daily newspapers (1994-1996); a television programme (1996) and leaflets plus supplementary details specifically authored for residents of Radon affected areas.
To analyse the content of these sources, a five-part analytical framework was developed and used to code written materials for: (1) the subject or focus of the article; (2) the presuppositions or the assumptions made about the readership; (3) suitability of the materials for learning about Radon; (4) the degree of sensationalism and bias; and (5) the practical advice offered.

Given its potential risk, the media coverage of radon is modest. Information is communicated in different forms and styles, and with a different focus and purpose depending on the medium involved. In most cases, the coverage presupposes some background knowledge and is predominantly 'informative' and 'science-centred' in its approach.

The newspress collectively ally Radon with mystery danger (and fear) and the link between Radon and cancer is usually taken as axiomatic and unproblematic. Commonly, news articles are health focused and cover either contemporary 'Radon events' (e.g. the publication of a research report confirming health concerns) or feature Radon as part of a more general review of public health. Although most of the material appears aimed at a non-specialist audience, texts differ in their expectations. The more superficial assume an understanding of the terms 'radioactive sources', 'leukaemia', 'cancer' and avoid a theoretical discussion of the scientific or medical principles involved. The more demanding use terms, such as; 'decay', 'radiation', 'contamination' and 'irradiation' and are more theoretical in their emphasis. Headlines tend to be sensationalist, although, the main body of text is usually factual. In general, the articles have a health focus and fall short of offering practical advice.

Information posted directly to residents (NRPB leaflets and circulars) has the purpose of encouraging Radon measurements. The information has more specific detail than the daily press and covers the scientific concepts of radioactivity decay, contamination, irradiation, risk estimation and reduction techniques. The style is factual, and risks are commonly presented as absolutes. The information is generally science-centred - it aims to inform rather than offer practical advice.
Rowan’s (1990) theory of explanatory writing was used as the framework to consider suitability for learning. This analysis revealed that, for all media, the implicit mode of communication was *informative* rather than *explanatory*. During the analysis no examples of *transformative* discourse were recorded. As Dunwoody (1992) laments, ‘the perceived complexity of scientific and technological information contrasts sharply with such journalistic norms as inform, don’t educate’ (p.14).

- **What sources of information do the sample of informal learners use to learn about Radon gas?**

Members of the public find out about Radon from a wide range of sources: leaflets and circulars, newspapers, television and radio news items and word of mouth. Their main sources of information are directly mailed circulars, television news programmes and newspaper articles (see Section 7.6.6). Of possible significance to science educators is that only a small percentage of participants considered formal education to be a main source of their information (see Section 6.6).

Essentially, the sample of informal learners appear ‘reactive’ and ‘opportunistic’ in their accumulation of information. They construct understandings by drawing on a variety of different sources but few actively sought supplementary and alternative information. Learners appear to rely on information which is readily available and accessible - they prefer to wait for information to arrive rather than make efforts to seek it out (see Chapter Ten).

Commonly, these informal learners were selective and concentrate on certain aspects of the information provided - sources of information were considered to be broad ‘information banks’ and were approached with clear agendas and learning goals. In general, these people approach the source as a ‘user’ [conative] rather than a ‘scholar’ [cognitive] (see Chapter 9). Layton *et al.* (1993) make a similar point well when reviewing their research findings:

[informal learners] view scientific knowledge less as an outstanding manifestation of human curiosity about the natural world, a conceptual cathedral of awe-inspiring
construction, than a quarry to be raided, a repository of resources which might further their particular endeavours and assist the solutions of specific problems (p124)

Different sources appeared to be attributed different status (see Sections: 6.6, 9.7.1 and 10.7). For many, the NRPB leaflet was considered important because it was seen to come from the government and had been posted directly to their homes. As Claire puts it

<table>
<thead>
<tr>
<th>Claire</th>
<th>I went mainly on the leaflet provided</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interviewer</td>
<td>Did you try to find out more about Radon?</td>
</tr>
<tr>
<td>Claire</td>
<td>Not really, I suppose that because the leaflet came to my door - I just assumed that it would cover what I needed to know.</td>
</tr>
</tbody>
</table>

(see Section 10.7)

For others, the source of the information caused the learner to lose faith in the science which was being offered (see Sections: 6.6, 9.7.1 and 10.7). This raises issues of epistemological status which are returned to in the following sections.

11.2.3 KNOWLEDGE OF RADIOACTIVITY

The research in this area was driven by the question:

- What knowledge do the sample of informal learners associate with radioactivity and Radon gas?

The sample of informal learners’ knowledge of radioactivity and Radon was found to be a rich blend of cognitive, social and emotional ingredients.

Radioactivity is conceptualised as an active, a-sensory, mysterious entity with potent destructive powers. Conceptions of radioactivity divide between the notion of it as an entity and the notion of its causation. Conceptions of the entity can be represented in network format under four broad categories: (i) differentiated and undifferentiated, (ii) existence, (iii) appearance, (iv) origins and activity (Figure 6.4). The majority of participants hold an undifferentiated conception of the concept labels radioactivity and
radiation (see for example Section 6.9.2): They considered the emanations to have the appearance and propagation of a gas (Section 6.9.3) and perceived the origins of radioactivity to be both naturally occurring and man-made (Section 6.9.5). Radioactivity was frequently perceived as eternal and unstoppable - any idea of the conservation of radioactivity was lacking.

Conceptions of causation are represented in network format in figure 6.5. In this context, radioactivity was seen as extremely active and powerful, capable of altering, poisoning, transforming and destroying both living and non-living things. Living things and metals were perceived as particularly vulnerable to attack and capable of attracting and, in some cases, actually 'soaking-up' radioactivity. Plastics were perceived as less vulnerable and can be immune (see Section 6.5). In most cases, causal processes were considered in terms of contamination rather than irradiation. The agent has to reach and touch the object to act upon it (see Table 6.3).

Knowledge of radioactivity has an affective perspective. It is a physical phenomena with a strong association with danger, fear and dread (Section 6.12). In the analysis, three affective categories were identified as conditional, intensity and expression (see Figure 6.7). In the majority of cases the participants considered the dangers of radioactivity as conditional, were 'cool' in their intensity and factual in their expression. Underpinning these categories were likely to be individuals who varied in their emotional responses - at two ends of a continuum, there where individuals who seemed deeply fearful and anxious and others who were more coolly objective and emotionally detached (Section 6.13).

