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Faculty of Education and Social Work

**Upper primary school students' scientific
and socio-scientific thinking:
A case study investigating epistemic challenges
in year-six inquiry science lessons**

David Mark Ashe

A thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

October 2014

Author's Declaration

This is to certify that:

1. This thesis comprises only my original work towards the Doctor of Philosophy degree
2. Due acknowledgment has been made in the text to all other material used
3. The thesis does not exceed the word length for this degree
4. No part of this work has been used for the award of another degree
5. This thesis meets the University of Sydney's Human Research Ethics Committee (HERC) requirements for the conduct of research.

Signature:



Name: David Mark Ashe

Date: 15th May 2015

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Abstract

Science education in schools has moved from the learning of scientific facts to investigating the impact that science has on students' lives; providing students with an understanding of how they relate to, and affect, their environment. This shift is evident in many countries' curricula (e.g. Australian National Curriculum). One example of this is the requirement for students to consider issues related to 'sustainability'; to consider scientific facts and to consider themselves as both part of the problem and part of the solution. Socio-scientific issues are ill-structured; that is, they may have many viable alternative solutions and it can be difficult to know when a satisfactory solution has been reached.

Solving socio-scientific problems involves the use of knowledge learnt in different contexts, including scientific knowledge and experiential knowledge. This study seeks to gain a better understanding of how and when year 6 primary school students (aged 10 to 12 years) activate prior knowledge while considering sustainability issues. The study sought to vary the context in which students were set sustainability problems. Using a 'knowledge in pieces' theoretical framework, which attunes to changes in context, the study investigates conditions that may promote appropriate knowledge activations. Based on a case study methodology, the research employs epistemic interviewing techniques coupled with close participant observations to gain a better, more nuanced understanding of the processes involved when year-six primary school students consider issues about sustainability.

The thesis reports on three empirical episodes during which different aspects of *context* were varied; the *problem* context, the *knowledge* context and the *physical* context. Data was analysed using inductive thematic analysis and the results were considered alongside existing pedagogical approaches. The results showed that the variation of all three contextual elements led to variations in the manner in which the students solved the sustainability problems. It was observed that epistemic prompts helped the participants to make progress towards viable solutions. These epistemic prompts came from the facilitator of learning, from other students, and from the activities in which the students were engaged.

When embarking on a learning program that involves socio-scientific issues, facilitators of learning can benefit from recognising that the nature of these issues will require students to integrate both taught knowledge and everyday experiences. Students may activate conflicting knowledge resources that lead to confusing results. It is at these points that *epistemic challenges* (challenging the students to consider their knowledge and to justify that knowledge) can prove beneficial in helping the students sort out their own solutions to these complex issues.

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Chapter 1 Introduction

There can be few more pressing and critical goals for the future of humankind than to ensure steady improvement in the quality of life for this and future generations in a way that respects our common heritage – the planet on which we live. As people we seek positive change for ourselves, our children and grandchildren; we must do it in ways that respect the right of all to do so. To do this we must learn constantly – about ourselves, our potential, our limitations, our relationships, our society, our environment, our world. Education for sustainable development is a life-wide and lifelong endeavour which challenges individuals, institutions and societies to view tomorrow as a day that belongs to all of us, or it will not belong to anyone. (UNESCO, 2006, p. 9)

This quotation is from the introduction to the United Nations (UN) framework for the international implementation of the UN Decade of Education for Sustainable Development (DESD). The framework was produced in response to resolution 57/254 of the UN General Assembly adopted in December 2002. The UN set up DESD in the hope of encouraging worldwide education about sustainability, providing everyone with the “opportunity to benefit from education and learn the values, behaviour and lifestyles required for a sustainable future and for positive societal transformation” (UNESCO, 2006, p. 4). These are bold ambitions that involve an understanding of society, of the environment, and of the world; along with opportunities to engage in change of lifestyle and behaviours.

This PhD research project was inspired by a visit to Calmsley Hill Farm¹, on the outskirts of Sydney, Australia. Calmsley Hill has been a working farm since 1806 and prior to this the land supported the indigenous Darug people. It has a rich heritage and is now used as a ‘show’ farm. Families and school groups visit the farm to gain an understanding of historical agricultural practices, to reconnect with nature, and to learn about sustainability, with particular reference to energy, land, water, and waste.

As part of the farm’s school education programs, three specific ‘out-of-school’ activity days are run, aimed at helping students learn about sustainability. These activities are titled: ‘Endangered and Unique’, ‘Sustainable Food’, and ‘A Big Sydney’. During these programs, both students and teachers become engaged in activities on the farm; this provided me with opportunities to observe and reflect on the activities that the students undertook, along with observations of the various suggested routes, to sustainable solutions, that the activities appeared to present. For example, the excursion that “allows students to ... learn the affect of food on good health” (Calmsley Hill Farm, 2010, p. 2) was approached differently by different school groups. There appeared to be an epistemological difference in how the visitors framed the experience. For some, the event was in the control of the ‘tour guides’; the group would follow along, listening to the presentations and, perhaps, take notes; others would interact with the guides, continually asking questions and challenging the ideas raised. The event was centred on learning about food production (where milk and eggs come from, and that beef is meat from cattle); however, despite interacting with the guides, those that questioned sought clarification rather than

¹ Calmsley Hill Farm, 31 Darling St Abbotsbury NSW 2176 Australia (<http://calmsleyhill.com.au>)

opportunities to ponder upon food production and its implications on the environment, on commerce, and on society.

Sustainability, it appeared, had been reduced to a series of ‘facts’ such as where food comes from, and which food is ‘healthy’. There appeared little to involve the students in thinking about their position in the system, about the complex issues that are raised when making sustainability decisions, or any provision for behavioural change. The learning of environmental facts is an important stepping-stone to the consideration of complex sustainability issues and, as such, these school excursions are fulfilling a necessary role. However, there appeared little to challenge either the students or the teachers to consider the sustainability of their actions.

Consequently, this research seeks to investigate the complex processes that take place when students consider sustainability issues. It is hoped that through a better, more nuanced, understanding of how individuals think about, and progress to solutions of, sustainability problems, better use can be made of learning opportunities. Students, rather than only considering environmental facts, may be helped to consider themselves as part of the environment, both having an effect on and being affected by the environment.

The thesis starts with an introduction to education for sustainability, outlines the purpose for the study, and poses research questions. It investigates the current state of research on this topic and considers appropriate methods to answer the research questions. There follow three empirical chapters that outline the data collection

activities, analysis, and findings. Finally, the findings are drawn together and conclusions presented.

Chapter two presents an overview of the current state of science education, with particular reference to Australia (where the data collection activities took place) and focuses on how sustainability is taught in schools. There are inherent challenges, for both teachers and learners, when considering sustainability issues; these are explored and the idea of 'context' is defined. Various theoretical perspectives are considered to provide guidance for this study. The chapter concludes by stating the research questions and outlining intended contributions to knowledge, methods and practice.

The literature review (Chapter 3) outlines current pedagogical approaches used in science education, and explores environmental learning, considering learning 'in', 'for', and 'with' the environment. Empirical studies, from various theoretical perspectives, are analysed and considered. The chapter concludes by drawing together methods and theoretical perspectives from previous studies to inform the theoretical underpinning and methodology for this study.

Chapter four provides details about the design of this study, justifying the overall design, the sample selected, and the sample size. The data collection methods are explained providing an overview of data collection techniques and explanations of how the different data collection activities are intended to provide data to help answer the research questions.

The three empirical chapters (Chapters 5, 6, and 7) have similar structures. The data collection activities are explained, including details of specific data collection techniques. An overview of the collected data is provided along with the procedures undertaken to produce various coding schemes to assist in the analysis of the data. Details of the data analyses are provided and the results are given.

Chapter eight draws together the results of the three empirical chapters and relates those results to the research questions. This leads to a discussion about the results and investigates possible implications for existing pedagogical approaches. The chapter concludes with suggestions on how, based on the evidence collected, existing pedagogical approaches can be enhanced through the integration of ‘epistemic challenges’.

Finally, Chapter nine draws conclusions from the study, specifically in the areas of pedagogy and epistemic challenges. Limitations of the study are discussed and future directions for on-going investigations are considered.

The writing of this thesis has taken inspiration from Billig (2011) who provides guidance on academic writing, and particularly writing in the social sciences.

One should try to use simple language and to avoid technical terms as much as possible. Do not assume that technical terms are clearer and more precise than the ordinary ones. It is actually harder to write simply, for you must clarify what you mean, and cannot hide behind stacks of big words. So as a rule, try to convert jargon-filled statements into simpler ones. If your ideas seem to

lose their shine in the translation, then you should take this as a sign that they weren't particularly special in the first place. (Billig, 2011, p. 17)

It is hoped that, in the writing of this thesis, the ideas presented, the results of the data collection activities, and the conclusions drawn are both clear and precise. Effort has been made to write in an accessible manner, retaining the precision necessary to enable both academic scholars and practicing teachers to gain a better understanding of the complex issues presented by sustainability, along with practical classroom advice.

