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Mike Summers , Colin Kruger & Ann Childs
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Understanding the science of environmental issues: development of a subject knowledge guide for primary teacher education

Mike Summers, Colin Kruger, Ann Childs, Oxford University Department of Educational Studies, UK and Jenny Mant, Oxford Brookes University, UK

In the light of an increased concern for environmental education (especially in the context of sustainable development) in the UK, this study used questionnaire surveys to explore the understanding of 170 practising primary school teachers, 120 primary trainees and 88 secondary science trainees in four areas: biodiversity, the carbon cycle, ozone and global warming. A methodological innovation in this research was the prior identification of basic scientific explanations of each area for a primary teacher and the use of these as benchmarks for judging understanding. Knowledge of the component parts of these explanations was tested in the questionnaires. Hence the study was able to identify those underpinning science concepts which were well understood, and those which were not so well understood. The frequencies of several misconceptions, uncovered in earlier interviews and also included in the questionnaires, are also reported. It is suggested that both the basic explanations and the difficulties of understanding displayed by the teachers in some areas can usefully inform programmes of professional development for sustainable development and environmental education. An outline of a guide for teachers adopting this approach is provided.

Introduction

Premise

A basic premise underpinning the research described in this article is that education about the environment is of such importance that it should begin in primary schools. Given national and international commitments to Agenda 21 following the Rio de Janeiro Earth Summit Conference (Quarrie 1992), it seems inconceivable that this should not be so. The future quality and stability of life on our planet depends on children developing the understanding necessary for making informed decisions about the environment. Francis *et al.* (1993) point to the importance of education about these issues starting early and before attitudes and prejudices based on misconceptions harden. Evidence that this is now an accepted argument in the UK can be found in a number of recent developments, the most significant of which are outlined below.

Environmental education and sustainable development

An increased recognition of the importance of education for sustainable development (see below) provides an important reason for developing children's understanding of environmental issues. The concept of sustainable development is

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multifaceted, and involves environmental, economic and social consequences of humanity's activities. However, the whole rationale underpinning arguments for sustainable development is the prevention of damage to the environment. This is reflected in the definition of the purpose of education for sustainable development in the schools sector provided by the Council for Environmental Education (1998):

> Education for sustainable development enables people to develop the knowledge, values and skills to participate in decisions about the way we do things individually and collectively, both locally and globally, that will improve the quality of life now and without damaging the planet for the future.

Hence we see sustainable development and environmental concerns as inextricably linked: education about the former is intimately bound up with consideration of the latter.

Recent initiatives in the UK

Three recent developments in the UK have provided impetus and support for the growth of sustainable development and environmental education:

(1) The government's paper 'A Better Quality of Life: a National Strategy for Sustainable Development for the United Kingdom' (DETR 1999). The consultation report leading up to the publication of this national strategy emphasises the key role of education:

> The most consistent theme is the need to integrate sustainable development into education and training at all levels. (DETR 1998: 69)

(2) The recent report to the Qualifications and Assessment Authority and the Department for Education and Employment by the Panel for Education for Sustainable Development headed by Sir Geoffrey Holland (Council for Environmental Education 1998). This advocates sustainable development education at all four Key Stages of the National Curriculum.

(3) A revised National Curriculum for implementation in September 2000 strongly influenced by the above report (Qualifications and Assessment Authority 1999). A substantially increased emphasis on the environment and sustainable development is evident in science and geography, and is also a prominent feature in a revised introduction setting out the aims of the curriculum as a whole.

The enquiry

An underlying assumption of this project is that secure subject knowledge (which in this article is taken to include understanding) is desirable for the most effective teaching. This point has been argued on many occasions elsewhere (e.g. Summers 1994, Summers and Mant 1995) and will not be revisited here.

The overarching aim of the work was to help teachers develop this secure knowledge. As such, the principal outcome was to be a guide to help primary teachers develop their understanding of several environmental issues. In recognition of the importance of prior knowledge as a basis for learning, the starting point was to investigate teachers' existing understanding of the targeted issues, and in particular, identify areas of difficulty. These were then to be given special emphasis when writing the guide. The main focus in what follows is the research programme and its findings, but the ways in which the work has been used to inform the production of the guide will also be outlined.

Scope

The earlier definition of education for sustainable development emphasized the three dimensions of knowledge, values and skills (for example, of decision making). Our own focus on teacher knowledge in the present research is clearly just one aspect of what will be required to help pupils develop their learning in these three dimensions. However, and as we said above, it is our view that good teacher knowledge is a prerequisite for the most effective teaching.

A further restriction is the concentration principally on *scientific* knowledge, to the exclusion of very important geographical and cross curricular perspectives. To some extent this reflects our own research tradition and expertise (science education). But it also stems from a belief in the centrality of science in understanding and making appropriate decisions about the environment.

Areas and issues explored

In selecting areas for the project, the vision was not constrained by the extant National Curriculum requirements of England and Wales at the time (July 1998). Rather, the approach was to identify current issues of significance for the future of the planet. Subsequently, and as already stated, the curriculum has been revised to include a far greater emphasis on environmental and sustainable development concerns, which may prove something of an unforeseen bonus for our work (in that teachers may more readily perceive its value). An ongoing research programme is exploring, through primary classroom case studies, ways in which the work described here can be used, adapted and extended in the context of National Curriculum delivery (Summers *et al*. 1999).

Returning to the selection of areas, seven were eventually identified as the focus for the project: biodiversity, the carbon cycle, global warming, ozone, energy sources, life-cycle analysis (of a manufactured product) and sustainability. This is not to deny the importance of other topics: a choice had to be made, and both the research team and sponsors felt that the significance of this selection could hardly be denied.