The analysis also provided some insight into how learners reason about radioactivity. Reasoning appears based on a diffuse background of common knowledge, salient images, episodes of the nuclear industry, analogies, metaphors and social expectations. Knowledge appears to be drawn from news media, films, fiction books and schooling. Images of nuclear accidents, genetic mutations, nuclear leaks and protective suits as worn by nuclear scientists are salient and long lasting. Commonly, it appears that conceptions of causation form a mechanism to reason about the ontology of the entity.
In general, Radon is considered a radioactive gas possessing all the properties of radioactivity (conceptions of the *entity* and *causation*) but in a less concentrated and harmful form. Most conceptions of Radon are *undifferentiated* and it is widely known that Radon is naturally occurring. In this respect, residents of Radon areas appeared no more knowledgeable about radioactivity than a similar group of participants from non-Radon areas (see Section 6.11 and Chapter 7). Most participants in the study held alternative conceptions of radioactivity and appeared familiar with aspects of the terminology involved (see Section 7.7; Chapter 9). However, in general, the Radon residents were more familiar with the practicalities of living with Radon, *Radon-in-practice* (see Chapter 7). For example, reduction mechanisms, how Radon enters houses and the local occurrence of the gas. Some evidence presented suggests that residents view their knowledge of science and Radon in different ways (see Section 7.10).

A disparity was noted between the science-centred and general nature of much Radon information (*Radon-in-general*, the cognitive) and learners’ knowledge of Radon which in some cases was more practical in emphasis (*Radon-in-practice*, the conative).

### 11.3 MODELLING THE INFORMAL LEARNING OF RADON

To model informal conceptual change learning a well established model of science learning from a formal context was adopted and adapted to explore learning in an informal context. The principle research has been driven by the question:

- **To what extent can a model of learning derived from within formal science education be used and adapted to describe informal learning in the public understanding of science?**

The conceptual change learning model of Posner, Strike, Hewson and Gertzog (1982) was adopted and building upon recent modifications (Hewson 1991 and Treagust 1997), it was adapted to meet the thesis’ specific needs. In the tradition of Grounded Theory (Glaser and Strauss 1967), the modifications proposed are rooted in the data
collected. These modifications have extended the original CCM model to include two additional theoretical perspectives: the affective and conative.

The Extended Conceptual Change Model (ECCM) is a multi-dimensional framework which can be used to interpret learning from three different theoretical perspectives: cognitive, affective and conative (see Chapter Nine). For the cognitive perspective, it adopts Posner, Strike et al.’s original model. This model resonates well with many studies and experiences in school science education, and has generated wide interest and exploration over time (see Chapter Four). It is validated in the present study through the identification of participants' comments and interview responses which illustrate their intellectual searches for intelligibility, plausibility and fruitfulness as they attempt to construct understandings of the science of radiation, radioactivity and Radon gas.

To elaborate this process, the words of one of a Somerset villagers, John are apposite (see Table 10.1 and Section 10.7):

*Interviewer:* Why did you find out about Radon?
*John* Well, I suppose more for intellectual curiosity more than a concern about the threat. I realise that it has been around for a long time and is not really an issue now. It was more to do with the fact that I enjoy science and like to find out as much as I can - I find these things interesting, that’s just me I suppose.

John is an informal learner with an intellectual quest - a learner who displays a clear intellectual commitment to knowing about Radon. For John, a knowledge of Radon is fruitful, he finds it useful in fulfilling his academic needs. In ECCM terms, John is a learner who attributes to Radon a high cognitive epistemological worth (or status).

The second perspective focused on the affective domain. As previously noted, radioactivity is a subject closely allied with fear and danger. Learning about Radon, particularly in an area with high exposure, is an emotional experience as the Villager, Mary, puts it (see Table 10.1 and Section 10.7):

*Mary* Radon concerns me, I have lived in this area all my life and the idea of finding out about something radioactive that seeps into
Affect is widely recognised as a major tenet in learning. As Hodgkins (1985) says, 'the activity of getting to know is compounded of feelings as well as of intellectual curiosity, of hunches as well as facts'. Any model of conceptual change which neglects an affective dimension is likely to be very partial at best. Yet, the influences that affect has on science learning have been largely ignored (Pintrich et al. 1993).

The ECCM captures the emotions of the informal learners through three conditions salient, palatable and germane (see Table 8.6). These conditions are used to illuminate the influences that affect has on the processes of conceptual change. Salient is a description of how prominent, conspicuous, striking or important knowledge is to a learner. For an idea or conception to be salient it stands out in some way (See Section 8.6.1 and Table 8.7). Palatable is a description of how agreeable or acceptable knowledge is for a learner. For an idea or conception to be palatable it must be something one can deal with, it must be appealing (see Section 8.6.2 and Table 8.7). Germane is a sense of emotional relevance it is a measure of how a learner views knowledge in terms of its personal applicability and appropriateness (see Section 8.6.3 and Table 8.7).

These conditions were used to describe the affective epistemological commitments informal learners attribute to Radon - termed its 'affective status'. For some of the sample learners, emotions get in the way of their learning. Their emotions have the effect of lowering epistemological status and consequently the affective overrides or hinders the conceptual change process. For others, a sense of emotional attachment acts to raise epistemological status and so enhances learning.

The third component of the ECCM is the conative perspective. This considers knowledge and its applicability - the articulation of science with praxis (c.f. Layton 1992). More specifically, it considers scientific knowledge and practical action in the social and physical worlds (see Section 8.7). The conative perspective embodies the need to act and for practical empowerment. To describe the conative perspective the ECCM deploys the conditions: actionable, trust and control (see table 8.5).
Actionable is a measure of how applicable the learners consider a conception or idea to be. It is a judgement of knowledge's ability to meet a practical everyday need (see Section 8.7.1). Trust is a measure of the credibility and faith the learner attributes to knowledge - the confidence and belief the learner has in a new idea (see Section 8.7.2). Control is the degree to which a learner feels knowledge is practically empowering - whether or not they feel they can use this knowledge to make decisions (see Section 8.7.3).

These three conditions have been used to describe the influences that 'conation' (knowledge's applicability) has on conceptual change. For many of the learners it was knowledge about Radon's conative worth that enhanced their learning. In ECCM terms, a knowledge of Radon has a high epistemological status because it is useful and applicable. This perspective is once more exemplified by one of the villagers, Hannah (see table 10.1, Section 10.7), as she compares her formal learning of science with her informal.

Hannah: You can't really ignore it [Radon] however much you are disinterested in it, the fact that perhaps you haven't had a very interesting start off with science -at school. If you have had bad teachers it turns you off, doesn't it and the very word of science you just sort of think well that's not for me. But when it relates to things that touch your life and you have to make decisions then whatever you'd like to call it you have to take notice.