Chapter 2 Purpose of the research

This chapter provides an introduction to school science education and in particular looks at the teaching of both well-structured problems (such as calculating the gravitational force acting on a body resting on an inclined plane) and ill-structured problems (such as issues around ‘sustainability’). These ill-structured problems contain ambiguities and draw upon knowledge from a number of different, and perhaps competing, domains. There are a number of pedagogical approaches that have been suggested to help students to think about ill-structured problems and the context of the learning appears to play an important role in student thinking. Context is discussed and four aspects of ‘context’ are defined. These four aspects of context are used to formulate the research questions that this study seeks to investigate.

2.1 School science

There has been a trend for the teaching of science to move from the teaching of facts to that of helping students to build their own knowledge about scientific concepts and procedures. This trend can trace its roots back to a variety of sources, including John Dewey's (1910) suggestion that school students should be equipped with skills to ascertain the evidence required to substantiate their scientific beliefs.

I do not mean that our schools should be expected to send forth their students equipped as judges of truth and falsity in specialized scientific matters. But that the great majority of those who leave school should have some idea of the kind of evidence required to substantiate given types of belief does not seem unreasonable. (Dewey, 1910, p. 126)

School texts have become more readable and geared towards students being able to make sense of data to understand science (Brown, 1965; Walpole, 1999). This trend is continuing with the advancement of the teaching of science by inquiry. The US National Research Council outlines the essence of inquiry science:

Learning science is something that students do, not something that is done to them. ‘Hands-on’ activities, while essential, are not enough. Students must have ‘minds-on’ experiences as well. (National Research Council, 1996, p. 2)

Bybee, Powell, and Trowbridge (2007) summarise an inquiry approach and posit that students should be allowed to generate creative ideas, analyse observed data, generate and test solutions, and be able to challenge ideas of others.

2.1.1 Classroom practice

The teaching of science in Australia is underpinned by the idea of ‘inquiry’. That is, students are encouraged to develop inquiry skills and to be able to apply those skills to draw their own conclusions based on evidence. The Australian National Curriculum includes inquiry in its aims of science education:

Science aims to ensure that students develop an understanding of the nature of scientific inquiry and the ability to use a range of scientific inquiry methods, including questioning; planning and conducting experiments and investigations based on ethical principles; collecting and analysing data; evaluating results; and drawing critical, evidence-based conclusions.

(ACARA, 2012a, p. 344)

This idea of inquiry is also reflected in other countries’ curricula, such as in the England’s Primary National Curriculum and the US National Research Council’s report on inquiry in science education (Olson & Loucks-Horsley, 2000). The Ruddock

and Sainsbury (2008) report, comparing the UK's school curriculum to other high performing countries' curricula – “based on performance in international comparative surveys” (p.16), stated that inquiry based science teaching was a common thread across all of the curricula studied. Despite this thrust for inquiry based science teaching, from the developers of the curricula, practice in schools may be somewhat different. While the curricula and teaching materials are promoting inquiry as a desired method for the teaching and learning of science in schools, research has suggested that teachers are not incorporating inquiry into their classroom practice (Kim, Tan, & Talaue, 2013; Lord & Orkwiszewski, 2006). To illustrate this issue, an example is provided; Capps and Crawford (2012) investigated whether teachers' views of inquiry based science teaching, and their classroom practice, aligned with the inquiry based approaches promoted by US educational reforms. They reported on the views and practices of 26 upper-primary and lower-secondary schoolteachers who were assessed as well qualified and highly motivated. They found that many of the teachers in their study believed that they were teaching science through inquiry, but observations of the teaching practices showed that this was not the case. Furthermore, even when teachers do integrate inquiry into their classroom practice, the emphasis on ‘inquiry’ can detract from the learning of science. For example, Roth and Garnier (2006) analysed the Third International Mathematics and Science Study (TIMSS) video recordings of eighth-grade science and mathematics lessons created in over 1000 classrooms across seven countries and concluded:

The TIMSS video study results challenge us to think more deeply about the role of science content in hands-on, inquiry teaching and to question how schools can better link such hands-on, inquiry teaching to the development of science content understandings. Those directing science education policy in

the United States need to look into science professional development and teacher education programs and ask, Is our emphasis on ‘inquiry’ unintentionally obscuring the importance of understanding science ideas? (Roth & Garnier, 2006, p. 22)

Classroom practice does not appear to be reflecting the desired goals of the curricula designers; inquiry is either not incorporated into lessons, or becomes so over-emphasized that the ‘science’ can become obscured.

2.1.2 Investigations and canonical inquiry

While proper implementation of inquiry as a pedagogical approach might not be widespread, there is certainly a trend for the use of a pedagogy aimed at enabling students to build their own knowledge; teachers are incorporating various kinds of investigations into their classroom practice (Andrée & Lager-Nyqvist, 2013; Bamberger, Cahill, Hagerty, Short, & Krajcik, 2011; Krajcik & Merritt, 2012; Martínez, Borko, & Stecher, 2012). These investigations, which are commonly referred to as semi-structured or open-ended investigations, provide students with opportunities to work collaboratively; they have been shown to encourage higher-level processing skills and can develop long-term engagement (Caton, Brewer, & Brown, 2000; Mohr-Schroeder et al., 2014; Windschitl, Dvornich, Ryken, Tudor, & Koehler, 2007). However, in most school subjects, the end result of ‘investigations’ or ‘inquiries’ is that the students are led to a predetermined result. There is a desired outcome of the investigation and students may be judged on whether or not they have ended up with the ‘correct’ or ‘desired’ result. This is well illustrated by viewing current school textbooks that promote inquiry. For example, in the Australian text book on Microorganisms for upper primary students (Australian Academy of Science,

2006), the session on “Investigating Mould” (p. 36) asks the teacher to lead the students through 14 steps of an investigation. Each of these steps has a desired result, culminating in the students producing a predetermined and consistent piece of work - in this case, all students produce a ‘word wall’.

This method of instruction enables the students to consider what information is required, to collect data, to analyse the data, and to draw their own conclusions about the science under investigation. This has many benefits, however, it should be recognised that, while this process is taking place, the teacher (or facilitator) is on hand to guide the students along correct canonical paths of inquiry. For much of school science this works well, as there *are* canonical methods of inquiry. For example, ACARA (2011) provide exemplars of work to be included in student portfolios; this includes the inquiry where “students were asked to design and make their own electrical switch” (ACARA, 2011, p. 3). In this case, both the teacher and the assessment board know the outcome of the inquiry; that is, the correct form of the electrical circuit. Investigating in this way is effective when there are canonical solutions to the problem being considered; when students are considering well-structured problems. Well-structured problems can be defined as those problems that have sufficient information to be solved and, therefore, present a high degree of certainty of a correct and discoverable solution; i.e. they have a discoverable right answer (King & Kitchener, 1994). Examples of these well-structured problems might be: finding the force required to move an object up an inclined plane, finding the value of x when $x+2=4$, and finding the time it takes for a train travelling at a constant speed to cover a set distance. In contrast to these well-structured problems, ill-structured problems enable no such confidence in a right answer. Ill-structured

problems are those that may have many solutions and, as such, it may be hard to determine when a solution has been reached (Churchman, 1971). King, Wood, and Mines (1990) give examples of phenomena that lead to ill-structured problems; “overpopulation, hunger, pollution, and inflation” (p. 168). When considering these phenomena, it is hard to ascertain what constitutes sufficient information, there may be multiple solutions, and it is difficult to know when a satisfactory solution has been reached.

Furthermore, in many areas of school science, there is general agreement on how students should perform their scientific inquiry, however, in other areas, the correct method of inquiry is not so clear. Issues of a scientific nature that involve the consideration of social, and other personal, ‘everyday’ experiences are replete with ill-structured problems. Science alone, with canonical solutions to problems, cannot provide a single, best solution to these socio-scientific problems.

2.2 Socio-scientific education

Socio-scientific education differs from science education; this difference, as outlined in the previous section, is based on the ill-structured nature of socio-scientific issues. Finding solutions to socio-scientific issues relies on integrating both scientific and social knowledge along with personal beliefs. This requires a melding of scientific knowledge with an individual’s worldview, their personal values, and the links between their personal desires and normative judgement. It is, therefore, difficult to determine a right or wrong method of inquiry, or to determine a fixed and final solution. To unpack this, the following sections look first at what is meant by socio-

scientific issues and then investigate some of the inherent problems with defining a 'right' way to approach these issues.

2.2.1 Defining socio-scientific issues

Since Dewey (1910) put forward the idea of science education equipping students with the abilities to evaluate and justify their scientific knowledge, there has been an increasing emphasis on the social aspects of science; e.g. how scientific knowledge impacts on everyday lives. Prior to the twentieth century, science did not appear (to the individual) to impact on individuals' lives or enter into the general discourse; however, during the twentieth century, science was much more in the public eye, due to, for example, space travel, moon landings, and home electronics and computers (DeBoer, 2000). During these periods of advancement in science, and science technology, science education began to consider the social impacts of science. Behnke (1961) stated that, in the years since World War II (1945-1961), there was an "upsurge in public interest in science and science teaching" (p. 193) and posited that both scientists and science teachers should be concerned with the social implications of scientific discoveries. However Behnke's study, that surveyed 621 school science teachers and 70 scientists, focused on how social forces influence science and science teaching:

There is no doubt that social forces outside the scientific enterprise influence the science teacher's attitude toward science and science teaching. (Behnke, 1961, p. 207)

By the mid 1970s, the social impacts of science were being considered in school education (see Popkewitz, 1972; Young, 1974) and this shift brought about a change in science education. This 'new' aspect of science education, which was branded as

STS (Science-Technology-Society), started in universities in the late 1970s and filtered down into the primary curriculum throughout the 1980s (see Shelanski, 1979; Zeidler, Sadler, Simmons, & Howes, 2005).