Each of the areas, except the carbon cycle, can be formulated in terms of an environmental issue. The word ‘issue’ is used to mean that which generates a concern and is at least potentially problematic for the environment. The carbon cycle was included as an area for research because a good understanding of it is a necessary prerequisite for a scientific understanding of many environmental concerns, and because it was identified as an area of difficulty in an earlier small scale study.

The way in which the issues were formulated is described later. For grammatical convenience all seven areas will be referred to, at times, as issues, but the distinctive nature of the carbon cycle should be kept in mind. The work was carried out in two phases: Phase I covered biodiversity, global warming, the carbon cycle and ozone, and Phase II the remaining three areas. This was an extensive programme of research and there is insufficient space in a single article to report all of the findings. Hence the focus here will be on the Phase I areas.

Previous work

A search of the research literature has uncovered no previous investigations of practising primary teachers' understanding of environmental issues and sustainable development. In a small scale interview study of six primary teachers carried out by the authors in 1997 evidence was found of: uncertainty about the carbon cycle, and a lack of knowledge of the key role of 'ancient carbon' in environmental concerns such as depletion of fossil fuels and global warming; a condemnation of carbon dioxide as universally a 'bad thing'; life-world only meanings for 'sustainable' and 'renewable' (i.e. meanings derived from everyday experiences and use of words, rather than scientific interpretations); lack of an appreciation of the role of life cycle analysis as a basis for making decisions about recycling; a confusion between global warming, ozone depletion and 'ground level' ozone; and a view that energy can be recovered and re-used (no concepts of dissipation and degradation).

Two studies of *trainee* primary school teachers were found. Dove (1996) used a questionnaire survey to investigate the understanding of 60 trainees in three areas: the greenhouse effect, ozone layer depletion and acid rain. Boyes *et al*. (1995) studied aspects of understanding of the ozone layer only but with a much larger questionnaire survey of 453 trainees. In the case of ozone, both studies found that trainees were aware of the function of the ozone layer in relation to its filtering effect of UV light, the consequent harmful effects when the ozone layer is depleted and the role of CFCs in ozone depletion. Boyes *et al*. also showed that the trainees were well informed about the location and the nature of the ozone layer. However both studies found that notable misconceptions. For example, many trainees thought that vehicle emissions were responsible for ozone depletion. Boyes *et el*. report that radioactivity and acid rain were also thought to be responsible. Both studies revealed a further commonly held misconception: that 'holes' in the ozone layer are a direct cause of global warming.

In the case of the greenhouse effect, Dove found that the trainees were generally familiar with the term itself but had little awareness of the concepts involved. They were aware, for example, of carbon dioxide as an important greenhouse gas but had little awareness of other greenhouse gases and were largely unaware of the natural greenhouse effect. They also held the common misconception that 'holes' in the ozone layer are a direct cause of global warming. Turning to acid rain, most trainees were aware that burning coal was responsible, but their knowledge of the specific gases involved was low. They were also aware of some of the effects of acid rain, such as increased weathering of rocks, but did not understand the reasons for this. In addition, although they knew forests in Scandinavia had been damaged by acid rain, they were again unable to explain the causes.

The present research therefore contributes to knowledge in two ways: (i) by extending the coverage to new aspects of environmental issues; and (ii) by extending the sparse amount of previous work carried out with trainee primary teachers to experienced practitioners. In addition, there is a methodological innovation in that benchmarks for understanding each issue were defined at the outset of the research and used as a framework for analysing the data. This is described further in the next section.

Scientific understanding

In recent years, the level of scientific understanding that might be expected of a primary teacher has been a matter of considerable debate (see, for example, Kruger *et al*. 1990; Russell *et al*. 1992; Golby *et al*. 1995; Summers and Mant 1995). In the UK the *official* resolution of this debate has been through publication of a mandatory Initial Teacher Training Curriculum for Primary Science (DfEE 1998). This specifies a far more sophisticated knowledge of science than that found in the National Curriculum for pupils (although it has little to say about environmental issues). We have always been in sympathy with the view that teachers need wider and deeper knowledge than that required of pupils, arguing that this is important for a whole variety of reasons: diagnosing pupil learning difficulties, responding flexibly to pupil needs, dealing with unforeseen questions, devising appropriate learning experiences in science and understanding what might validly count as progression.

An initial task for the present research was to decide what might constitute an appropriate understanding of the targeted environmental areas for a primary teacher and, for all except the carbon cycle, specify the issues involved. Given the above context, we did not feel constrained by the conceptual content of the UK pupil curriculum in deciding what might be appropriate for teachers.

Drawing upon an approach used successfully in an earlier study (Summers and Kruger 1994) a basic explanation was constructed for each of the seven areas. This consisted of a number of component statements (explanation components or ECs) which, when read in sequence, both provided an explanation of the area and, where appropriate, defined the issue. These basic explanations were used as benchmarks against which understanding was judged. The explanation components for biodiversity, the carbon cycle, ozone and global warming are given in tables 1-4 (left hand column in each case). For reasons of space, these are the only four topics reported in the present paper.

The process of devising these basic explanations went through several stages. Initially, the four team members (all science graduates) researched the areas and produced explanations at their own level. Then over a series of meetings these explanations were compared, combined and simplified to try to capture just the essential ingredients of each.

It must be emphasized that these explanations represent no more than our own shared and distilled professional judgements of what might be appropriate for primary teachers, and no status is claimed for them beyond this. However, it does seem that we can claim originality - a search of the literature has failed to uncover any other explicit attempts to define understanding of these issues for primary teachers.