It is possible to apply the ECCM and infer that Hannah attributes a high epistemological status to her Radon knowledge, not because of its intellectual worth but because of its conative worth. She can use it to make decisions because it is something which is actionable and enables control.

To return to the original research question, the evidence collected in each phase of the data collection supports the additions to the original model proposed. Empirical studies Four and Five have used the Extended Conceptual Change Model as an interpretative framework to describe the informal learning of radon in two contexts: from a Radon leaflet and, reflexively for a sample of Somerset villagers. The model is a useful and potentially powerful tool to describe this learning. In short, all the assembled evidence endorses the approach taken and the adaptations made. That is, a
model of learning originally derived from within formal science education can be successfully used and adapted to describe informal learning in the public understanding of science.

11.4 A CHALLENGE TO COGNITIVE DEFICIT ASSUMPTIONS

Debate surrounding the cognitive deficit model has been the centre of much PUS attention over the last five years (Durant 1997). Much of the debate has focused on the nature of science and, like many debates of scientific epistemology, discussions have become 'log-jammed' between the 'hard' scientists (e.g. Wolpert, 1993) and 'social' scientists (e.g. Irwin and Wynne, 1997). Conversations of this type have become affectionately known as the 'science wars' (Midgley, 1997) and are typified by a 'non-meeting of minds' (Rose, 1997).

The science-centred, enlightenment viewpoint, remains popular in science circles (Durant, 1997) and traditional surveys which purport to make measurements of scientific literacy proliferate on an international scale (see Chapter Three). Whether or not one accepts the 'illiteracy' documented by these surveys, they still have had many positive effects; they have caused alarm bells to ring in many different sections of society (governmental, scientific and educational) and attention has been drawn towards increasing levels of scientific understanding in the population - this is praiseworthy. In the UK, for example, the recent Millennium/ Royal Society grants (1997) are an illustration of the continued financial support given to innovative ways of bringing science to a public audience.

Other people question the fundamental basis of these endeavours, and they argue that the cognitive-deficit assumptions underpinning this approach characterises the public as ignorant and passive consumers of science. Fayard (1992) has made the plea 'let's stop persecuting people who don't think like Galileo' and Wynne (1992) maintains that the 'critical research agenda' should be realigned away from the public towards science. Recent publications have reflected this approach and expose science's epistemological weaknesses outside of the laboratory door (Wynne and Irwin 1996).
The research presented in this thesis certainly challenges a traditional science-centred cognitive deficit model. The sample of informal learners have been found to have multi-faceted understandings of radioactivity and Radon, they are documented as being reflexive and active learners engaging, assessing and weighing up the worth of knowledge. A simple image of ignorant people passively consuming scientific advice is untenable.

In the past, science educators have made a clear distinction between the construction of knowledge by the scientists who creates science and the construction of knowledge by the student who learns science (e.g. see Glasersfeld, 1991). This thesis has taken this one stage further and revealed another learner, the informal learner, a learner with an empowering practical and emotional agenda. Put simply, a clear message from this thesis is that members of the public learn science in different ways and for many different purposes than scientists and science students.

The original Posner, Strike, et al (1982) conceptual change model was derived from a rationalistic study of scientific epistemology. For Strike and Posner (1985), learning has certain generic features, ‘whether they concern scientists struggling with a new idea on the forefront of knowledge or the child trying to understand elementary concepts of motion’ (p213). This is an intellectual analysis of learning, it is unremittingly cognitive and rationalistic in outlook. To explore informal learning with this model, with out the modifications proposed would be to adopt a cognitive deficit model - the model that the data collected challenges.

However, the focus has not been an assault on science. Rather, from the outset it has been argued that science can offer much to everyday life. The view-point adopted is interactive; a bi-directional viewpoint that seeks a meeting point between scientists and the public (see Figure 2.3). It seems clear that if the field of the PUS is to progress, then it needs to recognise this approach - as Durant notes in his recent editorial of Public Understanding of Science journal:

Surely we should aspire instead to a model of the Public Understanding of Science that is even-handed in its critical analysis of science and the public; a model that attempts to
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do justice to the complexity, the subtlety, the strengths and the weaknesses of both. Here, perhaps, is where there is the greatest scope for further theoretical work that will carry research in the public understanding of science beyond the current debate about strengths and weaknesses of the cognitive deficit model. (Durant 1997, editorial)

Arguably, the adoption of such an approach is central to the success of science education. A challenge to the field, then, is to seek a 'common ground', a place where public and scientific expertise is acknowledged and attributed status. To find this ground requires scientists to recognise their audience: The public as informal learners; learners with cognitive, conative and affective epistemological commitments. It requires scientific advice to be reformulated within the context of everyday life, to be more practically and emotionally empowering. Under scrutiny here is the intersection of two world views. On one hand there are people functioning effectively in an intricate social, physical and emotional everyday world. On the other, there are the refined, rational, abstract and emotiveless explanatory systems of science and technology. These two domains collide at the point where science is brought to bear in the service of social need, such as: health technology, risk and conservation. To search for a meeting point requires the recognition of needs, the recognition of Radon-in-practice, (or arguably, in more general terms science-in-practice) - a public-centred and practically empowering scientific epistemology as distinctive from the traditional science-centred Radon-in-general (or, in more general terms science-in-general).

When viewed in this way, it is possible that an informal learner might be literate in one of these 'domains' and not the other. Radon-in-practice would appear to hold a particular importance when judging scientific literacy in the present social context.

There needs to be recognition that the public does not neatly detach their emotions from their learning and understandings. Learning about Radon, an invisible radioactive dust that quietly seeps into your home, is an emotional experience and needs to be recognised as such.
11.5 A CRITIQUE OF THE DATA INTERPRETATIONS

The extended model of conceptual change learning is not intended to be fully exhaustive: it has been a useful descriptive framework for examining data from the field. There is still considerable work to be done in exploring perspectives of the model, and in testing the proposed framework against further surveys and samples. The reader may feel concerned about the symmetry of the proposed model; there is nothing magic about the number three - a model has consciously been generated that gives similar weighting to the affective and conative as to the cognitive. The distinctions made between each of the conditions is designed to be characteristic but not intended to be categorical - they are principally to act as tools to explore informal learning of science.

All methodological approaches have weaknesses, the extent to which one can generalise from a series of case studies is an open question. However, cases are rich in detail and give substance and colour to the key points to be made about the ECCM. Questionnaires always have subjective dimensions and are open to interpretation. However, they have a been useful tool to supplement other means of data gathering and have provided a good background support for the direction taken. Interviews can also be biased to suit certain participants. However they offer an important way to show details of the phenomenological world of informal learners. Though, the analysis of transcripts has been undertaken mindful of the interpretations made, particularly concerning the attribution of conceptual status. The combination of research approaches has enabled some methodological triangulation to mitigate the inherent weaknesses in the research tools used. However, although every attempt was made to minimise bias, it is acknowledged that this thesis represents the author's interpretation of the data collected and the thinking underlying the approach will have been coloured to some extent by personal pre-conceptions. Nevertheless, there appears to be sufficient extensive empirical data to support the stance taken.