STS provided a forum for researchers and teachers to rethink many fundamental questions about science education, which included the purpose, politics, and nature of science education as well as the roles and abilities of both teachers and students (Aikenhead, 2003). In discussing a report from the American National Research Council's Committee on Behavioural and Social Aspects of Energy Consumption and Production, Layton, Davey, and Jenkins (1986) illustrated that energy can be considered in a variety of ways depending on a particular standpoint. The 'energy user' could consider energy as: a commodity (i.e. investing in energy products increases the value of their home), a benefit (i.e. energy products can warm the home), a social device (i.e. a desire to keep the neighbourhood looking good so does not put plastic insulation over windows), a personal value (i.e. desire to use solar panels), and a problem (i.e. managing energy use to fit in with low tariffs). Science education was now to take into consideration social implications of science informed decisions as well as scientific facts.

STS provided a route for science education to be considered alongside 'citizen' education. Jenkins (1999) refers to 'citizen thinking' and relates this thinking to science education:

'citizen thinking' is intimately related to the notion of 'citizen science', i.e. science which relates in reflexive ways to the concerns, interests and activities of citizens as they go about their everyday business. (Jenkins, 1999, p. 704)

This ‘citizen’ education considered the impact that science has on decisions that citizens make about their lives; however, it did not explicitly consider the ethical and moral dilemmas that students encounter when considering truly ill-structured problems in science. It is this *explicit* attention to the ambiguity of solutions to ill-structured problems, partly caused by personal beliefs and moral dilemmas, that brought about the term socio-scientific education. Zeidler, Walker, Ackett, and Simmons (2002) argue that socio-scientific education can be thought of as subsuming STS and also bringing into focus the ethical and moral issues faced by individuals. They state:

‘Socioscientific issues’ then, is a broader term that subsumes all that STS has to offer, while also considering the ethical dimensions of science, the moral reasoning of the child, and the emotional development of the student. (Zeidler et al., 2002, p. 344)

Therefore, when considering socio-scientific issues, it is not sufficient to consider scientific facts alone or to consider scientific facts in conjunction with their social origins; to reason about socio-scientific issues, students are required to consider their own perspective, their beliefs, their moral and ethical stance as well as their scientific knowledge and their knowledge of society. It is this combination of divergent domains of knowledge, which need to be integrated in the reasoning processes, which this study investigates.

2.2.2 Inherent challenges of socio-scientific issues

As previously mentioned, in much of school learning, there is a ‘desired’ or ‘correct’ outcome to a learning activity. When ‘inquiry’ is used as a pedagogical tool, the students are often led through an investigation with the teacher knowing the expected

outcome (for an example, see TES Connect, n.d.). Socio-scientific issues are, by definition, those that do not have a single 'known' outcome, or indeed a single route of inquiry. Socio-scientific issues are complex and open and, depending on an individual's own perspective, could be tackled in a multitude of different ways; they present ill-structured problems that have numerous correct outcomes. Present a socio-scientific problem to a group of experts and it is likely that each expert will not only respond with a different solution, but also have good and convincing arguments why their solution is the most appropriate. Whereas, in contrast, ask a group of expert physicists about the forces involved when a ball is tossed in the air and one would expect identical answers.

This study aims to investigate the complex inquiry process that students traverse when faced with ill-structured problems. Often, with socio-scientific issues, students are faced with combining different types of knowledge. For example, thinking about these issues may require a combination of taught scientific (classroom) knowledge and everyday (social) knowledge. It is this combination of knowledge types, coupled with an individual's own perspective on the issue under consideration, that this study seeks to better understand.

2.3 Sustainability

Sustainability is an example of a socio-scientific issue. The very nature of sustainability presents ill-structured problems with multiple correct answers, depending on one's own perspective. The complexity of the issue is increased, as it is difficult even to define what is meant by 'sustainability'. To illustrate this, the

Australian (New South Wales) Ministry for the Environment has difficulty defining the meaning of sustainability and says:

There is no simple definition of 'sustainability'. It can be an idea, a property of living systems, a manufacturing method or a way of life. In fact, there may be as many definitions of sustainability as there are people trying to define it.

(NSW Environment & Heritage, 2013, para. 1)

Despite there not being a simple definition of 'sustainability', school students are now required to learn about sustainability, and the subject is to be taught as a cross-curricular activity (ACARA, 2012a).

In the past, education about the environment has been absorbed into the science curriculum with the focus on environmental facts. To understand sustainability students require, not only an understanding of scientific facts relating to the environment, but also an understanding of how they, as individuals, relate to and affect the environment. This study defines 'sustainability' as:

The use of resources in such a way that we can meet the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland, 1987)

This includes the use of resources that we consider to be 'free' such as air and water as well as all other resources that we use and interact with. These resources (which may be environmental, economic and social) interact to produce different liveable conditions. For example, social and environmental resources interact to produce *bearable* conditions, social and economic resources interact to produce *equitable* conditions, and environmental and economic resources interact to produce *viable*

conditions; the interactions of all three types of resources produce conditions that are referred to as *sustainable* (Adams, 2006).

Schools in New South Wales, Australia are guided by this definition of sustainability and use it as the core message in their Environmental and Sustainability Education program (NSW Department of Education and Communities, 2010).

2.3.1 Environmental Education

Environmental Education has been a topic in school curricula for a number of years. In 1977, the Intergovernmental Conference on Environmental Education attempted to define 'Environmental Education' and, 20 years later, a charter was adopted for the future of *education for sustainability* (UNESCO, 1997). The Australian National Curriculum now identifies three cross-curriculum priorities, which are to be represented across learning areas. One of these priorities is 'Sustainability':

The Sustainability priority will allow young Australians to develop the knowledge, skills, values and world views necessary for them to act in ways that contribute to more sustainable patterns of living. (ACARA, 2012b, p. 18)

This shift from *Environmental Education* to *Education for Sustainability*, although subtle, changes the emphasis from learning about the environment to learning how we, as people, interact with the environment (Lang, 2007). To illustrate this difference, consider global warming and ozone depletion. Learning about these topics, students would consider factors that bring about the phenomena, such as greenhouse gasses and chlorofluorocarbons (CFCs). Students may have a good understanding about how excess carbon dioxide 'traps' heat in the atmosphere and how CFCs interact with ozone leading to higher levels of ultraviolet radiation. However,

education for sustainability emphasizes the role each individual plays in these processes, for example: use of aerosols containing CFCs releases the gases into the environment; boiling a kettle with excess water wastes electricity, the creation of which produced carbon dioxide gas, and hence contributes to global warming. While the scientific information is the same, the emphasis is now on individual actions that can have direct effects on the environment; namely, using products that contain CFCs contributes to the destruction of the ozone layer and wasting electricity contributes to global warming. There is an intention now that students should be able to have an understanding *of* the environment, to understand how individuals relate *to* the environment and to understand what individuals can do *for* the environment.

In New South Wales, the Board of Studies (which sets the core curriculum by developing syllabuses for Kindergarten to Year 12) currently defines ten topic areas that include education about the environment (see Appendix 1), for example outcome ESS3.6:

Recognise that the earth is the source of most materials and resources, and describe phenomena and processes, both natural and human, that form and change the earth over time. (Board of Studies, 2011)

These topic areas, to be studied in the early years (kindergarten to year 6), cover both environmental information and the effect individuals can have on the environment.

While these topic areas are currently taught in NSW schools, the emerging Australian curriculum extends these by “focusing on protecting environments and creating a more ecologically and socially just world through informed action” (ACARA, 2012b, p. 18), and these are combined into cross-curricula activities. It should be noted, however, that while there is a desire for environmental education to be considered as a

cross-curricula activity, existing school structures might make this difficult. In high school, individual teachers have responsibility for different areas of the curriculum each with their own priorities for their students and their classroom time. Day and Bryce (2011) highlight these differences, showing a difference between *humanities* and *science* teachers when leading classroom discussions. These issues are less apparent in primary schools as, in general, different subject areas are taught by the same *class* teacher.

2.3.2 Education for sustainability

As discussed earlier, learning about sustainability has moved away from being a *science subject* and is now a *cross-curricular activity*. It is not enough to rely on students learning about sustainability by some form of passive ‘osmosis’. As Pratt (2010) states, students should construct knowledge by being actively engaged in learning where they can collaborate, contribute and have a sense that they can make a difference. Without this ‘engaged’ activity, students may be left with the impression that their individual actions have no effect. For example, Barrett, Kuroda, and Miyamoto (2002) surveyed 1009 school students in Japan, asking questions about their environmental knowledge and attitudes. They found that students reported that they felt the following: their actions would not make any difference, there were no alternatives to existing actions, they did not know what to do, and they did not have enough time to change their actions. The authors concluded that providing students with “better, high quality information on the environment” would assist in enabling sustainable behaviour, but noted that students “appear unable to move from understanding to action” (Barrett et al., 2002, p.258). The authors also suggest that a more proactive approach to learning is required; the importance of this is further

emphasized when they state that today's students will be an important factor in bringing about change, with regard to the environment, and that it may not be until students, who are more aware of the need for change, become adults that we can truly move towards sustainability (Barrett et al., 2002). To formulate ideas of inquiry, when considering ill-structured problems such as sustainability, students are required to integrate knowledge that has been formed from both within the school environment and outside sources.