Methodology

Overview

Twelve primary teachers were interviewed about their understanding in the four areas forming Phase I of the research. Following this two questionnaire surveys were given to a much larger number of primary teachers. One questionnaire covered biodiversity and the carbon cycle, and the other ozone and global warming. The questionnaires were designed to test knowledge of each EC for each issue, and also included the most common misconceptions uncovered in the earlier interviews. Hence the questionnaires sought to establish the prevalence of scientific understanding and misconceptions in these larger samples.

The advantage of interviews is that they can provide in depth information of high validity. But the frequency of particular views within a small sample can, at best, give no more than an indication of what might be the case in the wider community of teachers. The advantage of questionnaires is that prevalence can be established with greater confidence (assuming of course that the sample is not unduly biased). But the disadvantages are that validity is less certain (we cannot be sure that respondents understood the questions in the way intended, or indeed that they responded seriously), and that knowledge statements are tested in isolation rather than as elements of an elaborated explanation. The reasons for employing both methods in the present research were: (i) to avoid the limitations of just one approach and hence provide a more comprehensive account of teachers' conceptions of the four issues investigated; and (ii) more specifically, to use the interviews to uncover any misconceptions and then include these in the questionnaires (to test prevalence).

Presentation

Even though this article covers only the first four areas targeted by the research programme, the data set is still very large. Hence just the questionnaire (prevalence) findings for these areas are reported here.

Sample

The sample for the first survey consisted of 85 primary teachers working in nine different state schools, and 120 student primary teachers. The second survey was made up of another 85 teachers in a further 19 state primary schools, and 88 science graduates nearing the end of their one year secondary teacher training (PGCE) course. Both sets of practising teachers were recruited by writing to headteachers requesting participation of staff, and through contacts with science advisers. These were not random samples, but we have no reason to believe that they were particularly biased.

The inclusion of a group of secondary trainees in a research project concerned with primary teaching deserves comment. Over the past decade we have produced several sets of research-based teacher education materials for primary science designed primarily to develop understanding of subject matter. Two of the present authors work mainly in secondary teacher education, and have found these materials to also be of use for helping non-specialist secondary PGCE science

THE SCHOOL VISIT
This shows an open-air industrial museum near a forest which is being cleared. A school party is watching coal and firewood being loaded into the furnace of a steam engine. Children are sitting on an old rotting log next to a tree whose leaves shade them from the sun. A few sheep are grazing on the grass nearby.

Figure 1. Line drawing and introductory description used in the questionnaire covering the carbon cycle.

students prepare for teaching outside of their specialist subject (e.g. a biologist teaching physics or chemistry, or vice versa). This non-specialist teaching is an increasing feature of secondary science teaching in the UK (at Key Stage 3 especially), but graduate scientists often feel insecure when working outside of their graduate specialism. In the case of the present research, we had little idea of the level of understanding of environmental issues possessed by recent science graduates. Hence a readily accessible group of secondary PGCE science students was included in the sample to give some indication of the extent to which the intended product (the guide for teachers) might be helpful for teaching at the lower secondary level. We revisit this point towards the end of the article.

The two questionnaires

Each questionnaire contained two line drawings, one for each of the two environmental issues covered. A drawing depicted an aspect of the issue under investigation (see figure 1 for an example). Underneath each drawing were about 20 statements covering every EC for the targeted issue and a selection of the misconceptions (including the most prevalent) which had been uncovered through the interviews. Teachers were asked to respond true, false, don't understand, or not sure to each statement by ticking the appropriate box.

The two questionnaires were each piloted with two teachers. Afterwards the respondents were interviewed about their responses to check that they had interpreted the statements in the way intended and that the responses were eliciting valid information. Statements which had not been understood in the intended way were reworded.

Questionnaires were in all cases administered in person by a member of the research team to ensure 100% returns and consistency of conditions for completion. Typically the time taken to complete a questionnaire was about 20 minutes. Analysis involved simple counting of the numbers of responses in each of the four response categories.

Results

These are shown in tables 1-4. The percentages given alongside each EC are the proportions of the sample affirming or showing uncertainty about the idea, as measured by the statement used to test the particular EC in the questionnaire. The latter point is an important limitation of the questionnaire methodology adopted for the prevalence stage, where consideration of length of the instrument dictated that usually only one statement could be used to test any one EC. In addition to ECs, the tables also include the main misconceptions for each of the four areas uncovered by the earlier interviews and subsequently included in the questionnaires. Again, and for the same reasons, each misconception was usually explored by just a single questionnaire statement.

In the following brief account, substantial understanding of an EC is taken to be shown by correct responses from about two thirds or more of respondents; a lesser degree of understanding is shown by fewer than this, by a third or more of 'not sure' responses, or by significant support for (or uncertainty about) a misconception.

Biodiversity

On the above basis, practising teachers showed substantial understanding of eight of the 12 ECs for biodiversity (table 1). They had difficulties with: the nature and uniqueness of a species (ECs 1, 8); the loss of diversity within species (EC 3a); the specific living conditions required by many species in ecosystems (EC 6) and the role of variation within a species in enabling it to adapt to change (EC 10). Incorrect views about genetic variation in modern crops (statement 5) and considerable uncertainty about Lamarckian statements (nos. 11, 17) bear out trends seen in the interview data indicating difficulty with ideas about evolution, diversity within species and how these are both related.

Trainee primary teachers showed greater uncertainty for nearly all ECs than practising teachers and a smaller proportion of correct responses. Half of the ECs were understood substantially but there was either considerable support for, or uncertainty about, all the misconceptions shown in table 1.