In many respects, the study has been a single case; a study of the informal learning of Radon. At a more general level, whether the conditions proposed are context specific is open to discussion. Throughout this thesis the importance of context has been
accentuated. As Furnham (1992) notes 'context is an integral variable not an artefact'. The thesis has sought to explore learning in a specific social group: residents of a Radon affected areas. To this group, Radon is a relatively unique subject and is likely to have strong emotional and practical dimensions. Given the relative uniqueness of this context, the extent to which the study can be generalised will always be open to question. Such is the inherent design of this particular approach which has been utilised to access this particular sample in relation to this specific Radon issue.

Much more work will need to be performed before such questions can be adequately addressed. However, heart is taken from the words of the Rogoff:

This is not to say that cognitive activities are completely specific to the episode in which they were originally learned or applied. In order to function, people must be able to generalise some aspects of knowledge and skill to new situations. Attention to the role of context removes the assumption of broad generality in cognitive activity across context instead on determining how generalisation of knowledge and skill occurs. The person's interpretation of the context in any particular activity may be important in facilitating or blocking the application of skills developed in one context to a new one.

(Rogoff, 1990, p.3)

11.6 IMPLICATIONS AND RECOMMENDATIONS

The following sections review the implications on this thesis. Although this work has been exclusively a study of adult learners in an informal educational setting, it arguably carries significant messages for children’s learning in schools. In the literature there is a surprising lack of interaction between formal and informal education providers and researchers. It is almost as though they are living in separate self contained worlds with differing research agendas. The concept of a life-long learner challenges this separation, and the first recommendation, addresses this concern:

*Informal and formal Science educationalist should share their experiences and expertise.*
A forum could usefully be established for an exchange of ideas. A strength of this research has been the attention paid to both groups and the recognition of their particular strengths. Science education has a long and well established cognitive tradition of research into science learning - models of conceptual change abound. On the other hand, informal learning considers science learning in more 'holistic' terms and research has focused on enjoyment, interest and curiosity (the affective domain).

A forum for life-long learning in science could include contributions from formal education providers (government departments [DfEE and TTA], teachers, lecturers and examination boards); informal providers (representatives from the media, newspapers, radio, television, museum centres, science shops, publishers and scientists); vocational providers (trainers and consultants of industry and commerce) and formal, informal and vocational learners.

11.7 INFORMAL LEARNING

In Chapter Three the arguments have been critical of 'all-embracing' theories of learning. Most discussions of andragogy have ended in a stale debate of 'age and stage' at the expense of questions of experience and purpose. Adults experience a wide range of sources of information with differing learning requirements. Informal learning research has tended, in emphasis, to focus on the stimulus to learning in isolation from the context in which it functions, ignoring the complex interactions of different educational experiences and the learning goals of the learners. Informal learning is currently 'under-theorised' (Crane et al., 1994) and, in an attempt to address this, it is recommend that:

*Research should concentrate on building theories and principles which aim to understand learning processes with a learner-focus. These studies should be cross-disciplinary in emphasis.*

Understanding these learning processes will necessitate a range of theories and a range of studies in differing contexts. This thesis offers to the field a multi-dimensional framework to describe the informal conceptual change learning of Radon gas.
Significantly, the model proposed recognises the need to interpret the multi-faceted world of informal learning from different theoretical perspectives.

*Research should look towards multi-dimensional theoretical frameworks that aim to interpret informal science learning from different theoretical perspectives. These perspectives need to embrace the cognitive, conative and affective facets of learning.*

We need to know and understand the boundaries and parameters of informal learning. It is suggested that a potentially fruitful and rich research agenda would stem from the consideration of cognitive, conative and affective perspectives. This point is returned to at the end of the chapter where future research questions are proposed.

11.8 INFORMAL EDUCATION PROVIDERS

The outcome of the work undertaken in this thesis has specific recommendations for Radon communicators and a more general message for informal science education providers. Although the following comments, in most cases, do not relate directly to a particular source of information, they do have a greater pertinence and immediacy for information which has specifically been designed for Radon residents: NRPB leaflets and circulars. As previously noted, this information was often attributed a high status by learners and, as such, has a particularly acute social responsibility.

The first recommendation is general and concerns the nature of communication:-

*Informal education providers need to recognise and respond to informal learners' needs. To recognise these needs means to be more interactive in their style of communication.*

The first rule of successful communication is to know about and be responsive to one's audience. Quite simply, the data suggests that informal learning providers must research their audiences in more detail. Arguably, for too long communication has been unidirectional from producer to consumer. This reinforces the 'superiority' of scientific knowledge and excludes discussion, debate, local knowledge and expertise
Communication in science must become more flexible, open and accessible; opportunities need to be provided for interactions and exchanges to occur between scientists and the public, particularly if the aim is to bring about conceptual change and deeper understanding.

To recognise the diversity of the public audience requires a diversity of approaches. Communicating with Radon residents is not a simple case of sending a generic pack of information to all householders - the current practice of the NRPB. This type of ‘top-down’, unidirectional, ‘blanket’ mailing approach has been rejected by contemporary marketing techniques (Wilmshurst, 1997). Contemporary techniques are far more subtle: information is individualised, fashioned and tailored to specific groups and particular needs.

Often the conversations with the Somerset villagers continued for up to an hour after the formal interview had stopped. These free-ranging discussions raised a plethora of questions, concerns and doubts. For example, one of the learners was concerned about dusting and hoovering in a Radon affected house. She was anxious that Radon would be drawn into her house by hoovering and concentrate in the ‘Hoover-bag’. In the survey, documented in Chapter Seven, just under half of the participants thought that Radon would contaminate meat if left out in the open (see Section 7.7). These are real questions suggestive of real needs. However, what is perhaps more important than answers to these specific questions is the lesson to be learned from the scope of these conversations. Informal Radon learners are usually interested in finding out more, they have a multitude of questions. Paying attention is a case of ‘freeing voices’ and listening. Arguably, this can be achieved with more open, approachable, informal and above all personalised communication.