2.4 Sustainability in the classroom

Asking school students to think about, and reason about, sustainability can present problems. These problems stem from three main factors: it is difficult to define what is meant by sustainability, sustainability does not have a single route of inquiry, and finding a suitable route of inquiry appears to require the student to integrate different knowledge types that include both everyday knowledge and taught scientific knowledge. This difficulty in thinking about socio-scientific issues is highlighted by Bryce and Day (2013); they posit that students “need to be explicitly taught how to be sceptical, how to identify bias in scientific claims and how to critically reflect on how science findings are actually reported” (p. 626). To make sense of the issues under consideration, students need to compare and contrast evidence from multiple sources. These sources are both those that are considered as facts and those considered as values. Colucci-Gray, Perazzone, Dodman, and Camino (2013) suggest that science educators should help students integrate specialist knowledge along with students' own world-views; thereby, enabling both values and scientific knowledge to play a part in the route towards finding sustainable solutions.

When considering socio-scientific issues, students are required to activate prior knowledge; context appears to influence which knowledge is available. diSessa and Sherin (1998) provide a theoretical construct that they call a ‘coordination class’ to help explain how knowledge may only be contextually available. When a student is faced with a problem, they first readout from the problem the relevant details (relevant to that student at that moment) and then coordinate these details with their prior knowledge (referred to as the ‘causal net’). In any one context, different students will attune to different details and this will activate different aspects of their prior knowledge. The following sections look at context in learning - starting with a broad definition of context, then focusing on context in learning environments, and exploring the ideas of conceptual change and knowledge transfer.

2.4.1 Defining context

There have been many attempts to define ‘context’. The Oxford English Dictionary definition of the word is “the circumstances that form the setting for an event, statement, or idea, and in terms of which it can be fully understood” (“context, n.,” 2013). However, the word originates from textual linguistics - allowing a word to be interpreted by considering words that appear (both in speech and writing) before and after the word. This linguistic meaning has evolved and broadened; the word ‘context’ is now used to signify the set of circumstances that help to make sense of a particular situation. Using this broad definition of context still presents a problem of definition as making sense of a situation involves more than the physical location of the situation. Bazire and Brézillon (2005) pose a number of questions about context when considering an activity:

Which context is relevant for our study? The context of the person? The context of the task? The context of the interaction? The context of the situation? When does a context begin and where does it stop? (p. 29)

Bazire and Brézillon (2005) sought different definitions of 'context' and report on more than 150 definitions, collected "from various disciplines such as computer science, philosophy, economy, business, HCI, etc." (p. 31). They conclude that there is no consensus on whether context should be considered as internal or external, or whether it should be considered as static or dynamic (Bazire & Brézillon, 2005).

Goodwin and Duranti (1992) suggest that context "involves a fundamental juxtaposition of two entities: (1) a focal event; and (2) a field of action within which that event is embedded" (p. 3). This idea is extended by Hanks (2006) who introduces a third influence on context; in addition to the focal event (figure) and the field of action (ground), Hanks adds the observer (viewpoint). However, even with the addition of the observer, this conception of context retains a unidirectional field of influence; the field of action may have an impact on the focal event, and the observer may or may not observe certain features of the focal event. It does not entertain the possibility of the focal event influencing the field of action or the field of action influencing the observer. The three elements of context may all interact and any one may cause change in any other. Cicourel (1987) extends the idea of context beyond the local event. He refers to "several senses of context narrowly or broadly" (p. 218) and frequently attunes to 'local' context (for example pp. 221 & 225). This extended notion of context brings an individual's prior knowledge to bear on a local event.

In an attempt to clarify ‘context’, Gero and Smith (2009) discuss the difference between ‘context’ and ‘situation’. They consider ‘context’ to be those elements that are external to an individual that they use during reasoning, whereas ‘situation’ is an internal sense-making process that utilises the external context. Context provides the common ground that individuals require to communicate; however, each individual may interpret the context differently. That is, they situate themselves (or make sense of the context) differently. Gero and Smith (2009) state that “even though the term ‘context’ is widely used, by itself it doesn’t make sense without understanding what situations are and what role they play” (p. 609). It is, therefore, necessary to consider both the external context and the way individuals situate themselves within the context, which includes prior knowledge that individuals bring, when considering how students engage in an inquiry process.

2.4.2 Context in learning

Context appears to play an important role in learning; for example much research is conducted into ‘learning spaces’ which endeavours to understand the relationships between physical space and learning (see Boddington & Boys, 2011; Boys, 2010; Joint Information Systems Committee, 2006; Kolb & Kolb, 2005; Oblinger, 2006). The context is, in some way, affecting the manner in which individuals perceive the world around them. Cognition is sometimes considered as ‘information processing’, where external input is processed according to ‘rules’ and coherent output is obtained (see Simon, 1979; Sweller, 1988). Barsalou (2009), however, takes the view that cognition comprises many ‘simulators’ that provide an individual with concepts needed to make sense of the world around them. These simulators can provide the individual with a wide range of ‘simulations’ that are appropriate to a given context;

the context activates the relevant simulation provided from an appropriate simulator; i.e. the context activates relevant cognition. Context has been seen to affect how individuals solve mathematical problems; Lave (1988) shows evidence that when 'real life' problems are presented in school, the real-life part of the problem is generally ignored, or treated as some kind of *red-herring*, designed to disguise the real problem. However, when a similar problem is encountered in real life, the context is not only recognised, it is used as an integral part of finding a solution. For example, Carraher, Carraher, and Schliemann (1985) found that street sellers could make complex mathematical calculations when trading but were unable to perform similar calculations in a school setting.

The idea that context plays an important role when thinking about, and progressing towards a solution to, socio-scientific issues is highlighted by a study investigating the effect of context on pre-service teachers' reasoning (Topcu, Sadler, & Yilmaz-Tuzun, 2010). Their study, which interviewed 39 pre-service teachers about their ideas concerning three socio-scientific issues, reported that the "result supports the notion that informal reasoning is context-dependent particularly in terms of the extent to which those engaged in reasoning understand the underlying science content" (p. 2490).

Ceci and Roazzi (1994) distinguish three types of context, the physical, the social, and the mental:

- 1) The physical context, the location and the surrounding artefacts, can have an impact on how an individual sets about solving a problem. To illustrate this, Lave (1988) provides an example from observations of a weight-watchers class where the participants were preparing a correct amount of food. In the example, the desire was to measure out three-quarters of two-thirds of a cup of cottage cheese. The participant started the task by considering 'school' mathematics to solve the problem, and this would be one method of arriving at a solution (two-thirds of three-quarters is the same as six-twelfths or one-half). However, rather than struggling with the mathematics of the problem, the participant used the physical context (the surrounding artefacts) to help solve the problem. He measured out two-thirds of a cup, placed the cheese on a cutting board as a round 'cake' and cut the 'cake' into four quadrants. By only taking three of the quadrants, he had achieved three-quarters of two-thirds without having to calculate, or even notice, that he had taken one-half of the original cheese.

- 2) The social context may be thought of as the agreed and accepted social norms of a group without which understanding would be impossible. Turner and Oakes (1994) explain this as "the idea that the use of categories and their meanings are governed by social norms and therefore anchored in group memberships" (p. 460), and Turner (1991) takes the view that

knowledge is, at least in some part, validated by how it aligns with current social values.

- 3) The mental context is the way an individual represents the problem, which is influenced by how the problem is set. For example, when considering issues related to the use of the Earth's resources, the problem could be set in a mining context or a fishing context. These two mental contexts may have some similar underlying issues (for example pollution, financial gain, and ownership) but the way in which an individual represents these issues will be different. Ceci and Roazzi (1994) give the example of three year olds who are asked about the cutting of fruit. When asked how many pieces result from cutting an apple in half they respond "two"; however, when asked the same question about a watermelon, they claim that it may depend on how big the melon is. The researchers further illustrate the effect of changing the context of the problem setting by reporting on an experiment where students were asked to work out an algorithm that determined where shapes moved on a computer screen. When *geometric* shapes were used, after 750 trials, the students were unable to work out the underlying algorithm that determined the movements of the shapes. However, when the task was re-administered as a 'game' (shapes turned into birds, bees and butterflies, and sound effects added), the students managed to solve the underlying algorithm after 300 trials. The change in the problem context resulted in a change in the students' cognition (Ceci & Roazzi, 1994, pp. 78-79).

When thinking about sustainability issues, students bring with them prior knowledge; this knowledge comes from previous, out-of-school experiences and from previous learning episodes. Knowledge brought to bear on a current task has, in the past, been useful; however, the fact that particular knowledge was useful in a previous context does not necessarily mean that it will be useful in this context; it might be that a previous way of thinking is not appropriate in this current context. To illustrate this, Hammer, Elby, Scherr, and Redish (2005) provide the example of thinking about the size of a mirror and ask their participant the question “*How big a mirror do you need to see your whole body?*” (p. 90). The participant’s reported response was that a mirror the same size as the person would be required. The researchers suggest that the participant may have brought with her prior knowledge of experience with doors (a door at least as big as the person would be required to fit through) or pictures (to have a life-sized picture would require a life-sized canvas). Both of these (doors and life-sized pictures) would require an object the same size as the individual. This prior knowledge is inappropriate in the current situation. When thinking about a mirror, it would have been more appropriate to activate prior knowledge of windows; one can view a tall tree through a window without the window being as tall as the tree. The participant’s knowledge about doorways is not in itself incorrect, but it is inappropriate in the current context.