Carbon cycle

For the carbon cycle (table 2), practising teachers showed substantial understanding of four of the 11 ECs; overall few gave correct responses and more expressed doubt than for biodiversity ECs. Trends described in the interviews were largely supported by the questionnaire findings. Problem areas for teachers were: the proportion of carbon dioxide in the atmosphere (EC 1); production of carbon dioxide from the burning of fossil fuels (EC 2); the ‘fixing’ of atmospheric carbon dioxide into the bodies of plants (ECs 3, 7); the relationship between decay, carbon dioxide production and fossil fuel formation (ECs 4, 6); humanity’s upsetting of the balance in today’s atmosphere by returning ‘ancient carbon’ to it (ECs 9, 10) and confusion between respiration and photosynthesis (Statement 28).

The findings for primary trainees mirrored those for practising teachers but to a lesser extent than with biodiversity. Usually, more of the students were uncertain or incorrect but they did show better understanding than the practising teachers of some ECs, namely, carbon dioxide production from the burning of fossil fuels or decay (ECs 2, 4), humanity’s disturbance of the carbon cycle, e.g. by deforestation (ECs 9, 11), and the notion of ‘ancient carbon’ (EC 10) - although this last one was still poorly understood by the sample as a whole.

Ozone

In the case of ozone, practising teachers showed substantial understanding of only two of the nine ECs and a third or more agreed with, or were uncertain about, seven of the misconceptions in table 3. Substantial understanding of ozone layer depletion (EC 2a), its adverse effects on human health (part of EC 2b) and its causes (EC 5) was evident but other ECs were less well understood; seven of them elicited correct responses from only about one half or less of the teachers and eight elicited notable proportions (about one third or more) of ‘not sure’ responses. A significant finding is the large support (88%) shown for the misconception that pollution from fossil fuels is destroying the ozone layer.

The trainee secondary science teachers showed substantial understanding of only four of the nine ozone ECs - those already described plus the beneficial nature of the ozone layer (part of EC 2b) and its ability to repair itself (EC 6). The recent increase in ground-level ozone, its toxicity, the role of the sun in its production and the unnatural nature of fluctuations in the ozone layer were all areas which seemed to be less well understood. About one third or more of these students affirmed or were unsure about seven of the misconceptions shown in table 3.

Global warming

With global warming, as with the ozone data just described, the questionnaire findings (table 4) largely supported trends seen during the interviews. Seven of the 11 ECs for global warming were understood substantially with the areas of particular difficulty being: the role of carbon dioxide as the most important greenhouse gas controllable by humanity (EC 4); the natural greenhouse effect (EC 5); the Earth’s balance of incoming and outgoing solar energy (EC 6); Man’s effect on greenhouse gases (EC 7) and the uncertainty about the causes of global warming

Table 1. Understanding of biodiversity shown by practising ($N = 85$: bold figures) and trainee ($N = 120$: plain figures) primary teachers as measured by the prevalence questionnaire statements. The correct response (TRUE or FALSE) is given alongside each statement

Explanation components	*Statement(s)*	*Correct (%)*		*Not sure (%)*	
Preliminary knowledge					
1. A species is a group of living things which can breed with each other and produce fertile offspring.	1. Different species in the main forest can breed with each other. (FALSE)	**59**	*58*	**27**	*29*
The issues					
2a. There is a loss of the diversity *of* species	2. The total number of species on Earth is getting less. (TRUE)	**78**	*55*	**11**	*35*
2b. This diversity is needed for aesthetic, moral and practical (e.g. beneficial to Man) reasons.	3. The enormous number of species found on Earth is of practical benefit to Mankind. (TRUE)	**93**	*77*	**6**	*18*
3a. There is a loss of the diversity *within* species	4. There is less variety now in food crops such as wheat than there was in former times. (TRUE)	**26**	*24*	**34**	*33*
3b. This diversity is needed to resist extinction by pests or disease.	6. If a species has lots of variation among its individuals, it's more able to resist becoming extinct. (TRUE)	**69**	*73*	**20**	*23*
Diversity of species: main ideas					
4. Living things exist in communities made up of many inter-dependent species linked by a network of relationships e.g. feeding, competition.	7. Most species in the rain forest are independent of the other species in the community. (FALSE)	**67**	*64*	**18**	*19*
5. The living things interact with each other and with their non-living environment to form a balanced, self-sufficient unit called an *ecosystem* e.g. a particular woodland, forest, tundra, stream, pond etc.	8. The rain forest ecosystem is made up of just the plants and the animals in it. (FALSE)	**65**	*71*	**15**	*16*
6. Most species in the wild can survive only in the conditions pertaining in their particular ecosystem.	10. Most species' flexibility about living requirements enable them to tolerate a change in the habitat. (FALSE)	**25**	*35*	**28**	*25*
7. Human activity (e.g. habitat destruction, foreign introductions, pollution, over-harvesting) adversely affects many ecosystems, causing extinction of species and consequent loss of biodiversity.	12. Human activity has adversely affected many ecosystems. (TRUE)	**98**	*96*	**0**	*3*