Moreover, there are messages to be learned from a consideration of the specific context in which learners encounter Radon. For example, the learners linked Radon with granite rock, and this is reinforced by the educational materials available (leaflets and circular from the NRPB - see Section 5.12). Learners are acutely aware of their local geology and many of the Somerset villagers dismissed Radon as a health issue, not because of ignorance, but because they knew they were situated in a sandstone...
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Although commonly found in granite, Radon can occur in sandstone (NRPB, 1997) - the information provided needed to make this point clear - it needed to be responsive to local geology. Similarly, interpretations are likely to differ if, for example, a resident is living in a house or a flat, one has stone floors or tiles, the learner is young or old, or has young children.

*Radon communication should re-orientate itself away from the universal to the local and recognise the context-sensitive nature of communication.*

A prominent feature of the analysis has been the differences between the informal learners. On the one hand, some learners have needed to know as much as possible about Radon and have sought cognitive mastery, or conceptual completeness. On the other, some learners would prefer to know as little as possible because of the unpleasant risk it presents. Informal learners have different learning needs: some seek cognitive satisfaction; others conative satisfaction, and yet others affective satisfaction. Recognising these needs requires information which is practically empowering and engaging - cognitively, conatively and emotionally rewarding. The following three sections consider these needs.

**11.8.1 THE COGNITIVE PERSPECTIVE**

*Informal learning providers need to recognise the alternative conceptions held by informal learners.*

Some of the learners looked on the NRPB material as a basis to improve their understanding of radioactivity (see for example Section 10.7). The materials fell short of achieving this aim. When Radon communicators cover scientific concepts, the most frequent mode of communication is *informative* (see Section 5.12). Radon information materials need to become *transformative* and, to achieve this, they need to recognise and address learners' alternative conceptions. Two common alternative conceptions to have emerged from this study include: an undifferentiated conception of radioactivity and a 'contamination' model of irradiation. The confusion between radioactivity and radiation has been comprehensively documented in science
education. Eijkelhof (1990), for example, has proposed a conceptual scheme which clarifies the relations and distinctions between these concepts (Figure 11.1).

![Diagram of scientific concepts regarding radioactivity and ionising radiation](image)

**Figure 11.1** Relations between scientific concepts regarding radioactivity and ionising radiation (Eijkelhof p180).

This scheme has formed the basis of curriculum materials which have now been successfully tried and tested (Eijkelhof 1994). Informal educational providers should use these developments to adapt their material to be transformative in intent.

### 11.8.2 THE CONATIVE PERSPECTIVE

*Informal learning providers should provide materials which are practically empowering.*

The data collected indicates that majority of the learners in this study have not been seeking intellectual enlightenment as much as practical empowerment - they wanted to know what they could do to reduce Radon levels in their homes. Informing the public about Radon is not a simple case of telling them ‘watered down, simplified science’ - information must focus on particular needs. That is, the epistemological emphasis needs to shift from *Radon-in-general* (concepts and constructs of radioactivity, such as half-life and radioactive decay) to *Radon-in-practice* (such as, details of reduction mechanisms, how Radon enters houses and the accumulative effects of Radon). To engage learners conatively, this thesis offers three recommendations:

*The content of educational materials should be 'actionable'.*
Layton (1991) has noted that the task facing consumers of science is not a straightforward one of applying scientific knowledge to a practical solution - it is often the case that this science needs restructuring, translating and reworking to fit with practical action. This emphasis is supported by the data collected in this study within the condition actionable. Given a disparity between the abstract and generalised nature of traditional science and science-for-action, informal learning providers need to reorientate the science they provide to relate to, and service, practical needs.

Informing the public about Radon is not just a case of providing general concepts of radioactivity, it should also provide local information which is responsive, applicable and relevant to practice. Specifically, it should contain more details about:

- The nature of remedial work;
- details of local Radon levels and geology;
- why Radon hazards are a recent occurrence - i.e. the improvements in home insulation have reduced ventilation;
- the probabilistic nature of the causal effects - i.e. why it is never too late to address Radon concerns;
- and most importantly, where additional scientific information and advice can be sought.

_The content of material should be trustworthy._

Wynne (1991) comments 'the social basis of trust and credibility is the crucial (yet largely neglected) question affecting the public uptake of science'. The current study has found that the judgement of trust and validity sways epistemological status. This seems influenced by: i) the institutional source of information; ii) the information type; and iii) the style of presentation (see Section 9.8).

Greater research is needed to explore how sources, forms and styles of information influence peoples' trust. However, this significant component of the public learning of science should be recognised by science communicators.
The content of materials should facilitate control.

Recommendations have already considered the need for communication to be interactive and bi-directional. This appears crucial when considering control: Informal learners must be encouraged to seek answers to their questions - they must feel in control of their learning. They need to know how they can find out more and where can they find out more. Communicators they need to provide opportunities for the exchange of ideas. Learners need to be given autonomy and self-direction.

11.8.3 THE EMOTIONAL PERSPECTIVE

Informal educational providers need to acknowledge the emotional nature of learning.

Communicators need to recognise that learning about Radon is an emotional experience. The affective can override or enhance learning. On occasions, the route to cognitive aspects of learning may be through the affective (c.f. Gardner, 1983) - for example, it may be necessary to address concerns and anxieties before learning can commence - to overcome the 'personal construction of ignorance' (Alsop and Watts, 1997). Informal educational materials need to acknowledge and manage emotions rather than avoid them. Emotions are a central part of learning, not a peripheral issue to be sidelined. Communicators need to provide educational experiences that are salient, have personal relevance and are emotionally rewarding. They must avoid experiences that are alien, unappealing and unappetising. They need to balance on an affective tightrope between the imperative to find out more and the pragmatism of avoidance.

11.8.4 GENERAL COMMENTS

There are some general messages about informal science education provision which can also be drawn from this Radon-specific study.
The importance of *affect* is widely recognised in informal learning circles and positive experiences - enjoyment and interest are recognised as valid learning outcomes of museum visits (e.g. see Rennie and McClafferty 1996). Popular science, through museum education for example, may make science colourful, attractive and allow confident autonomous learning. But to what extent can it cope with conative dimensions to science education? Few of the sample of citizens in the current study head directly towards a museum in order to empower themselves in dealing with Radon issues.

In many respects there is a need for the reverse of merely popularising science - to draw the public into science rather than to take science to the public. Public science needs to change so that it becomes a form of supermarket where informal learners can 'shop' for their requirements, a resource centre to foster their needs. That is, it is public need which should drive the 'public understanding in science' rather than scientists' and science educators' simply 'patching-up' perceived deficiencies in public knowledge.

