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Exploring elementary students' understanding of energy and climate change

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Abstract

As environmental changes become a significant societal issue, elementary science curricula need to develop students' understanding about the key concepts of energy and climate change. For teachers, developing quality learning experiences involves establishing what their students' prior understanding about energy and climate change are. A survey was developed to explore what elementary students know and understand about renewable and non-renewable sources of energy and their relationship to climate change issues. The findings from this survey are reported in this paper.

Key words: *Elementary students, energy, climate change*

Introduction

One of the current challenges facing people around the world focuses on energy. In particular, issues surrounding access to continuing energy sources, the rate of usage of known non-renewable energy resources, the use of renewable energy sources, the impact that society's use of energy can have on the environment and earth's climate are regularly reported in the media.

For elementary students, these are key issues that will have a major impact on their quality of life both in the short term and in the longer term. For elementary teachers, the challenge is to teach about energy and climate change in ways that promote deep knowledge and deep understanding of these concepts. In the New South Wales education system, elementary students (K-6) engage in the study of Science and Technology through a curriculum document that brings both Science and Technology studies together. The Science and Technology K-6 syllabus

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(www.boardofstudies.nsw.edu.au) provides the direction and focus of developing teaching and learning experiences for elementary students.

Related Literature

Student prior knowledge

Through the research of Corney (2000), Dawson (1997), Driver (1985), Osborne and Freyberg (1985) and Tytler (2002), some recurring themes about students' prior knowledge of science related topics can be made. These themes are:

1) students bring to their studies their own ideas about science and environmental concepts;
2) these pre-conceived ideas are formed through prior experiences and they are very persistent; and,
3) the pre-conceived ideas are difficult to change.

For the classroom teacher, the underlying message from these authors draws attention to how important it is for teachers to establish what students do know, do not know, and partially know about science concepts as the first step in quality teaching practices.

These authors then suggest that elementary teachers design their teaching and learning programs in ways that build from what the students know and provide opportunities to engage in experiential learning practices that will lead to elementary students developing new and deeper understandings.

Understandings about energy

As part of the Learning in Science Project, the New Zealand researchers concluded that the concept of energy is a difficult concept to teach (Osborne and Freyberg, 1985). Kirkwood and Carr (1988) investigated the concept of energy using both elementary and secondary students. Their research found that children across the world typically perceived energy as something which:

1. Is a general kind of fuel that does work for us.
2. Is associated with living things often linked to terms including energetic, and human-centred.
3. Is associated with moving things, e.g. fire, cars, ringing telephones.
4. Can take on different forms as it travels through wires or chains of bicycles.
5. Is a source of force or activity stored in objects, for example, water has energy in it so it can turn a water wheel.
6. Is a storehouse used to make things work such as a battery.
7. Can be obtained from food, the body, sun, and soil, it is regarded as an ingredient stored in them.
8. Is a fluid-like material that flows from one body to another, as an electric current or a stream.
9. Is given off like a waste product, for example, chemicals give off heat.

From this set of observations, it is clear that students do hold a variety of ideas about the nature of energy. The diversity and reported persistence of scientific and non-scientific understandings about energy has been shown to extend beyond school (Trumper, 1997). In his study, Trumper (1997) explored the ideas that pre-service elementary teachers hold about the concept of energy. His analysis revealed a number of persistent misconceptions that pre-service teachers hold including:

1. Hold a number of different, alternative conceptual frameworks when describing physical situations involving energy, instead of the accepted scientific concept.
2. Mostly think that energy is a *concrete entity*.
3. Mostly do *not* accept the idea of energy conservation.
4. Are *ambiguous* in their recognition of different types of energy.
5. Mostly *confuse* the concepts of energy and force.

In the investigation reported in this paper, the more specific link between energy and environment related issues is the central focus. Very little research literature was found that specifically dealt with elementary students' understanding of concepts such as sources of energy, climate change, and renewable and non-renewable energy sources. Corney (2000) noted also that very little research had been conducted that sought to establish what students knew about environmental concepts.