8. These lost species cannot be replaced.	14. A rain forest species which has become extinct can re-appear during the course of evolution. (FALSE)	**61**	*63*	**35**	*32*
Diversity within species: main ideas					
9. All members of a species have the same basic genetic makeup but there is a diversity due to small variations between individuals.	15. Individuals of a particular species of forest plant have a basically similar genetic makeup. (TRUE)	**76**	*59*	**19**	*32*
	18. The genetic makeup of each individual of the species of butterfly shown in the forest picture is slightly different. (TRUE)	**64**	*67*	**27**	*29*
10. These variations enable some individuals to survive and the species to adapt to changed conditions (e.g. to resist extinction by new pests or diseases which kill the rest - see 3b above).	16. A species adapts to changed conditions because its members are all a bit different. (TRUE)	**36**	*31*	**42**	*36*
	20. The survival of some slightly different individuals when conditions change enables a species to adapt. (TRUE)	**79**	*70*	**14**	*24*
Misconceptions	*Statement(s)*	*Occurrence (%)*		*Not sure (%)*	
• Unaware that selective breeding from wild forebears much *reduces* their original varied genetic makeup.	5. Modern types of crops such as wheat are more genetically varied than their ancestors. (FALSE)	**64**	*53*	**22**	*27*
• Confusing 'ecosystem' (includes non-living factors) in a habitat and 'community' (living things only).	9. The terms 'rain ecosystem' and 'rain forest community' have the same meaning. (FALSE)	**7**	*3*	**31**	*33*
• A Lamarckian view of evolution (i.e. inheritance of acquired characteristics). The Darwinian view is that changes in an organism acquired during its lifetime are not passed on to its descendants. Only genetic changes in reproductive cells are passed on.	11. The fore-limbs of rain forest monkeys have become elongated due to the stretching of them by many previous generations moving through the upper canopy. (FALSE)	**29**	*14*	**44**	*52*
	19. Disease-resistance given to wheat plants by the farmer spraying them passes on to their descendants. (FALSE)	**22**	*18*	**22**	*33*
• Confusion between 'ecosystem' and 'biosphere'.	13. The entire planet Earth consists of one ecosystem. (FALSE)	**24**	*18*	**25**	*31*
• Confusing the differences between individuals due to lifetime influences with those (not found in identical twins) due to normal genetic variation in individuals.	17. The differences between each of the individual mahogany trees in the rain forest are due solely to the influence of the environment. (FALSE)	**16**	*15*	**40**	*39*

Table 2. Understanding of the carbon cycle shown by practising ($N = 85$: bold figures) and trainee ($N = 120$: plain figures) primary teachers as measured by the prevalence questionnaire statements. The correct response (TRUE or FALSE) is given alongside each statement

Explanation components	*Statement(s)*	*Correct (%)*		*Not sure (%)*	
Preliminary knowledge					
1. Carbon dioxide (CO_2) is a gas found in very small amounts in the atmosphere.	21. Normally there is a tiny proportion (less than 0.1%) of carbon dioxide in the air children breathe. (TRUE)	**41**	*32*	**32**	*32*
2. Because fossil fuels (coal, oil) contain carbon, burning them produces carbon dioxide.	22. Burning coal produces carbon dioxide. (TRUE)	**56**	*79*	**21**	*15*
The natural carbon cycle					
3. During photosynthesis, plants *remove* CO_2 from the atmosphere with the carbon eventually becoming much of the tissue of plants, of herbivores or of their predators.	24. When leaves take in carbon dioxide, some of the carbon eventually forms the body of the tree. (TRUE)	**39**	*35*	**42**	*53*
	39. Carbon is not a constituent of the flesh of the sheep. (FALSE)	**11**	*24*	**68**	*56*
4. Living things *release* CO_2 into the atmosphere during respiration and through bodily decay after death.	25. When the log the children are sitting on decays, carbon dioxide goes into the air. (TRUE)	**22**	*33*	**62**	*45*
	27. When the children respire, they produce carbon dioxide. (TRUE)	**85**	*83*	**8**	*9*
5. For millions of years these processes of removal and release kept the amount CO_2 in the atmosphere about the same (i.e. the 2 processes balanced each other).	29. For long periods in the past the natural movement of carbon dioxide into and out of the atmosphere kept it at roughly the same level. (TRUE)	**64**	*53*	**28**	*38*
A side effect of the natural carbon cycle - formation of fossil fuels					
6. When decay of living things' bodies is prevented (e.g. through burial in environments lacking oxygen), fossil fuels are formed.	30. When decay doesn't happen, fossil fuels are formed. (TRUE)	**18**	*14*	**42**	*50*
7. Hence, instead of being returned to the atmosphere as CO_2 through decay, the carbon is 'locked up' in the fossil fuel.	32. A lot of carbon from the atmosphere of long ago is now inside fossil fuels. (TRUE)	**54**	*53*	**36**	*49*