A radical rethink of the institutional structure of informal science provision along these lines has given rise in some areas to the advent of science shops and help-lines. For example, in the UK, science shops have been established in Liverpool (http://web.qub.ac.uk/scisho) and Belfast (http://science.shop@qub.ac.uk) and Ulster (http://scienceshop@ulst.ac.uk) funded by the Nuffield Foundation. In London, the Wellcome Institute has set up a help line (0345-600-444) open Monday-Friday 1pm-7pm and the questions and answers are available on the world wide web. Science shops were a concept introduced in the Netherlands as early as the 1960's, and are now common across Europe; for example, Eindhoven University (http://idefix.tue.nl/wew/twg/english.html) has run consultancy groups in chemistry, physics, architecture, healthcare, mechanical engineering, electrical engineering and technology in society since the late 70's. The responsive nature of the INTERNET makes it ideal for forums of this type for members of the public who are computer 'literate'.
However, what is acutely perplexing is why the information available to Radon residents does not contain details of any of these forums? It does pose a question that, perhaps, such omissions reflect a deeper anxiety about ownership and control of the subject.

11.9 SCIENCE EDUCATION RESEARCH

Over the last two decades science education research has concentrated on identifying students’ alternative, often pre-instructional, conceptions. An abundance of data has been collected and collated on almost every concept covered in the school curriculum. Research is now turning its attention to the processes involved in changing and developing these conceptions in accordance with those of scientific orthodoxy; conceptual change learning. To date, research has pursued a single track in a cognitive, intellectual direction, however:

*Science education research should seek a more multi-faceted picture of conceptual change and, to achieve this, it is necessary to interpret learning situations from different theoretical perspectives.*

The multi-dimensional interpretative framework proposed has broadened and enhanced the conceptual change research agenda. It has shown a way that conative and affective aspects of learning can be best investigated to determine how they facilitate or hinder the conceptual change process. It is recommended that in future:

*Science education research needs to acknowledge and explore the crucial affective and conative influences on learning.*

11.9.1 FORMAL EDUCATION PROVIDERS

An understanding of the public learning of science as a complex interaction of cognitive, conative and affective ingredients has practical implication for learning in the classroom. The Strike and Posner (1992) model of conceptual change remains one of the most influential models of conceptual change learning in science education.
research. By extending this model (even beyond the Treagust version) the analysis highlights some of the differences which exist between learning in formal and informal contexts.

There are many exhortations for the school curriculum to address everyday needs (ASE 1996, Millar 1996). Scientific literacy is cited as a central aim by many curriculum designers (see, for example, The Department for Education, 1995 and AAAS, 1996). If schooling is to assist 'life-long learners' it must address their informal learning needs. It is a matter of considerable concern that few of the sample made overt reference to their school science in order to organise their thinking about Radon, although - it is hoped - it must have provided some sense of what was taking place. Perhaps this was in the form of a 'plateau' of general knowledge which informs their lives.

To recognise lifelong learning is to recognise some of the adjustments that have been made; the first recommendation is straightforward:

*Radon should be a part of the school science curriculum*

It would seem a folly that Radon is not explicitly mentioned in national curricula (DFE 1995, AAAS 1993). Even syllabuses with a 'social emphasis' give only an incidental coverage to this internationally significant health concern (SATIS 1988, PLON 1985). It should not be forgotten that Radon is the second largest cause of lung cancer after smoking (EPA 1988) - how can such a significant risk not be considered?

Studies of informal learning have many far reaching messages for pedagogy. Studies of situated cognition have highlighted the considerable difference between formal learning and everyday learning (see Hennessy 1993). Everyday learning is goal-directed and often incidental and opportunistic, whereas formal learning is deliberate and conducted for its own sake (Reeve, Palincsar and Brown, 1987). Formal learning problems are pre-formulated and the data is supplied with the problem, in contrast to out-of-school learning where problems need defining and data must be sought from a variety of different sources. Hennessy makes the point clear:
Conventional pedagogic practice still tend to emphasise routines for solving text book problems, and domain (conceptual and factual) knowledge and procedures. Heuristic, control and learning strategies - the crucial elements to problems solving- are usually ignored (Hennessy 1993, p16).

These differences are apparent from this study of Radon learners. School science needs to recognise these differences and adapt to meet everyday learning needs.

*If school science is to assist learners to become life long learners and consumers of science it must recognise the conative domain.*

Teachers should assist learners to become active consumers and practical users of science in everyday contexts. They should encourage independent learners who are aware of everyday scientific issues and feel confident in seeking out information from a variety of different sources. Learners who are able to judge the validity, trustworthiness and usefulness of these sources of information are learners who feel able to take control of their learning and use their experiences in a practical way. Teachers need to encourage a greater awareness of and encourage debate about social-institutional forces to teach pupils how to use experts points of view.

*If school science is to assist learners to become life long learners and consumers of science it must recognise the affective domain.*

Informal learning fuses intellectual and emotional factors - these are separated in formal learning (Harris and Evans, 1991). Teachers should recognise that learning is an emotional experience and that some subjects are more closely allied with feelings. They should acknowledge that affect can influence learning and make science more conspicuous, relevant and appetising. It is noticeable that the images and events of the media appeared to have a more profound influence on these learners understanding of radioactivity than any part of their schooling. Learning outcomes can be affective as well as cognitive. Pupils should enjoy science, become engaged in science and see the relevance of science in meeting everyday needs. Teachers should recognise that one
way to the cognitive is through the affective. They need to be conscious of the importance of presenting science in a way that is salient, palatable and germane.

Sadly, the overall trend in science education seems to be running in the opposite direction (Claxton, 1991). Reform appears to at the level of ad-hoc changes, with the introduction of an occasional STS activity if time permits (Watts and Mcgrath 1997). Currently, school science is more abstract than it is actionable, it can be a 'turn off' every bit as much as it can inform. Figures suggest (Braithaupt 1997; see Section 2.5.1) that formal school science is failing (at least in the UK) with the commensurate need for us to challenge the basis upon which it is established. Arguably, the unremitting bias towards the cognitive neglects other dimensions to learning.

For some observers, currently, in the UK, there is a culture of conservatism; it is now time to 'challenge the sacred-cows of physics' (Osborne, 1990); to keep our nerve and consider the social component of science (Ogborn 1995). We need to identify that school science is more than a gateway to higher study and that it will need re-conceptualising to address the needs of life-long informal learners.

11.10 FURTHER STUDIES AND RESEARCH QUESTIONS

What is abundantly clear is that a substantial research agenda awaits to be addressed at the interface of cognition, emotion and conation in both formal and informal science education. Here, a few selected suggestions are made for future work.

Research needs to chart the boundaries of both formal and informal learning and consider life-long learning. There is much to be done in exploring learning in different contexts with the proposed multi-dimensional framework.