One study by Papadimitriou (2004) reported that both students' and adults' understanding about environmental concepts, including climate change, are often incorrect as well as being very persistent to teaching interventions. In Papadmitriou's (2004) research with pre-service elementary teachers the following findings revealed a set of common misconceptions held by many of the students:

1. weather effects and climate change are often confused.
2. climate change is linked to air pollution and environmental pollution.
3. climate change is incorrectly associated with ozone layer depletion.

Through her research, the author sought to explicate the deep science conceptual understandings held by these pre-service teachers. She concluded that the concept of energy in its various forms (electromagnetic radiation, heat and chemical) was a difficult concept which these students did not fully understand.

Additionally, environmental terminology misconceptions were identified by Boyes and Stanisstreet (1997) which led to the inclusion of one question in the student survey (Appendix 1: Question 8) that sought to determine if students were able to recognise differences between these environmental terms: climate change; greenhouse effect and global warming.

The findings from Boyes and Stanisstreet (1997), Kirkwood and Carr (1988), Papadimitriou (2004) and Trumper (1997) research are reinforced by those reported by Cavanagh (2007). He acknowledged that, as public concern about global warming increases, teachers realise the significance of teaching about these environmental issues and they 'are carving out a larger place for those issues in science classes, particularly at the high school level.' However, he noted that the need to increase the teaching time devoted to these issues has not been supported by appropriate curriculum materials. Cavanagh (2007) stated that teachers faced challenges in finding accurate and student-friendly classroom resources for teaching about these environmental topics. Cavanagh (2007) identified *The Keystone Centre* (www.keystonecurriculum.org) as a useful high school curriculum resource designed to solve the problem of locating up-to-date and relevant resources. While The Keystone Centre resources are appropriate for high school students, he did not identify relevant elementary teacher resources. This omission in elementary teaching resources has been addressed through the e-learning materials that have been developed as part of the research reported in this paper.

In summary, the literature suggests that students frequently define energy as the 'ability to do work' but their understanding is superficial. Additionally, many students hold inaccurate ideas about the nature of energy which are very persistent. When energy is linked with environmental concepts such as climate change, little research has been conducted into this area. Research that has been conducted suggests that students hold views that are confused, often inaccurate, and persistent. Coupled to these topical and important concepts is that fact that teachers find that many textbooks have very little up-to-date and relevant information about energy and climate change in them. One of the goals of this paper is to identify what elementary aged students know about energy and related environmental concepts.

Energy and Climate Change

Among the many concepts that elementary students encounter as part of their education in science, energy is one of the more important. Currently society is becoming more aware of the importance of energy, the supply of energy, its continuing longevity, and its impacts on the natural and built environment. One particularly topical issue is the relationship between energy and climate change and how it is affecting our lives.

The concepts of energy, renewable and non-renewable sources of energy, and climate change are introduced in the elementary curriculum in New South Wales. These concepts are progressively extended through the New South Wales Years 7-10 junior secondary science curriculum and into a number of the Year 11/12 syllabuses in Biology, Earth and Environmental Science, and Senior Science (see www.boardofstudies.nsw.edu.au/syllabus_hsc/syllabus-a-z.html) In the elementary (K-6) curriculum, the Science and Technology syllabus introduces students to ideas about the environment, human impacts on the environment, human use of Earth's resources, and the energy needs of society.

Context for this study
The impetus for the research reported in this paper arose from a state-wide educational initiative in environmental education within the state of New South Wales Australia. This initiative focused on developing students' knowledge and understanding about energy and related environmental concepts as a priority teaching area for 2007.

Regional Environmental Education Policy
During 2007, the Riverina Region of the New South Wales Department of Education and Training implemented the Riverina Regional Environmental Education Plan for its 197 schools. The major focus in this policy was the development of a teaching program about energy that sought to promote students' understanding of the relationship between energy and key environmental concepts such as climate change, and renewable and non-renewable energy sources.

The Riverina Environmental Education Centre
Within the Riverina Region is the Riverina Environmental Education Centre (REEC) which is one of 24 environmental education centres located throughout New South Wales. The principle role of an environmental education centre is to assist schools, teachers and their students with curriculum based environmental fieldwork and to help schools become more environmentally friendly. The task of devising and implementing the region wide program about energy was allocated to the staff at the Riverina Environmental Education Centre.