8. Fossil fuels were formed in the distant past over a period of millions of years, locking up a huge quantity of CO_2 Disturbance of the natural carbon cycle	33. The formation of fossil fuels took place during millions of years in ancient times. (TRUE)	**86**	*80*	**12**	*17*
'Disturbance of the natural carbon cycle'					
9. Man has disturbed the balance of the natural cycle since the industrial revolution, and more so in recent years, by the rapid increase in the burning of fossil fuels.	35. Man's burning of fossil fuels has kept the level of carbon dioxide in the atmosphere about the same. (FALSE)	**55**	*66*	**39**	*31*
10. This returns a huge quantity of 'ancient carbon' as CO_2 into the atmosphere over a short period (a few tens of years).	36. The atmosphere of today has lots of extra carbon in it which came from the atmosphere of long ago. (TRUE)	**15**	*16*	**59**	*44*
11. Deforestation adds to the problem by reducing a main way in which CO_2 is removed from the atmosphere i.e. photosynthesis.	27. Cutting trees down increases atmospheric CO_2. (TRUE)	**55**	*67*	**28**	*24*
	40. Cutting down trees makes the effect of burning fossil fuels on the atmosphere even worse. (TRUE)	**69**	*74*	**25**	*23*
Misconceptions	*Statement(s)*	*Occurrence (%)*		*Not sure (%)*	
• The burning of coal releases CO_2 trapped in it.	23. Coal already contains carbon dioxide trapped within it. (FALSE)	**34**	*31*	**48**	*34*
• Decay returns carbon only to the soil and not to the air (as CO_2) i.e. not aware of CO_2 production.	26. In the carbon cycle, during decay, carbon only goes into the soil. (FALSE)	**6**	*13*	**59**	*48*
• Mixed up about the role of CO_2 in respiration (confusion with photosynthesis?).	28. In plants, carbon dioxide is taken in as part of the process of respiration. (FALSE)	**75**	*75*	**9**	*12*
• Not aware that it is the *absence* of normal processes of decay that results in fossil fuel formation.	31. Fossil fuels are formed from the decay of things that were once alive. (FALSE)	**80**	*73*	**16**	*20*
• Similar to above (see 26) but specifies the process of leaf fall which returns the carbon to the soil.	34. The carbon cycle is about returning carbon to the soil during leaf fall rather than carbon dioxide to the air. (FALSE)	**22**	*18*	**56**	*57*
• Not aware of the *indirect* route (via plants eaten) by which atmospheric carbon become animal tissue.	38. The flesh of the sheep is made up from carbon which they took in from the air. (FALSE)	**4**	*3*	**67**	*53*

Table 3. Understanding of ozone shown by primary teachers ($N = 85$: bold figures) and trainee secondary science teachers ($N = 88$: plain figures) as measured by the prevalence questionnaire statements. The correct response (TRUE or FALSE) is given alongside each statement

Explanation components	*Statement(s)*	*Correct (%)*		*Not sure (%)*	
Preliminary knowledge					
1. Ozone is a gas found concentrated in the upper atmosphere and at ground level.	41. Lots of ozone is only found in the atmosphere at a high altitude. (FALSE)	**36**	*30*	**32**	*31*
	42. There is too little ozone at ground level to cause any environmental problem. (FALSE)	**54**	*46*	**27**	*24*
The issues					
2a. The concentration of ozone in the upper atmosphere has become depleted everywhere, particularly (as 'holes') over Antarctica.	43. Over the past 20 years or so, the amount of ozone in the atmosphere at high altitude has stayed roughly the same. (FALSE)	**72**	*89*	**21**	*7*
2b. In the upper atmosphere ozone is protective, shielding living things from the sun's harmful ultra-violet radiation which, if more reaches Earth, causes increased rates of skin cancer.	44. The ozone in the upper atmosphere is beneficial for living things. (TRUE)	**54**	*82*	**33**	*10*
	60. Increased amounts of ultra-violet light entering through holes in the ozone layer adversely affect human health. (TRUE)	**89**	*93*	**9**	*3*
3a. Ground-level ozone has greatly increased on concentration in recent decades.	47. There is now more ozone at ground level than in former times. (TRUE)	**31**	*36*	**49**	*44*
3b. Ozone is toxic to living things - it damages plants and causes respiratory problems in humans and animals.	50. Ozone in the atmosphere at ground level is toxic to living things. (TRUE)	**28**	*48*	**52**	*34*
Ozone layer - main ideas					
4. The amount of upper atmosphere ozone normally remains about the same.	51. Before Man's intervention, the amount of upper atmosphere ozone naturally fluctuated a lot all over the world. (FALSE)	**13**	*25*	**55**	*36*
5. A number of man-made chemicals (e.g. in fridges, fire extinguishers and some fertilisers) diffuse upwards and destroy upper atmosphere ozone.	52. The amount of ozone in the upper atmosphere fluctuates due to man-made chemicals. (TRUE)	**71**	*83*	**29**	*9*

6. 'Repair' of the ozone layer occurs naturally but more slowly than the rate of destruction.	54. If 'holes' appear in the ozone layer they can slowly be 'repaired' by natural processes. (TRUE)	**33**	*58*	**32**	*21*
Ground level ozone - main idea					
7. Ground-level ozone is produced by the action of sunlight on gases produced by human activity, especially burning fossil fuels e.g. car exhausts and evaporating solvents.	57. The Sun acting on man-made air pollution makes ozone at ground level. (TRUE)	**16**	*39*	**61**	*38*
Misconceptions	*Statement(s)*	*Occurrence (%)*		*Not sure (%)*	
• Holes in the ozone layer are responsible for global warming. (This is not true. Ozone has nothing to do with global warming)	45. Holes in the ozone layer let too much heat from the Sun get through to Earth. (FALSE)	**81**	*55*	**5**	*6*
• The burning of fossil fuels destroys the ozone layer.	46. Pollution from burning fossil fuels, e.g. in car engines, is destroying the ozone layer. (FALSE)	**88**	*49*	**4**	*7*
• Industry/burning fossil fuels produce ozone directly. (This is untrue - industry and e.g. cars do so *indirectly* when sunlight acts on the polluting gases they produce)	53. Car engines emit lots of ozone directly into the air. (FALSE)	**16**	*5*	**20**	*15*
	56. Industrial processes in factories emit lots of ozone directly into the air. (FALSE)	**22**	*6*	**33**	*31*
• Confuses destructive effect of CFCs on ozone high up with productive role of pollutants at ground level.	48. Pollution has reduced the amount of ozone at ground level. (FALSE)	**19**	*11*	**42**	*34*
• Ozone is non-toxic (Perhaps confusion with the beneficial effects of the ozone layer in blocking UV light or an 'urban myth' from seaside postcards)	49. The fresh smell of ozone makes it 'bracing' to breathe in. (FALSE)	**13**	*18*	**44**	*42*
• Ozone layer 'holes' are not naturally repaired.	55. Holes in the ozone layer will never be repaired naturally. (FALSE)	**24**	*23*	**40**	*23*
• The Sun has no role in ozone formation. (This is not true. UV light causes ozone formation in the upper atmosphere and acts on man-made pollution at ground level to form ozone)	58. The Sun has nothing to do with ozone formation in the atmosphere. (FALSE)	**13**	*10*	**62**	*32*
• Confusion between ozone as a pollutant (at ground level) and effect of pollutants on ozone high up.	59. Ozone is a pollutant which thins the atmosphere to let more ultra-violet light through. (FALSE)	**26**	*11*	**24**	*10*