There is much work to be done in extending and expanding the model proposed. In Chapter Ten an additional perspective was introduced, self esteem. This is a perspective which considers confidence lifestyle and self image (Alsop and Watts, 1997). Future research needs to consider these components and the important role they play in learning.
Chapter Eleven: Conclusions and Implications

Science is encountered in daily life in a wealth of situations embracing: neighbours of industrial hazards [chemical and nuclear plants]; medical advice; pollution levels, weather reports and electricity in the home. There are also recreational pursuits which involve science: gardening; scuba diving; amateur astronomy, as well as numerous vocational needs. All these, to some extent, stand beyond traditional formal educational provision. Multi-dimensional models of learning are required to better describe these encounters.

Standard science education (Millar 1989) needs to venture beyond the cognitive to model learning more holistically and open up a new research agenda. For example, the original CCM has recently been employed as a theoretical framework to describe teacher development (see Hewson and Hewson 1988; Thorley and Stofflett 1993; Thorley and Stofflett, 1996). Again, a possible criticism of this approach is that it limits itself to the cognitive domain. The proposed ECCM opens up new research possibilities. It has long been recognised that teachers require competence in subject knowledge (Summers et al. 1993) [the cognitive domain]; they also need to be able to translate this knowledge into action in the classroom (pedagogical content knowledge, Shulman 1987) [the conative domain]. Furthermore, teachers are recognised as emotional carers (Hargreaves, 1995) [the affective domain]. These areas have traditionally been separate, the theoretical framework proposed could provide a means of unification - only research can tell.

A future focus of research should be the 'life-long learner' and the efficacy of school, and out-of-school, provision in meeting life-long needs could be explored. Answers to these questions can provide a platform for formal and informal educational reform.

Posner, Strike et al.'s (1982) model was derived from a study of the history of science. In some circles, it is widely recognised that science is not always a purely rational cognitive pursuit (Knorr-Cetina, 1981). It would be a fascinating adventure to explore scientific epistemology with an affective and conative lens.
11.11 ENDING

This thesis has sought to bring together two disparate worlds, the world of the scientist and the everyday world of the public. To unit these worlds it has been necessary to rethink traditional models of learning. The Extended Conceptual Change model provides an alternative view to learning science as a cognitive pursuit - this thesis has drawn science out of its cognitive hideaway and added conative and affective ingredients. It is suggested that the synthesis of these three perspectives has made the analysis particularly rich.

Throughout the last twenty years science educators have paid an ever increasing attention to the informal ideas which pupils bring into the classroom, the 'outside-in'. The extent to which learning in the classroom aids or hinders the demands of informal learning, the 'inside-out', has escaped due consideration. In the opening chapter, a quotation was adapted from Tressel (1994, p 8), 'for most of the time, most of us learn most of what we know about science outside of school'. It is somewhat ironic that this is the area that we probably know least about. It is hoped that the offerings here have illuminated some of the complexities associated with this research imperative.

To pave a path towards the needs of informal learners and life-long learning is to recognise some of the additions that have been proposed. Arguably, for too long, the worlds of formal and informal science education have remained separate. A suggested starting point for a new life-long learning research agenda is to consider the cognitive, conative and affective.

Strike and Posner (1985) described their model of learning as a 'modern alternative to empiricism, the main tradition in western philosophy and philosophy of science for centuries' (p.216). Philosophers have shown intensive interest in the nature of knowledge, its production, validation and organisation, however, the relationship between knowledge and emotions, knowledge and practical action, has yet to be a major theme.
The thesis finishes - as it started - with two quotations. The opening quotes were chosen to highlight the considerable differences between scientists and informal learners. The concluding quotations have been chosen to be more optimistic - they highlight an openness, an eagerness to engage and exchange ideas, a willingness to listen and recognise and share expertise - a freeing of voices.

Persons directly affected by an environmental problem will have a keener awareness of its symptoms, and a more pressing concern with the quality of official reassurances, than those in other roles. Thus they perform a function analogous to that of professional science, which otherwise might not occur in these new contexts

(Funtowicz and Ravetz 1993, p740)

I need to know more. I need to know why, what our levels [of radioactivity] are, how that compares to the national average, what are the incidences of risk. I can understand figures, I need to know the odds so that I can do something about it all.

(Nigel, a case study Chapter 10)
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APPENDIX ONE

A MEDIA ANALYSIS

CONTENT

1. A LIST OF NEWSPAPER ARTICLES USED
2. AN INDICATIVE NEWSPAPER ARTICLE
3. THE RADON LEAFLETS USED*
4. A SECTION OF TELEVISION TRANSCRIPT

* The At-a-Glance Leaflet (NRPB, 1995) also formed the intervention in phase four of the data collection, Learning from an Informal Information Source.
1. A LIST OF NEWSPAPER ARTICLES USED

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MORE than 16,000 homes in Britain have been found to have dangerous levels of the Radioactive gas radon, which can cause lung cancer, the National Radiological Protection Board said yesterday. Continuing research could show a further 84,000 homes are involved. Only one in ten families affected take action to avert the threat, according to the board, but it is at a loss to know how to convince people that they are in real danger. Although public education in the worst radon areas was beginning to have effect, said the board, the public was much more alarmed about man-made Radiation which, a the extremely low levels found in the UK, was in fact far less dangerous. An encouraging trend was that some mortgage companies were requiring prospective purchasers to have radon levels measured, and if necessary, reduced. The work on radon was originally concentrated in Cornwall and Devon, where the worst exposure was known to occur, but has been expanded to cover Derbyshire, Northamptonshire and Somerset in England, Grampian and Highland in Scotland, and Down and Armagh in Northern Ireland. The board believes that other pockets may yet be found, but the larger areas have all now been identified. The organisation provides free testing to homes in high risk areas. Homes most vulnerable to radon are built on granite, limestone, and sandstone. The radon seeps up through foundations and is trapped in the houses, particularly those with poor ventilation. Grants are available for remedial action, which can cost from a few pounds up to pounds 1,000 at most. New houses in the affected areas are now built to prevent the entry of radon. Naturally occurring radon gas has long been known to be a killer, but the extent of public exposure to it in British houses has only gradually unfolded in the last 10 years. Studies among miners exposed to radon show that lung cancer deaths can increase up to six times the expected amount among the normal population. Children between five and 14 years are most at risk The international maximum dose of radon in air is 200 Becquerels per cubic metre, but exposure in some homes has been found to be well above 1,000bq. Worst affected towns in the newer areas to be identified are Buxton in Derbyshire and Northampton and Kettering in Northamptonshire. In Devon and Cornwall and Northamptonshire, 24 per cent of the homes tested have been found to be above the danger level. Remedial measures include sealing the floor of the house or increasing the ventilation, but the most effective way is to use a fan to draw off the gas below the floorboard level so it cannot enter the living space.
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APPENDIX TWO

INTERVIEWS ABOUT SCENARIOS

CONTENT

1. THE SCENARIOS
2. A SECTION OF TRANSCRIPT
1. **THE SCENARIOS**

In the study each scenario was presented on an A4 piece of card.