At the Riverina Environmental Education Centre, this regional focus was translated into developing learning activities that were based on a theme of Energy and Climate Change specifically for elementary students. The plan involved two major initiatives:

1. a collaboratively planned program between Charles Sturt University staff, third year elementary teacher education students and REEC staff that led to a major regional Energy learning event; and,
2. the development of the e-learning resources on *Energy and Climate Change* that supported the New South Wales Science and Technology K-6 syllabus.

The first element of the regional energy plan revolved around a set of six learning activities developed by REEC staff. Participating elementary students rotated around these activities and the CSU elementary teacher education students became group leaders for specific activities. As part of the planning for this day, the author was asked to develop a short survey that would identify what the elementary students' level of knowledge and understanding about energy sources, and renewable and non-renewable sources of energy was. This survey and its analysis is the primary focus of the reminder of this paper.

This second initiative involved the development of a student self-paced, e-learning guide. Riverina teachers were encouraged to incorporate these e-learning resources and

activities into their teaching programs. These e-learning materials are accessible to all teachers and students by accessing the REEC website (www.reec.nsw.edu.au). The *Energy and Climate Change* resource is accessed from the K-6 section of the REEC website as shown in figure 1 below.

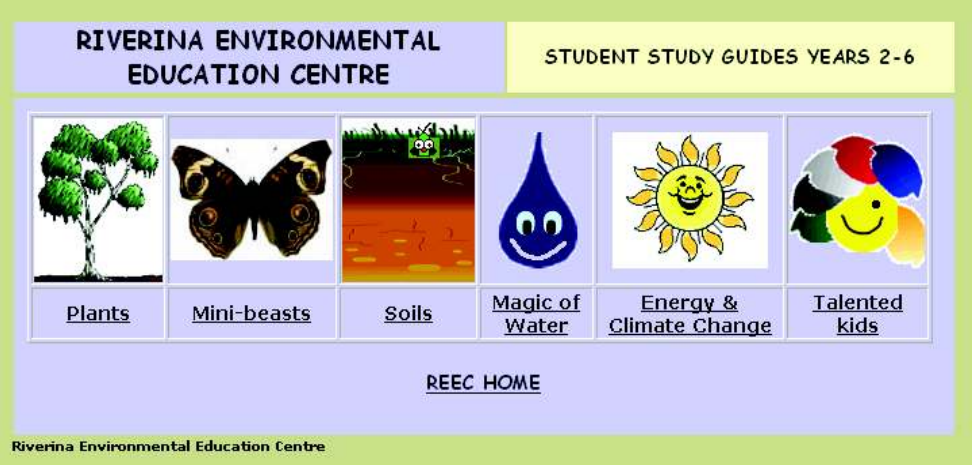

Figure 1: Available elementary e-learning activities

In the next figure a sample web page from the e-learning materials within the *Energy and Climate Change* learning resource is shown.