There are two large bodies of research that provide a means to consider knowledge that is not currently useful: 1) conceptual change and 2) inappropriate knowledge activations. These are explored in the following sections.

2.4.3 Conceptual change

Scientific knowledge in society develops by the use of theories. Theories explain observed events (data) and hold true until such time that new experiences conflict with the theory and a new theory has to be developed; for example, the development of physics (from Aristotelian to Newtonian theory) and the understanding of the solar system (from geocentric to heliocentric theory). This development of scientific knowledge was documented in Thomas Kuhn's seminal work on scientific knowledge (Kuhn, 1970). Kuhn considered knowledge that is shared, such as scientific knowledge, as fitting into a structure, which he called a "paradigm". He posited that human knowledge conforms to this knowledge structure until such time as an event sparks a change in the structure and a new structure is created. Kuhn referred to this as a "paradigm shift" (Kuhn, 1970, p. 85). Kuhn continued to articulate the belief that, once a new paradigm had been accepted and the shift had occurred, then there was no switching back to the old paradigm. Kuhn put forward the idea that, as scientists accumulate evidence that does not fit within their currently accepted paradigm, there is a confrontation and, at some point, a new paradigm has to be created:

In the process of being assimilated, the second must displace the first. Even a theory like energy conservation, which today seems a logical superstructure that relates to nature only through independently established theories, did not develop historically without paradigm destruction. (Kuhn, 1970, pp. 97-98)

Kuhn's ideas about scientific theories undergoing radical change when confronted with evidence that does not fit existing theories, have been used as a metaphor to help understand conceptual knowledge held by individuals, how people develop that knowledge, and how individuals progress from being novices to experts (see Carey, 1985).

The theory that human understanding develops along similar lines to the development of scientific theory has become known as ‘the theory theory’. This term, introduced by Morton (1980) when discussing human understanding, is used to refer to the idea that concepts, when challenged, may undergo radical change (see Gopnik & Meltzoff, 1997). The theory theory of development holds that individuals have fixed ‘theory’ like structures that enable them to make sense of situations. These theories are used, as needed, until an event happens that renders an existing theory untenable; at this point a new theory has to be created. Piaget (see, e.g. Piaget & Vonèche, 2007) introduced the ideas of ‘assimilation’ and ‘accommodation’ when considering how children’s theory-like mental structures develop. ‘Assimilation’ was considered to be the ability to incorporate a new experience into an existing theory and ‘accommodation’ was considered to be the restructuring of an existing theory to accommodate the new experience. Piaget linked these processes together and saw them as one mechanism. However, Block (1982) divorces these two processes and sees them as separate mechanisms that operate when needed. First, an attempt is made to assimilate and, if that fails, “the individual is de-structured or disorganized, that is, is without effective assimilative structures” (Block, 1982, p. 291). This ‘destructure’ then leads to the individual being “drawn to actively formulate a structure sufficient to encompass what was not encompassable before” (p. 291). This restructuring may entail the destructuring of other cognitive structures before the new structures can be completed (Block, 1982). As new evidence is experienced, processes either incorporate the evidence into existing structures or existing structures are reconfigured to accommodate the new evidence.

Theory notions of cognitive development rely on transformations taking place, which are brought about by some form of ‘cognitive dissonance’ (Festinger, 1962). That is, once a situation is experienced that can no longer be explained with existing conceptual understanding, a new conceptual understanding has to be created. Once created, this new understanding is then used to make sense of both the previous experiences and the new experience. Therefore, these cognitive structures are considered to be used ‘en-mass’ and hence lead to a consistent and coherent use of knowledge. Posner and Strike (1982) outline ideas about conceptual change that they call ‘accommodation’. In their account of conceptual change, they refer to various conditions that are needed for this radical change to take place; these are that an old conception should provide dissatisfaction, and a new conception should be intelligible, plausible, and fruitful (Posner & Strike, 1982, p. 214). These ways of thinking about personal knowledge have the central idea of a ‘concept’ that may need to be changed, when confronted with experiences that do not fit the current conception, in a similar way to Kuhn's (1970) paradigm shifts in scientific knowledge.

Various grain sizes of restructuring have been suggested. Chi (2008) puts forward three grain sizes to be considered. First, *beliefs* that are incorrect ideas; i.e. those beliefs, previously held, that are in conflict with newly encountered ideas. Second, *mental models* (organised structures of beliefs); i.e. coherent internal representations that are in conflict with a deemed correct model. Third, *categories* – attributing mental models (and therefore beliefs) to incorrect ontological categories. Each of these grain sizes provides opportunities for individuals to undergo conceptual change; however, the third and largest grain size (categorical shifts) presents the most robust misconceptions and, therefore, the most resistance to conceptual change. As

inconsistencies between prior knowledge and new knowledge are noticed, some form of belief revision is required. This may be as simple as accommodating the new ideas into existing mental models (within ontological categories) or as complex as restructuring knowledge across ontological categories.

Conceptual change occurs once a misconception has been identified and an individual undergoes some form of 'theory' change (whether gradual or radical) and then continues with a new conception that a) makes sense of both the old and new experiences and b) is then used until it again requires changing.

2.4.4 Coherence versus fragmentation

The idea that personal knowledge develops through theory-like structures that hold until such time that an individual undergoes a theory change provides grounds for knowledge to be considered as stable and coherent. That is that knowledge, once acquired, is available for use in a coherent fashion until such time that the current knowledge is no longer useful and, at that time, the individual's knowledge structure changes to a new stable and coherent structure (Gopnik & Wellman, 1994). This view would see individuals passing through various stages of knowledge - from naïve to expert theories. On the other hand, the fragmented view of knowledge does not consider 'stages' of knowledge (in the sense of moving from one theory to another), but rather that an individual holds a multitude of knowledge 'pieces' (diSessa, 1988, 1993). These pieces activate together and, as the individual moves from a state of being a novice to an expert, develop and change. Taking a 'knowledge in pieces' view, provides an opportunity to understand how an individual's knowledge can, at times, appear to be coherent and stable (coherent knowledge pieces are activating

together) and also how an individual's knowledge can, at times, appear incoherent (incoherent knowledge pieces are activating together). The debate around coherence and fragmentation is not settled (in research terms), however, when investigating implications for classroom-based strategies, considering knowledge at a fine-grained (in pieces) level enables a closer scrutiny of what may be happening when students are faced with challenging socio-scientific issues across different contexts.

2.4.5 Knowledge activation

While 'conceptual change' may account for many of the experiences that learners go through on their passage from novice to expert, it does not explain why experts may use novice-type thinking when useful. Gupta, Hammer, and Redish (2010), while arguing about ontological categories, provide a number of examples of experts using knowledge that may be deemed as misconceptions in their expert reasoning, not because the expert believes in the misconception but rather because the misconception is useful at that time. For example, expert physicists will use 'matter-like' terms such as "trapped in a well", and "a *barrier* through which electrons can *tunnel*" when thinking about non-material items such as 'potential' (Gupta et al., 2010, p.299). It would appear that experts are able to use two 'theory' structures simultaneously and switch between them according to their usefulness. This is not explained by the 'theory theory' approach that assumes a 'gestalt switch' (Kuhn, 1970) from an old, now defunct theory to a new, now useful theory. It appears that there is a need to look deeper into the construct of a concept, to understand how and when a particular 'way' of thinking may be appropriate.

Minsky (2006) considered how individuals use knowledge and referred to the contents of the mind as comprising many parts that he called “resources”. He referred to these resources as acting in ‘collections’ that produce a certain state of mind. For example, he spoke of emotions as being particular states of mind:

For example, the state called ‘Anger’ appears to arouse resources that make us react with unusual speed and strength—while suppressing resources that we otherwise use to plan and act more prudently; thus, Anger replaces your cautiousness with aggressiveness and trades your sympathy for hostility.

(Minsky, 2006, p. 3)

Minsky extends his ideas of mental resources to common-sense knowledge (see Minsky, 2006, chp. 6) and he considers that mental resources may be suppressed or enhanced, thereby having an effect on an individual’s thinking. In the same way that ‘anger’ may be deliberately activated (such as when *outraged*) or spontaneously activated (without deliberate mental control), other mental resources may be either deliberately or spontaneously activated. Knowledge may be available in a particular context either spontaneously or through a deliberate mental action. Mental resources, as described by Minsky, are activated in context; these activated resources provide an individual with contextually appropriate knowledge. That knowledge may not always be available; in the same way that particular emotions are not always evident². For example, consider a young child playing in a sand pit with water and various containers. The child is trying to move the water from one container to another by scooping it up using a tea strainer. Each attempt is met with disappointment as the water pours through the mesh. Sitting next to the container is a spoon, but it does not occur to the child to swap the strainer for the spoon. The child already has the

² Knowledge that is *not available* signifies knowledge that an individual has, but which is not currently at the forefront, not displayed, not useable. Just as the emotion ‘anger’ may be displayed in some contexts but not in others, knowledge may be available in some contexts but not in others.

knowledge that a spoon is used to move liquid from one container to another; in a *meal* context a spoon is used to move soup (liquid) from one container (bowl) to another container (mouth), but in this *play* context, at this moment in time, that knowledge is not available. However, as the child continues to play, different mental resources may activate (the continued failure may enable the child to read the situation differently), the child may look around for a more appropriate tool and recognise the affordance of the spoon. The child's prior knowledge activations are influenced by the immediate context.