- **Scenario 1**: A box containing a radioactive substance is left open. What happens?
- **Scenario 2**: A radioactive substance is heated. What happens?
- **Scenario 3**: A radioactive substance is dumped in the sea. What happens?
- **Scenario 4**: A radioactive substance is left for a long time. What happens?
- **Scenario 5**: A radioactive substance is cooled. What happens?
- **Scenario 6**: A radioactive substance is looked at under a very powerful microscope. What would you see?
- **Scenario 7**: A radioactive substance is dropped. What happens?
- **Scenario 8**: A radioactive substance is listened to. What would you hear?
- **Scenario 9**: A radioactive substance is placed near a thermometer. What happens?
A radioactive substance is held near somebody’s hand

What Happens?

Scenario 10

A radioactive substance is placed near a mirror

What happens?

Scenario 11

A metal object is placed near a radioactive substance

What happens?

Scenario 12

Somebody swallows a radioactive substance

What happens?

Scenario 13

A house is built on rock which contains high levels of radioactivity

What happens?

Scenario 14

Some parts of the UK have high levels of background radiation?

Where does it come from?

Scenario 15

A scientist wishes to find out if low levels of radioactivity are harmful

What can they do?

Scenario 16

Somebody breathes in a radioactive substance

What happens?

Scenario 17

A radioactive substance needs to be made safe

What needs to happen?

Scenario 18
2. A SECTION OF IAS TRANSCRIPT

The following section of indicative transcript documents the discussions about scenarios one to four and is taken from Cathy’s interview.

**INTERVIEW WITH CATHY, PART I.**

*Interviewer:* A box containing a radioactive substance is left open. What happens?

[Scenario one]

*Cathy* It will give of these particles...alpha, beta and gamma seems to ring a bell somewhere.

*Interviewer:* It does. And what are those?

*Cathy* Well, alpha and beta are different sizes. I can’t remember which one’s bigger and which one’s the other. Gamma are rays.

*Interviewer:* Are they different in other ways?

*Cathy* Yes, rays I think travel faster.... yes much faster than the particles. They would travel in about a second.

*Interviewer:* Where did you learn about this

*Cathy* From my physics at school, I think, I also remember talking about it with my brother, who has a physics A level.

*Interviewer:* Would they come out in all directions?

*Cathy:* Yes, I think they would, but maybe the lid would effect them.
Interviewer: How?

Cathy: Well it might be made of a metal, like lead which blocks radioactivity.

Interviewer: Could you see it? or taste it?

Cathy: No

Interviewer: Would you be able to sense it at all?

Cathy: No, no sense can pick it up - but it can be detected by a machine.

Interviewer: if you had a peep in the box - what would you see

Cathy: A lump of - a radioactive piece of metal

Interviewer: What would it look like?

Cathy: Mm greyish a bit like a lump of something like Iron.

Interviewer: A radioactive substance is heated -what happens? [Scenario two]

Cathy: Oh - well it melts

Interviewer: Would it make it more radioactive?

Cathy: It might speed up the half life because the particles are moving around so it mixes it all up and makes it happen faster.

Interviewer: You have mentioned the word - half life - what does that mean?

Cathy: Half life is the length of time it takes for half of the radioactive atoms to decompose and release their particles.

Interviewer: Where does that come from?

Cathy: Again it is something that I remember from school.

Interviewer: A radioactive substance is dumped in the sea [scenario three]

Cathy: Yes

Interviewer: What happens?

Cathy: It releases its radioactivity into the sea and the radioactivity is then absorbed by the plants and the animals and things and we come along and fish them out and eat them.

Interviewer: and then what happens

Cathy: They would die a horrible death,

Interviewer: Does it effect the plants

Cathy: Yes it would, it would get inside the plants, I am not sure how - it might attaches itself to salt or something and gets absorbed into the plant. I know it gets into the food chain.

Interviewer: What happens to the fish?

Cathy: if you pulled the fish out and had a look at them you wouldn't see any difference- immediately-the texture-would the skin show any affects
Interviewer: What happens to the fish them?
Cathy: Well the radioactivity gets inside them and then causes cancer and then they die.

Interviewer: You associate radioactivity with cancer?
Cathy: Yes I do - you hear all these news stories and reports about cancer which has been caused by radioactivity.

Interviewer: How does it get in the fish?
Cathy: Well, they will either breathe it in or they will eat the plants and it is passed down the food chain.

Interviewer: What happens to the plants?
Cathy: I don't think the plants get cancer, but they might get some type of genetic mutations - I know it will not be very good for them.

Interviewer: A radioactive substance is left for a very long time. What happens?
Cathy: It will start to decompose.

Interviewer: What do you mean by decompose?
Cathy: It means that the atoms of the radioactive substance break down and release their particles while the radioactive substance goes shooting off. I don't think it actually visually looks very different, but it might actually shrink over time. I know that the radioactivity goes away and I know it takes a long time because of the half-life thing.

Interviewer: So if somebody opened the box in many years time would it look different
Cathy: Well I guess not, the decomposing and the bits are going off- but I think it would be a very tiny bit that's coming out.

Interviewer: Would it ever go down to zero?
Cathy: Mmm, I wouldn't have thought so - no I don't think it would. There's the atoms which are decomposing and the bits are going off- but what happens to the rest of it, you know, it is a very tiny bit that's coming out.

Interviewer: So if I weighed the box and then left it for a long time and then re-weighed it you wouldn't notice any differences?
Cathy: No I don't think you would.

Interviewer: A radioactive substance is cooled? [Scenario, 4]
Cathy: I don't think it would make any difference to the radioactivity of it. It might make a difference to the half-life.

Interviewer: What difference would it make?
Cathy: Because the reverse of the heating, if you are cooling it down, it stops
them moving around- it stops the atoms moving around.

*Interviewer:* Is there a temperature where radioactivity substances are most active?

*Cathy:* I am not sure, but I suspect they are more active at room temperature.

*Interviewer:* Why do you think that?

*Cathy:* Well, I know radioactivity is very dangerous and I find it difficult to imagine how it can get any more dangerous - it seems very active and dangerous at room temperature.
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