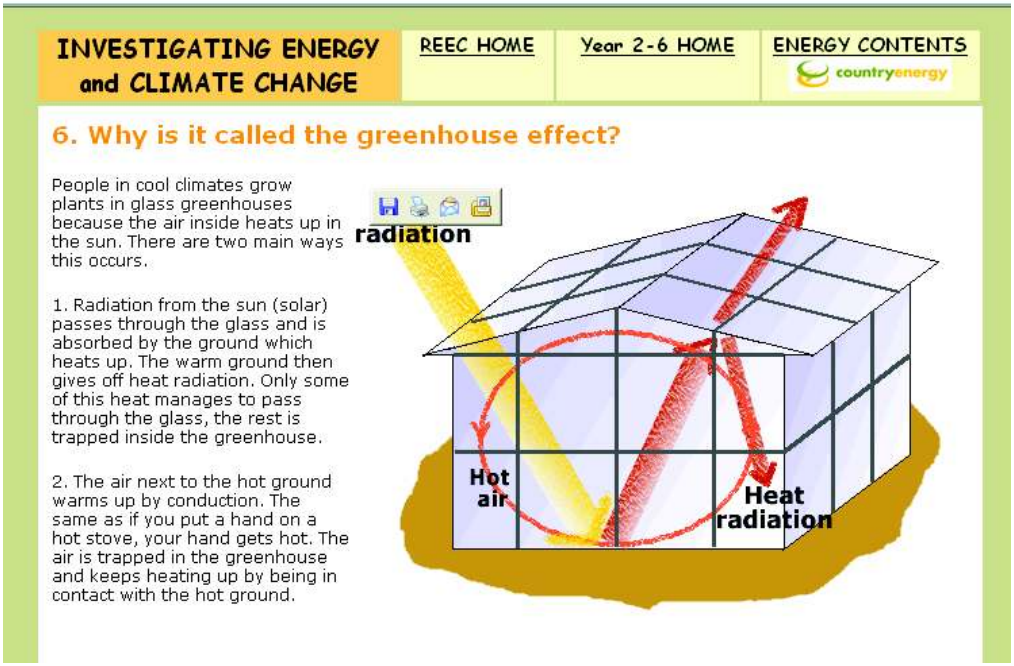

Figure 2: A sample page from the Energy and Climate Change e-learning resource

Methodology

Instrumentation

The *Energy and Climate Change* survey was designed using guidelines for establishing what prior understandings students hold based on the seminal work of Osborne and Freyberg (1985). The specific questions in the survey were developed following analysis of: a) the syllabus learning outcomes in the Science and Technology K-6 Syllabus (Board of Studies, 2006); b) misconceptions about energy and the environment identified from the literature analysis; and, c) the major ideas presented in the on-line e-learning resource on *Energy and Climate Change* contained on the REEC website (www.reec.nsw.edu.au). The instrument, see Appendix 1, included 8 questions that were designed to determine what the students' level of understanding about the following concepts was: energy, climate change, and renewable and non-renewable sources of energy.

Participants

132 elementary aged students who participated in the major regional Energy program of learning in 2007 were surveyed. 44 students were in Years 3/4 (identified as Stage 2 within the New South Wales context) and 87 students were in Years 5/6 (identified as Stage 3 within the New South Wales context). 56% of the students were boys and 44% were girls.

Overall, the response rates to individual questions on the survey were high (minimum respondents per question = 90%). No students omitted Question 1; 1 student omitted Question 2; 2 students omitted Question 3; 2 students omitted Question 4; 3 students omitted Question 5; and, 1 student omitted Question 6. For Question 7 which contained 8 different sub-parts, the number of students who omitted a response to any one energy source ranged from 7 (Hydro Electricity) to 12 (Nuclear Electricity). The average non-responses rate for this question was 9 students per energy source. For the final question, Question 8, 6 students omitted a response to this question. Statistical analyses included generating descriptive statistics and conducting Chi-square tests to determine if response pattern differences between groups were evident: namely Year 3/4 (Stage 2) vs Year 5/6 (Stage 3); and, gender (Boys vs Girls).

Results

Students' responses to Q1 to Q6 are presented in Table 1 below. Descriptive frequencies and their associated percentages are reported. Further the data were divided into: a) educational stage which is derived from how the Science and Technology K-6 syllabus is organised namely, Stage 2 (Year 3/4) and Stage 3 (Year 5/6); and, b) gender, Boys and Girls.

Questions 1 - 3 were designed to reveal what students knew about the types of energy while questions 4 – 6 asked to students about where energy comes from.