Knowledge and *emotions* should not be equated or indeed considered as one and the same but, as with emotions, knowledge may be activated spontaneously and/or deliberately as the context demands. Goldie (2004) provides the example of seeing a mouse in the corner of a room. In his example, the spontaneous resource of being afraid may be activated, along with the deliberate resource of the knowledge that the mouse is not dangerous. The manner in which emotions and conceptual knowledge are activated (and used) is similar.

diSessa (1993), using Minsky's ideas of mental resources, considers that conceptual knowledge comprises many 'fine-grained' resources and uses this to help explain how students learn physics and in particular Newtonian mechanics. diSessa refers to this 'mental resource' perspective as *knowledge in pieces*. Rather than considering conceptual knowledge as being made up of whole cognitive 'units', diSessa considers conceptual knowledge as comprising many fine-grained resources or, as he describes them, "phenomenological primitives" (p-prims) which are activated in combinations, dependent on situational prompts, to produce particular cognitive states.

In contrast to thinking about knowledge as theory-like structures of concepts that enable coherent ‘thinking’ across situations, knowledge may be thought of as fine-grained and fragmented. It is these ‘fragments’ of knowledge (mental resources) that, when activated together in context, enable an individual to make sense of an experience or situation. While, in some contexts, these mental resources may produce a coherent ‘concept-like’ structure of knowledge, they may also activate differently, as the context demands, providing a sometimes-incoherent result. It is acknowledged that, in many situations, groups (or sets) of fine-grained knowledge elements may activate together and act as a cognitive structure that may appear as coherent units; these units are not, in themselves, atomic but comprise smaller resource elements.

Mental resources are part of a *knowledge system* outlined by diSessa (1993). He identified four parts of the knowledge system: elements, cognitive mechanism, development, and systematicity (diSessa, 1993, p. 111). Here, these are defined as:

Elements – The knowledge system is made up of parts. These parts may be fine-grained (such as p-prims) or more complex, already coordinated elements of knowledge.

Mechanism – Knowledge is activated (or not activated) dependent on particular situations. There is a mechanism for the activation of knowledge and the knowledge is only available for use if the necessary conditions for activation are satisfied.

Development – The way that knowledge elements are formed, and how they activate, develops over time. New elements are created, existing elements are revised and the mechanisms of activation are changing.

Systems – There are systems in place; these include hierarchical structures, which are built on sub-systems. Some parts of the knowledge system are integrated and some parts function independently.

diSessa's physics p-prims are formed from everyday experiences and may be activated alongside other mental resources to provide an individual with an interpretive frame for a particular context. For example, two people in the same physical context may situate themselves differently. Consider loud banging noises at night. A person with prior knowledge that water pipes bang may ignore the nocturnal interruptions, however, someone without the prior knowledge may feel uneasy and imagine a prowler stumbling around. This knowledge can be combined with other mental resources, such as the belief in the certainty of knowledge. In this example, an individual having been told about the banging water pipes may feel content 'knowing' the source of the noise, however, an individual who questions the certainty of knowledge may remain uneasy, suspecting that the 'knowledge' may be false and there really *is* a prowler. Combining mental resources provides an individual with an interpretive frame. This 'knowledge in pieces' approach helps explain how 'experts' are able to utilise ideas (that may be deemed as 'misconceptions') when they are useful, but continue to hold more accurate conceptions and are able to use these conceptions when needed. The activations of appropriate mental resources come

about due to a particular context; a different context may activate a different set of mental resources.

diSessa (1993) outlines seventeen principles that, when considered together, provide a basis for defining and uncovering p-prims. These criteria include principles such as obviousness, unproblematic genesis, functionality, and ready availability. An example of a p-prim, defined by diSessa, is “Ohm’s p-prim” (p. 126). Ohm’s p-prim accounts for the knowledge that increasing something results in a corresponding increase in effect (and conversely that decreasing something results in a diminishing effect).

When considering forces and motion, the statement “more push means more resulting motion” (diSessa, 1993, p. 130) illustrates that Ohm’s p-prim is activated. Hammer (1996) provides further examples of p-prims and uses diSessa’s ‘continuing push’ p-prim to describe ‘maintaining agency’; that is, the knowledge that to keep something happening requires a continuing driving ‘force’. Hammer provides examples of when this p-prim is activated:

such as an engine maintaining the motion of a car, but it can also be involved in understanding that a supply of energy is necessary to keep a bulb lit or an oven hot, or that continuous encouragement is needed to keep a student motivated. (Hammer, 1996, p. 103)

These p-prims are not, in themselves, either correct or incorrect; in many circumstances, an increase of effort *does* produce an increase in results and the supply of electricity *is* needed to keep an incandescent bulb alight. However, there are some circumstances when these p-prims can be activated inappropriately; for example continued force *is not* a necessary prerequisite for continued motion.

Building on the idea of p-prims, Kapon and diSessa (2010) developed the notion of ‘explanatory primitive’ or e-prim. Explanatory primitives are those knowledge elements, based on prior knowledge and experience, that are used when problem solving, and are described as “self- explanatory, unquestioned units of explanation, which students take as simply ‘the way things are’” (Kapon & diSessa, 2012, p. 266). e-prims meet some of the criteria that diSessa (1993) outlines for p-prims (such as obviousness), however, they do not necessarily meet all seventeen principles that define p-prims. As such, e-prims can be thought of as a superset of p-prims; that is, all p-prims are also e-prims, but not all e-prims are p-prims. An example of e-prim would be Ohm’s p-prim; an individual may use the knowledge that an increase of one variable leads to an increase in another variable as a self-explanatory, obvious piece of knowledge. There are however, other pieces of knowledge that may be self-explanatory and obvious to one individual (based on prior knowledge and experience) that are neither self-explanatory nor obvious to another individual. For example, an expert in a field may consider some knowledge obvious whereas a novice may still need further experience to understand what is going on. In this case, the expert would use the knowledge as an e-prim, but it could not be considered as a p-prim as it is not self-explanatory or obvious to the novice.

In the same way that Goldie (2004) combines the emotion of being afraid and the knowledge that mice are not (in usual circumstances) dangerous, the concepts and functionality of p-prims and e-prims can combine students’ scientific knowledge with their personal knowledge (that includes their own perspective, their beliefs, and their moral and ethical stance). The activation of students’ mental resources is bound to the context, which incorporates the students’ worldviews, values, and judgments.

Therefore, investigating the activation of the students' mental resources within a specific context (at a moment in time), takes into consideration students' scientific knowledge along with their worldviews, their personal values, and their links between personal desires and normative judgements.

2.4.6 Knowledge transfer

The ability to use knowledge, learned in one context, in another new context is fundamental to the idea of learning. Referred to as 'knowledge transfer', much research has been completed to help gain an understanding of how individuals go about transferring their knowledge from one context to another. Much of the early work was influenced by Thorndike (1906), who took the approach that transfer takes place (or is made easier) when elements of the two contexts are perceived to be the same, i.e. it is easier to transfer knowledge from one context to another when one recognises similarities between the two contexts. Whether the 'similarities' that are recognised are similarities in the physical context, or similarities in some form of abstracted cognitive structure has been debated (see Bransford, Brown, & Cocking, 2000; Perkins & Salomon, 1988; 1992; Salomon & Perkins, 1989). On the one hand, the similarities (needed to effect transfer) may be considered to be abstracted, mental models of the knowledge (the 'essence' of the knowledge) with any bound contextual elements removed. Fuchs et al. (2003) describe this as removing details from ideas that are not relevant to the general concept. The example that they provide is that, when considering the idea of "flying things" and comparing aeroplanes and birds, the materials (metal and feathers) are not relevant (Fuchs et al., 2003, p. 294). These contextual elements are removed before being stored for future use. This approach assumes that knowledge, once abstracted (contextual details removed), will be

available in all relevant contexts. On the other hand, Wagner (2006) challenges this idea and considers knowledge transfer to be highly contextual and that transfer is effected when contextual elements are recognised as being similar. Particular knowledge may be activated (or deactivated) dependent on the context. In his study, Wagner looks, not for a coherent system of abstracted knowledge, but for context dependent knowledge elements. Wagner focuses on one undergraduate student as she completes a mathematics course. He selected one 'concept', the law of large numbers, and follows the progress of the student as she applies, and fails to apply, her knowledge of the concept across different contexts. Wagner's findings show that, rather than utilizing coherent abstracted knowledge, his student sought out similarities between the problem context and a previously 'known' context. Once these similarities in context had been established the student was able to activate the knowledge that had been useful in the previous context.