Table 4. Understanding of global warming shown by primary teachers ($N = 85$: bold figures) and trainee secondary science teachers ($N = 88$: plain figures) as measured by the prevalence questionnaire statements. The correct response (TRUE or FALSE) is given alongside each statement

Explanation components	*Statement(s)*	*Correct (%)*		*Not sure (%)*	
Preliminary knowledge					
1. The inside of a greenhouse is hotter than its surroundings because the glass 'traps' energy from the sun i.e. allows it in but prevents it being transferred away from the greenhouse to the outside.	61. The glass traps the sun's energy by letting more in to the seedlings than it allows to leave. (TRUE)	**61**	*74*	**11**	*13*
The issues					
2a. There has been an observed rise in mean global temperatures (0.5 deg C) this century.	62. Overall, the Earth has *not* become warmer during the past 100 years. (FALSE)	**68**	*78*	**15**	*13*
2b This could give rise to changes in climate patterns which will adversely affect human societies.	63. Any warming of the Earth that occurs in future won't have much effect on climate. (FALSE)	**89**	*88*	**9**	*9*
Main ideas					
3. Some gases in the Earth's atmosphere act like the glass in a greenhouse by trapping some of the energy from the Sun.	65. Some particular gases in the atmosphere act on the planet like the glass of a greenhouse. (TRUE)	**85**	*90*	**15**	*8*
4. Carbon dioxide is the most important greenhouse gas over which Man has control.	66. CO_2 in the atmosphere is the most important factor in global warming over which man has control. (TRUE)	**51**	*74*	**32**	*15*
5. The trapped energy warms the Earth and atmosphere - this is the natural greenhouse effect - enough to give an average temperature suitable to sustain life.	68. The Earth is warm enough to support life because of a natural greenhouse effect. (TRUE)	**53**	*75*	**35**	*16*
6. Overall, the incoming energy (E) from the Sun equals the energy escaping (not trapped by the greenhouse effect); this balance (E in = E out) keeps the Earth at the same temperature, on average.	72. Before the intervention of Man, the Earth radiated enough of the Sun's energy back into space to remain at the same temperature, on average. (TRUE)	**35**	*49*	**49**	*17*

7. Man is increasing the concentration of greenhouse gases in the atmosphere, particularly CO_2, which results in more energy being trapped and the balance upset.	70. Man's influence on the gases present in the atmosphere causes more of the Sun's energy to be trapped there. (TRUE)	**46**	*81*	**44**	*13*
8. The *man-made* increase in atmospheric carbon dioxide is due to burning of fossil fuels and deforestation (which reduces a means by which CO_2 is removed from the atmosphere)	73. Man's burning of fossil fuels has increased the amount of carbon dioxide in Earth's atmosphere. (TRUE)	**87**	*96*	**11**	*3*
	75. By planting new forests, Man will reduce the amount of Carbon dioxide in the atmosphere. (TRUE	**81**	*85*	**9**	*8*
9. This leads to an enhanced 'greenhouse effect' and *may* be the reason for observed global warming.	77. Natural global warming *may* be being increased by Man-made carbon dioxide. (TRUE)	**65**	*77*	**34**	*15*
10. It is uncertain whether observed global warming is due to natural cycles or to man-made contributions, but the consequences of the latter are so profound that precautionary measures should be taken.	79. Global warming may be due to a natural cycle of warming and cooling of the Earth. (TRUE)	**28**	*67*	**48**	*25*
	80. Since global warming may be a natural effect there is no need to take precautions against it. (FALSE)	**85**	*91*	**13**	*7*
Misconceptions	*Statement(s)*	*Occurrence (%)*		*Not sure (%)*	
• Holes in the ozone layer are responsible for global warming. This is not true. Ozone has nothing to do with global warming.	64. Man-made pollution traps heat entering through holes in the ozone layer to cause global warming. (FALSE)	**68**	*44*	**26**	*10*
	71. Global warming is caused by the ozone layer trapping the extra heat entering through its 'holes'. (FALSE)	**45**	*19*	**37**	*11*
• There is no natural greenhouse effect which supports life, only that due to pollution by Man.	67. It is the gases produced by Man which makes the Earth warm enough to support life. (FALSE)	**2**	*0*	**18**	*6*
• No idea of the necessary balance between energy received from the Sun and that radiated into space.	69. All the energy the Earth gets from the Sun is retained by the planet and its atmosphere. (FALSE)	**13**	*9*	**47**	*8*
• No understanding of relationship between trees and the amount of CO_2 in the atmosphere.	74. Man cutting down forests has no effect on the amount of carbon dioxide present in the Earth's atmosphere. (FALSE)	**2**	*5*	**2**	*2*
• Ozone layer confused with atmospheric CO_2.	76. Global warming is caused by a layer of high altitude CO_2. (FALSE)	**25**	*41*	**71**	*34*
• Global warming is definitely due to Man' activities - no idea of the uncertainty about its causes.	78. It is certain that present global warming is caused by Man's activities. (FALSE)	**46**	*25*	**41**	*23*

(EC 10). Four misconceptions from table 4 elicited significant support by, or doubt in, the teachers, notably holes in the ozone layer as the cause of global warming (68% agreement).