Table 1: Response about energy (Q 1 – Q 6)

Question	Response Choices	All students Number (%)	Stage 2 Number (%)	Stage 3 Number (%)	Boys Number (%)	Girls Number (%)
Is light coming from the bulb a type of energy?	Yes	112 (91)	37 (90)	76 (94)	61 (92)	47 (92)
	No	11 (9)	4 (10)	5 (6)	5 (8)	4 (8)
Is the person using energy when she runs?	Yes	121 (92)	36 (88) [a]	79 (99) [a]	65 (98) [b]	45 (90) [b]
	No	11 (8)	5 (12) [a]	1 (1) [a]	1 (2) [b]	5 (10) [b]
When the radio is turned on, is the sound coming from the speaker a form of energy?	Yes	89 (69)	19 (48) [c]	64 (80) [c]	43 (67)	35 (69)
	No	41 (31)	21 (52) [c]	16 (20) [c]	21 (33)	16 (31)
As wood burns, what type of energy is produced?	Electrical	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	Heat	31 (24)	10 (24)	18 (23)	16 (25)	10 (20)
	Light	2 (1)	1 (2)	0 (0)	0 (0)	1 (2)
	Light and Heat	97 (75)	30 (74)	61 (77)	48 (75)	40 (78)
The energy in our bodies comes from:	Sleeping	44 (34)	15 (37)	23 (29)	25 (39)	8 (16)
	Eating food	49 (38)	11 (27)	36 (46)	29 (45)	18 (36)
	Drinking water	36 (28)	15 (37)	19 (24)	10 (16)	24 (48)
On our planet Earth, all life depends on the Sun for its energy.	Yes	109 (83)	34 (83)	66 (83)	55 (83)	40 (78)
	No	22 (17)	7 (17)	14 (17)	10 (17)	11 (22)

Key

a: Significant difference detected: Chi–square statistic = 6.891, df=1, p<0.01

b: Significant difference detected: Chi–square statistic = 4.176, df=1, p<0.05

c: Significant difference detected: Chi–square statistic = 13.207, df=1, p<0.001

Discussion of Table 1 results.

Types of energy (Q1 – Q3)

Overall the results suggest that elementary (Stage 2 and 3) students do know quite a deal about the different types of energy. In question 1, overall about 9 in 10 students correctly responded to this question. With question 2, the majority of students (92%) successfully recognised that when a person is running, energy is being expended / consumed. When the secondary analyses of this question were conducted it revealed that: a) more Year 5/6 (Stage 3) students correctly understood what was happening than

Year 3/4 (Stage 2) students; and, b) boys more frequently than girls correctly recognised that the person used energy while running. The third question revealed that about 2 in 3 students correctly knew that sound emanating from a radio was a form of energy. The secondary analyses conducted in this question also identified that Year 5/6 (Stage 3) students were significantly better at recognising that sound was a form of energy than the younger Year 3/4 (Stage 2) students. This finding suggests that these younger elementary students hold prior understandings about sound energy that are different to the accepted scientific explanations. This finding can also be linked back to the syllabus as sound production and energy are concepts that are first introduced in the Physical Phenomenon and Using Technology strands of the Science and Technology (K-6) syllabus for student investigation sometime during their studies over Years 3 and 4.

Origins of energy (Q4 – Q6)

The next three questions probed what students know about where does energy come from. These questions drew upon the some of misconceptions identified in the research by Kirkwood and Carr (1988) and Trumper (1997). Question 4 required the student to appreciate that both light and heat energy are produced when wood burns. It was pleasing to report that no student selected electrical energy as the product of burning wood. In fact, 3 in 4 students (75%) recognised that both light energy and heat energy are produced. Almost all of the remaining students (24%) stated that only heat energy was produced. The misconception that burning wood in a fire does not produce light energy is a topic that elementary teachers need to include when teaching about burning. Secondary analyses of the data revealed that this misconception is very persistent and consistent across both Stages and gender. Question 5 asked what students knew about where does the energy used in our bodies originate. The responses to this question revealed a surprising and unexpected set of results which were consistent across Stages and gender. About 1 in 3 students (34%) believed that sleeping was where the energy in our bodies originated. Similarly almost 1 in 3 students (31%) believed that drinking water supplied the energy our bodies needed. Just over one-third of the students (38%) correctly stated that it was through eating food that our bodies gained the energy they needed. These findings indicate that the majority of students hold alternate ideas about the origins of energy in our body. For elementary teachers, the body and food are common topics taught in elementary science classes, they need to make more explicit the links between food as a source of energy and how our body processes food to provide the necessary energy for normal cellular and bodily functioning. The final question (Q6) revealed that the majority of students (83%) knew that the Sun was the source of energy for all life on Earth. This finding was consistent across Stages 2 and 3 and by gender.