An example of utilising prior knowledge is provided by Gick and Holyoak (1983). Students were presented with a problem of needing to destroy a tumour in the human body. The amount of radiation required to destroy the tumour would also destroy all the healthy tissue in its path. If the radiation dose were reduced so as not to destroy healthy tissue, then it would not be strong enough to destroy the tumour. Some students, prior to being exposed to the tumour problem, were asked to read a military story, which was analogous to the tumour problem. In the military story, a town under siege had many roads radiating out from the centre, each with explosives that would be triggered if the full army were to travel down the road, but small groups of men could pass safely along any of the roads. About 75% of the students who had read the military analogy solved the tumour problem compared to only about 10% of the

students who had not received the military analogy. Gick and Holyoak (1983) explain the mechanism of the students' use of the analogy through abstraction and the removal of context-specific information. They state, "the process of schema induction involves deleting the differences between the analogs while preserving their commonalities" (p. 8). However, rather than decontextualizing the knowledge and using an abstracted form later, the students may have been recognizing similarities in the context (for example, the need to 'attack', and pathways lead to the 'thing' under attack) and, by recognizing these similarities, knowledge that was useful in the military context was again activated in the tumour context.

2.4.7 Context in socio-scientific inquiry

When students are faced with socio-scientific problems, context affects the manner in which inquiry takes place. Previously, three aspects of context were considered: the physical, the mental, and the social (see Section 2.4.2). This study investigates four aspects of context which broadly align with the three already discussed. The physical context is divided between the 'physical location' (that is, the setting of the problem solver) and the 'problem context' (that is, the setting of the problem). For example, when considering the use of the Earth's resources, students may be in a classroom (physical location) and asked to consider marine life or land animals (problem contexts). Many of the underlying sustainability issues are the same (over-use of resources, contamination, bio-diversity) but, while the physical location is the same, the *problem context* has changed. Students bring prior knowledge to an inquiry session; this is here referred to as the 'knowledge context' and, while considering socio-scientific issues, the students will 'frame' (that is, make sense of) the problem.

These four aspects of context (problem context, knowledge context, students' framing, and the physical context) are now discussed.

1. *Problem context*

(the context of the problem being considered)

It has been noted that knowledge transfer takes place when the student notices similarities in the context (Bransford et al., 2000; Gick & Holyoak, 1983; Wagner, 2006). Wagner (2010) reports on students who had been asked to consider two problems that required the use of the law of large numbers. While the two problems use the same underlying mathematics, the contexts of the problems were different; the first concerned the strategy a skier should use when attempting to qualify for a race and the second concerned the optimum scoring system to be used when two friends were playing squash (pp. 456 – 459). Wagner describes these as “instances of the same mathematical principle” (p. 452) and seeks to discover when and how the students come to ‘see’ the two problems as alike. By using ‘teaching interviews’ (Hershkowitz, Schwarz, & Dreyfus, 2001), Wagner challenged the students’ thinking as they attempted to solve the two problems and hence gained an insight into the solution ‘trajectories’ that the students followed. Even when the students stated that the two problems were essentially the same, the different problem contexts produced different interpretive ideas and different causal explanations for the different problems. The context of the problem to be solved changed the manner in which the students activated their knowledge. A variation of the problem context occurs when the instance of the problem changes, while the underlying knowledge needed to solve the problem remains the same.

2. *Knowledge context*

(existing knowledge: the activation of appropriate and inappropriate prior knowledge)

Students bring prior knowledge to a problem under consideration. Some of this prior knowledge may be challenged while the student attempts to find a solution to the problem. Gero and Smith (2009) state that for any individual (agent) there is an external world “that it interacts with and is aware of”, and an interpretive world that is made up of experiences “that direct how interactive experiences proceed” (p. 609). An individual has to be aware of the external world (the problem) and then interpret (make sense of) the problem. Not all individuals will ‘see’ the same things in the same problem.

diSessa and Sherin (1998) introduced the idea of ‘coordination classes’ that account for ‘readout strategy’ (what an individual ‘sees’, considers relevant, and uses) and ‘causal net’ (the ensuing activation of prior knowledge to assist in the reasoning process). They distinguish between these two phases of sense-making; an individual may read the information correctly, but be unable to interpret that information in a meaningful way. diSessa and Sherin (1998) use Piaget’s example of children’s understanding of time intervals. The example uses an imagined scenario of two trains travelling different distances at different speeds; the train that went a shorter distance ran for a longer time. When asked which train ran for a longer time, the children often answered incorrectly; however, when questioned further, the children who answered incorrectly had understood that the train that went a shorter distance had stopped later (p. 1174). The children had read the information accurately, but were unable to interpret their correct reading. When attempting to solve a problem, students are

required to integrate the process of extracting information and interpreting that information. As different students bring with them different prior knowledge and different abilities to extract and interpret information from a problem, individuals may activate prior knowledge in different ways.

3. *Framing*

(situating the problem under consideration)

When faced with finding a solution to a problem, students will set about framing the problem - that is, working out what is going on. Hammer, Elby, Scherr, and Redish (2005) refer to framing as “moments when the participants challenge each others’ [sic] understanding of ‘what’s going on here’” (p. 99). This initial framing may take into account various contextual prompts. In an example provided by Hammer et al. (2005), different students engage in framing a lecture in different ways. Although the physical context is the same - they are both sitting in a lecture theatre - they

might frame the situation in the same way socially, expecting to sit still and speak only when called upon, but frame it in different ways epistemologically: One may expect to deliberate over what the professor says, while the other may expect to record information. (pp. 98-99)

Knowledge can be thought of as being declarative (knowing *that*) and procedural (knowing *how*) (Chipman, Segal, & Glaser, 1985; Glaser, 1984). Declarative knowledge relates to knowledge of facts: ‘I know that a chisel is used to carve wood’; whereas procedural knowledge relates to actions: ‘I know how to carve wood with a chisel’. Broudy (1977) adds an additional way of knowing, knowing *with*, which is contextually based. Knowing requires “a context within which a particular situation is perceived, interpreted, and judged” (Broudy, 1977, p. 12). Knowing *with* provides a

means to consider locally attuned contextual elements, or frames, that can affect the activation of an individual's prior knowledge. Shaffer (2006) extends these contextual frames to consider:

Knowing where to begin looking and asking questions, knowing what constitutes appropriate evidence to consider or information to assess, knowing how to go about gathering that evidence, and knowing when to draw a conclusion and/or move on to a different issue. (Shaffer, 2006, p. 228).

When considering well-structured problems (those that have canonical solutions) there may be a desired (or best) way to frame the problem. Students can be guided on how to interpret the problem and how to work out what is going on. However, ill-structured problems do not have known and desired manners of framing; there may be many ways to work out what is going on and many routes to many different, but equally valid, solutions. It is in these cases that knowing *with* (knowing where to begin, knowing what to look for, knowing what to consider, knowing when to draw conclusions, and knowing when to move on) becomes significant.

Attempting to solve ill-structured problems, such as those encountered in socio-scientific issues, is akin to solving design problems; designers face the same ill-structured issues when considering design problems (Zimring & Craig, 2001). In attempting to define ill-structured design problems, Zimring and Craig (2001) suggest that the multitude of variables that make up a design problem can be restructured and that a finer level of granularity can increase the lack of structure of a problem. They compare 'tinker-toys' (a toy construction set for children) and a lump of clay: "Both can be restructured, but the clay can be transformed at the molecular level [sic], resulting in what seem to be almost fluid transformations" (Zimring & Craig, 2001, p.

136); giving rise to multiple possible solutions. They also argue that ill-structured design problems may contain a large amount of ‘social’ information, which is likely to change from person to person. These social variables not only produce ambiguity, but also raise conflicting solutions.

Considering that problems about socio-scientific issues are similar to design problems may provide insights into the solution processes. When encountering a design problem, once students have undergone a framing process, they may ‘get stuck’ as the framing process hinders advancing towards a solution. Dong, Kleinsmann, and Deken (2013) talk about the need for designers to reflect; “reflections evaluate the activities of the team in relation to the frame in which they are operating, for example ‘being stuck’” (p. 15). Students may need to reflect and begin a reframing process while attempting to find solutions to ill-structured problems.

4. *Physical context*

(the physical location of the problem solving activity)

While students are attempting to find solutions to socio-scientific issues, they are in a physical location, surrounded by artefacts. The physical location and artefacts provide possibilities of use, for students, as ‘tools’ in reasoning; tools that may or may not be useful to the students. Gibson (1977) put forward the idea that perceptions go beyond simple shape/spatial relationships; items can also be perceived to have possibilities of action. Gibson’s *affordance* theory provides a possibility of action that is apparent to the user/observer; an individual’s perception of their surroundings may lead to some form of action (Gibson, 1986). However, the affordance of an object or a situation is not held within either object or the context. To illustrate this, consider a new design of

an everyday object; for example, a new design of a basin/tap (faucet) arrangement. While some people will see the new design as a basin, and understand how to use it, others will stand looking mystified by the new device. The function of the device is obvious to some people and a mystery to others. Those people who find the new design difficult have no problems using an older design of basin. The understanding of use, therefore, does not lie completely within the object or completely within the individual, but spans both. Greeno (1994) discusses Gibson's affordances and concludes that, while the presence of a situation may provide an affordance for a particular action, it can only increase the likelihood of the action taking place; it does not imply that the action will take place. Gibson uses an example of mailboxes and suggests that mailboxes provide the affordance for posting letters (Gibson, 1977). While this may be true, it may not be the case for all individuals. For example, someone from the United Kingdom who is familiar with red pillar-boxes, may be somewhat bemused when they see an American blue mailbox with a pull down handle. The affordance of a tool is not determined by the tool or by the individual, but exists in the relationship between the two.