The trainee secondary science teachers demonstrated substantial understanding of all global warming ECs, apart from EC 6, and showed some support for, and uncertainty about, two misconceptions (statements 64 and 76).

Summary

Overall, for practising teachers, knowledge was best in the areas of biodiversity and global warming. In each case 64% of responses to the ECs were correct. There were far fewer correct responses in the cases of the carbon cycle (48%) and ozone (45%). The trainee primary teachers completed the questionnaires for biodiversity and the carbon cycle only. Their responses were almost identical to those of practising teachers i.e. 60% and 50% correct for each issue, respectively. The trainee secondary science teachers completed the questionnaires for ozone and global warming only. Compared with the practising primary teachers, their knowledge was in each case better, with 57% correct for ozone and 79% for global warming.

Some aspects of the four areas which seemed particularly well understood by practising primary teachers and trainees were:

- the loss of diversity of species (but recognized to a lesser extent by trainees), the benefits of this kind of diversity for humanity and the adverse effect of humanity on ecosystems.
- the production of carbon dioxide during human respiration, the length of time needed for the production of fossil fuels and the effect on atmospheric carbon dioxide of deforestation.
- recent fluctuations in the amount of upper atmosphere ozone (i.e. 'holes' in the ozone layer), the role of manufactured chemicals in this and the increased amounts of UV light resulting from it.
- the increase in atmospheric carbon dioxide resulting from the burning of fossil fuels, possible climatic effects of global warming, and the need to take precautions against it.

Striking features of the lack of understanding or uncertainty seen in the groups were:

- the small proportions of practising and trainee primary teachers who appreciated the loss of diversity that has occurred within species, the role of variation between individuals in enabling adaptation of species, and the sensitivity to changes in habitat of most species in ecosystems. Trainees' doubts about the loss of diversity of species and the cause of variation in individuals (i.e. genetic versus environmental) were also noticeable.
- the lack of understanding or considerable uncertainty shown by practising and trainee primary teachers about the role of carbon in the processes of decay and of manufacture of tissues in animals and plants, and hence of the 'locking up' of 'ancient carbon' in fossil fuels and its release into today's atmosphere when they are burned; also the confusion shown in both groups about the role of carbon dioxide in respiration and photosynthesis.

- secondary science trainees' and practising primary teachers' low awareness of increased ground-level ozone, its toxicity and how it is produced; also (less so in the trainees) their uncertainty about the natural stability of the ozone layer and the predominance of non-scientific ideas about the agents which cause 'holes' and the relationship of the latter to global warming.
- practising primary teachers' low awareness of, or uncertainty about, energy exchange between the sun, Earth and space (also seen to an extent in the secondary trainees), about the role of carbon dioxide in global warming, and about the possibility of present warming being a natural phenomenon.
- the support for or uncertainty about non-scientific ideas about global warming (particularly those involving the ozone layer) by practising primary teachers and, to a lesser extent, by trainee secondary science teachers.

Using the findings

It was argued earlier that good subject knowledge is important for the best teaching. In the case of the science of environmental issues, our starting point was an explicit formulation of an appropriate knowledge base i.e. simple explanations of environmental issues for primary teachers. Using these explanations as benchmarks for judging understanding, the study has identified specific underpinning ideas which were well understood and not so well understood in samples of 290 practising and trainee primary teachers and 88 secondary science trainees. The frequencies of occurrence of a number of misconceptions are also reported. It is suggested that both the basic explanations and the difficulties of understanding displayed by the teachers and trainees can usefully inform programmes of professional development. In fulfilment of this purpose and of the main goal of the research stated at the start of this article, a guide to help teachers develop their knowledge in all seven areas identified earlier has been produced (Summers *et al.* 2000). Although this is intended principally for primary teacher education, the above evidence suggests that it may also be useful at secondary level.

The guide makes use of both the questionnaire findings and the earlier interview study (Summers *et al.*, in press). For each environmental issue, it includes:

- a 'basic story'. This is a prose version of the explanation components which acts as a simple account of the issue appropriate (in our judgement) for many primary teachers. The inspiration for this approach was the use of explanatory stories in the Nuffield Foundation report Beyond 2000 (Millar and Osborne 1998).
- a summary of the basic story (essentially the explanatory components shown in the tables of this article).
- a very brief summary of the research highlighting those aspects of the issue which were well understood, not so well understood, non-scientific or absent.
- sections which deal specifically with non-scientific or absent ideas, comparing the views uncovered by the research with scientific interpretations.

- a 'beyond the basics' section which further develops the science underpinning each issue for those with stronger scientific backgrounds or who simply wish to know more.
- diagnostic questionnaires (with answers) which focus on the explanation components for each issue and enable teachers to assess their own starting points. These were developed as a parallel strand of the present research.

The guide outlined above has a limited focus on personal scientific understanding. We have written before on the distinction between subject knowledge and pedagogical knowledge (Summers *et al.* 1998) and the vital importance of the latter. As mentioned earlier, the next step of our work is to use our materials to enhance the environmental knowledge of a small group of primary teachers, and then follow them through into their classrooms to document the ways in which they translate this knowledge into effective learning experiences for children.

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