Renewable and non renewable energy sources

Students' knowledge and understanding about how they classified different sources of energy as either renewable or non-renewable were specifically explored by Question 7 of the survey. In the following table, the responses of the elementary students are reported.

Table 2: Renewable and non-renewable sources of energy

Question ***Which of the following are renewable and non-renewable energies?***	**Response choices**	**All Students Number (%)**	**Stage 2 Number (%)**	**Stage 3 Number (%)**	**Boys Number (%)**	**Girls Number (%)**
Hydro Electricity	Renewable	89 (71)	25 (71)	59 (74)	45 (70)	36 (78)
	Non-Renewable	36 (29)	10 (29)	21 (26)	19 (30)	10 (22)
Coal	Renewable	35 (28)	10 (29)	24 (30)	20 (31)	11 (26)
	Non-Renewable	88 (72)	24 (71)	55 (70)	45 (69)	32 (74)
Natural Gas	Renewable	63 (52)	20 (59)	35 (44)	35 (55)	18 (41)
	Non-Renewable	59 (48)	14 (41)	44 (56)	29 (46)	26 (59)
Nuclear Electricity	Renewable	71 (59)	27 (77) [d]	40 (53) [d]	38 (59)	24 (57)
	Non-Renewable	49 (41)	8 (23) [d]	36 (47) [d]	26 (41)	18 (43)
Food	Renewable	69 (56)	21 (62)	42 (53)	35 (54)	27 (63)
	Non-Renewable	54 (44)	13 (36)	37 (47)	30 (46)	16 (37)
Solar Electricity	Renewable	109 (89)	35 (97)	66 (86)	59 (89)	38 (88)
	Non-Renewable	13 (11)	1 (3)	11 (14)	7 (11)	5 (12)
Oil / Petrol	Renewable	41 (34)	14 (39)	25 (33)	23 (36)	15 (34)
	Non-Renewable	81 (66)	22 (61)	52 (67)	41 (64)	29 (66)
Wind Generated Electricity	Renewable	95 (77)	24 (69)	62 (78)	51 (78)	32 (73)
	Non-Renewable	29 (23)	11 (31)	17 (22)	14 (22)	12 (23)

Key

d: Significant difference detected: Chi–square statistic = 6.017, df=1, p<0.05

Discussion of Table 2 results

Overall many students' ideas about which energy sources are renewable and which are non-renewable revealed considerable confusion. On average, 7 in 10 students answered correctly to Hydroelectricity being a renewable source of energy. This response rate was consistent across Stage 2 and Stage 3. A very similar correct response rate was found for Coal as a non-renewable energy with 7 in 10 students being successful. The responses provided for Natural Gas were more interesting with only 5 in 10 students understanding that Natural Gas is a non-renewable source of energy. The misconception about Natural Gas being a renewable source of energy may be in part due to the word 'Natural'. Students may interpret 'Natural' as implying it must be renewable. On average 6 out of 10 students believed Nuclear Electricity was a renewable source of energy. Upon further investigation, a significant difference was found in how students in Stage 2 understood this example compared with Stage 3 students with a larger proportion of the latter group holding the correct understanding. There is a 24% increase from Stage 2 to Stage 3 in the number of students correctly identifying Nuclear Electricity as a non-renewable source of energy suggesting that this improvement may be linked to specific topics about energy contained only in the Year 5/6 (Stage 3) syllabus learning outcomes. However the elementary students' response to this example still emphasise that 5 in 10 students are unaware that Nuclear Electricity is a non-renewable source of energy. The implication for teachers when teaching about types of energy sources and whether they are renewable or non-renewable is clear. A detailed consideration about how and where nuclear electricity comes from needs to be included in the teaching sequence.

Determining if food was a renewable or non-renewable source of energy was also a question that revealed students held misconceptions. Between 5 and 6 in every 10 students correctly identified food as a renewable source of energy. This finding when linked with Question 5's responses indicated that holistically the level of understanding about food as an energy source and whether food is a renewable or non-renewable source does not align with the accepted scientific understandings. One possible explanation for the high level of misconception associated with this question could be that students do not link eating food with the food chains, energy flow and life cycles. Further, students may think that food must be non-renewable because when you eat it, it is gone. Solar electricity produced the highest successful response rate with 9 out of 10 students understanding that it is a renewable source of energy. The high response rate can be attributed to the high media focus on solar power making it a 'hot topic' at the moment. However, Oil/Petrol consumption is also a high priority media event, yet only about 2 in 3 students responded correctly that they understood that Oil/Petrol is a non-renewable source of energy. The final example revealed that 8 in every 10 students recognised wind generated electricity as a renewable source of energy. This response was consistent across both Stage and gender.

Environmental terminology

The final question (Q8) was included in the survey as the literature suggested that these environmental terms were not well understood by students. In Table 3, the responses from the elementary students are reported. This question explored whether students recognised the three selected terms as being the same or different.

Table 3: Knowledge about environmental terms

Question.	Response choices	All Students Number (%)	Stage 2 Number (%)	Stage 3 Number (%)	Boys Number (%)	Girls Number (%)
Climate change, greenhouse effect and global warming all mean different things	Yes	74 (59)	21 (53)	51 (66)	40 (63)	28 (57)
	No	52 (41)	17 (47)	26 (34)	24 (37)	21 (43)

No Significant differences found between Year 3/4 and 5/6 (Stages 2 & 3) and between boys and girls.

Discussion of Table 3 results

Only 6 in 10 students could correctly identify that climate change, greenhouse effect and global warming all mean different things. There was a slight improvement in the correct response rates from Year 3/4 (Stage 2) to Year 5/6 (Stage 3), however this change was not statistically significant. This response was surprising given the high level of current media coverage on these issues world-wide and specifically the Australian media coverage of the ongoing drought (now into its 6th year) in inland Australia which has reached crisis point.

Conclusion

This paper set out to report upon an investigation designed to establish what elementary students knew about sources of energy, climate change, and renewable and non-renewable energy sources while attending an Energy learning event at the Riverina Environmental Education Centre. The findings revealed that students' ideas about the types of energy are still developing with their understanding about sound energy revealing some persistent misconceptions. Further, most students realised that the Sun is the major energy source for all life on earth but many students held misconceptions about food as an energy source for humans. Up to half of the elementary students held specific misunderstandings about renewable and non-renewable energy sources. Finally, many students were not clear about how the key environmental concepts of climate change, greenhouse emissions and global warming are different from each other. For elementary teachers, this investigation suggests a strategy for assisting students to overtly consider their tacit ideas about energy and climate change and the need to explicitly teach these concepts within real world contexts. For these teachers, this study highlights the important pedagogical practice of establishing what ideas students already hold about a concept at the start of their teaching program and developing a responsive teaching program to promote deep understandings of the

concept. The *Energy and Climate Change* survey developed and used in this study provides one easy to use strategy that teachers can implement to assist them in finding out what concepts and misconceptions students in their class hold.

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Appendix 1

ENERGY and CLIMATE CHANGE

Please circle: I am a boy/girl in Year _____

Q1. When the torch is switched on, the light bulb glows.
Is the light coming from the bulb a type of energy?

YES NO

Q2. Is this person using energy when she runs?

YES NO

Q3. When the radio is turned on, is the sound coming from the speaker a form of energy?

YES NO

Q4. As the wood burns, what type of energy is produced?

a) Electrical c) Light
b) Heat d) Light and Heat

Q5. The energy in our bodies comes from:

a) sleeping b) eating food
c) drinking water

Q7. Which of the following are Renewable (R) or
Non-Renewable (NR) energies?

a) Hydro Electricity R NR
b) Coal R NR
c) Natural Gas R NR
d) Nuclear Electricity R NR
e) Food R NR
f) Solar Electricity R NR
g) Oil/Petrol R NR
h) Wind Generated Electricity R NR

Q8. Climate change, greenhouse effect and global warming all mean different things.

YES NO

Q6. On our planet Earth, all life depends on the Sun for its energy. YES  NO	