When considering 'sustainability' issues, students are faced with a problem (set in a problem context); they bring with them conceptualisations, formed from prior experiences and prior knowledge, which may or may not be appropriate (their knowledge context), and they initially situate the problem by framing and then may subsequently re-frame the problem as they work towards a solution. They do this while in a physical location, surrounded by artefacts that may or may not be useful (the physical context).

2.5 Research Questions

This study investigates school students' problem solving when faced with socio-scientific issues about sustainability. Making decisions about sustainability is a priority outlined in the Australian National Curriculum (ACARA, 2012b) and is destined to become a lifelong skill. Sustainability problems are inherently ill-structured as they do not have a fixed single canonical solution. The study seeks to extend the knowledge about school students' problem solving abilities and in particular sets out to consider *how context affects students' route to solutions*.

Four aspects of context have been discussed; the problem context, the knowledge context, students' framing, and the physical context. Previous research has suggested that the problem context can have significant impact on students' ability to activate appropriate prior knowledge, that contextual prompts can influence the activation of prior knowledge, and that the physical context can influence the way in which students go about making sense of the problem under consideration (see, e.g. Ceci & Roazzi, 1994; diSessa, Elby, & Hammer, 2002; Wagner, 2006)

These aspects of context are investigated:

1. How does the *problem context* affect school students when solving problems about sustainability issues?
2. How does an individual's *knowledge context* influence problem solving when considering sustainability issues?

3. How does the physical context affect the way schools students *frame and re-frame* their ideas when solving problems about sustainability issues?

Within the limitations of this PhD study, it is necessary to reduce the scope of the investigation to a manageable level. The scope of each of the research questions is large. For example, in the first question, there are many types of problem contexts, many kinds of school students, and many issues about sustainability. Therefore a problem reduction process is necessary to limit that which this study can investigate.

First, for the purposes of this study, the participants will be limited to year-six. While this is a limit to the depth of the study, it should not imply that any findings, relevant to year-six primary school students, are not relevant to other age groups. However, any further inference would need further empirical testing.

Second, the problem context could be drawn from many attributes of sustainability that students come across during their studies or from outside of school life.

Therefore, to provide a manageable scope to the research, two specific problem contexts concerning one aspect of sustainability will be tested.

Third, the various aspects of context that are to be investigated relate to issues surrounding sustainability and how various factors may influence school students' thinking. It would not be possible to test all aspects of sustainability across all contexts; therefore, this study seeks to investigate which factors students take into

account when considering the sustainability of a number of objects and how individuals' prior knowledge can affect these factors.

With these three limitations in mind, the scope of the research is reduced to these, more manageable, research questions:

1. How is the activation of prior knowledge affected when year-six primary school students are asked to apply their knowledge of the law of conservation of mass in two different but similar problem contexts?
2. How is year-six primary school students' reasoning affected by contextual prompts that may activate conflicting prior understandings of sustainability?
3. How do year-six primary school students go about framing and reframing sustainability issues, both individually and collaboratively, when faced with a sustainability challenge?

These three research questions are investigated through three empirical data collection episodes. While the scope of the investigation has been reduced to a manageable size for this PhD study, the outcomes from the research can be seen as exploratory work that can shed light on some of the complex processes that are at work when school students are considering socio-scientific issues.

2.6 Contributions to knowledge, methods and practice

It is hoped that, through the investigation of the research questions, this study will provide a more nuanced understanding of the complex processes that students undertake when considering socio-scientific issues. The study uses qualitative research methods and utilises 'epistemic interviewing' techniques. By gaining a better

understanding of the complex processes that students undertake when thinking about socio-scientific issues, it is hoped that conclusions can be drawn which may lead to the advancement of pedagogical approaches that are used when both teachers and learners embark on investigations into these issues. It is further hoped that these conclusions will point to new teaching and learning practices, which could include the integration of challenging interviews, and highlight areas for further research.

Chapter 3 Socio-scientific issues in schools

This chapter reviews the literature relevant to the three research questions. The study investigates school students' learning about sustainability and specifically looks at three aspects of the context of learning: the problem context, the knowledge context, and the physical context. The theoretical perspective for this study is based on a 'knowledge in pieces' (KIP) view of cognition; knowledge comprises many fine-grained resources that activate depending upon context. This chapter starts with an introduction to socio-scientific issues in the classroom and continues with a review of KIP and the studies that use a KIP perspective to help understand learning. There follows a review of school science education that focuses on three pedagogical approaches: inquiry, the positive effects of 'failure', and design activities. The chapter concludes with a review of current practices of teaching and learning socio-scientific issues; theoretical perspectives and research methods are discussed and conclusions drawn for this study.

3.1 Introduction

School students, when considering socio-scientific issues, and particularly issues about sustainability, are required to think about a broad range of environmental resources and to consider how these resources can be used without restricting their use by future generations. The very nature of socio-scientific issues requires students to consider the issues from different perspectives and this inevitably leads to ill-structured problems with no clear single solution. This is illustrated when attempts are made to list the various factors that need to be taken into consideration when thinking about sustainability issues. For example, Ferreira (2007) provides a list of nine

dimensions that should be taken into consideration when studying sustainability, these are: personal, social, spatial, temporal, economic, political, historical, cultural and aesthetic.

It may be considered that the end result of students' thinking about sustainability issues is to lead to some form of behavioural change; Barrett, Kuroda, and Miyamoto (2002) have suggested that better conceptual understanding of the issues leads to more sustainable behaviour. For knowledge about sustainability to be effective, students will need to be able to access the knowledge in different contexts. It is one thing to consider the environment in a classroom and understand the importance of recycling; another to take reusable bags to the supermarket. Attempts have been made to gauge whether a conceptual understanding of the environment leads to a change in behaviour. However, the evidence appears to suggest that becoming more aware of environmental issues has little impact on a change in behaviour. Hungerford and Volk (1990) investigated the effect that environmental education has on learners' behaviour and concluded that while "most educators firmly believe that, if we teach learners about something, behaviour can be modified" they found evidence that "typically, issue awareness does not lead to behaviour in the environmental dimension" (p. 17). Kollmuss and Agyeman (2002) suggest that there are many factors, in addition to environmental knowledge, that have to be taken into consideration when assessing behavioural change. These include personal values, attitudes, and emotional involvement. The idea that communicating facts will, necessarily, lead to behavioural change is also contested in health education. Nutbeam (2000) stated that health education campaigns were

characterized by their emphasis on the transmission of information, and were based on a relatively simplistic understanding of the relationship between communication and behaviour change. Over time, it became apparent that campaigns which focused only on the transmission of information and failed to take into account the social and economic circumstances of individuals were not achieving the results which had been expected in terms of their impact on health behaviour. (Nutbeam, 2000, p. 260)

The Hines, Hungerford, and Tomera (1987) meta-analysis of research on responsible environmental behaviour reviewed 128 studies carried out between 1971 and 1987. They found that, while knowledge of environmental issues and knowledge of action strategies played a part in moving towards responsible environmental behaviour, they were not the only factors. Figure 3.1 shows their proposed model of factors that lead to responsible environmental behaviour.

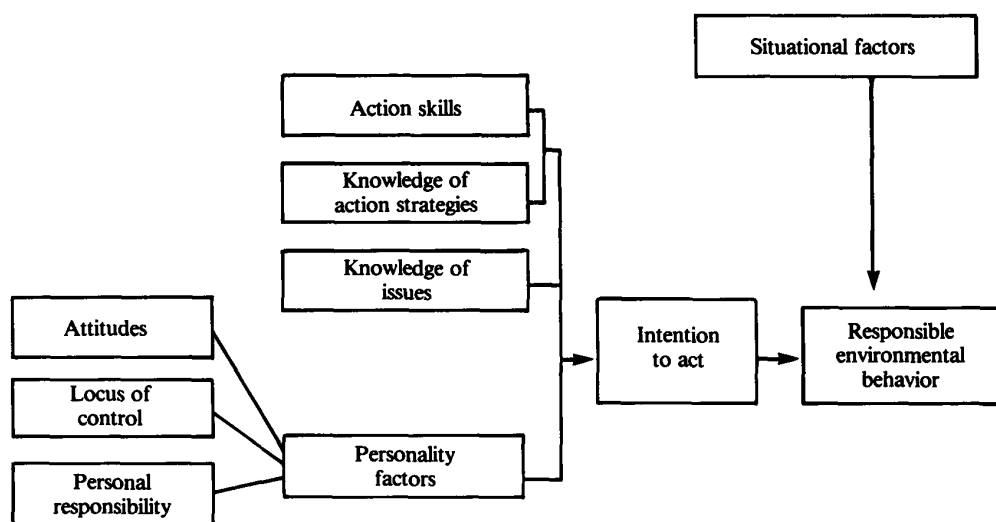


Figure 3.1 Proposed model of responsible environmental behaviour (Hines et al., 1987, p. 7)

Environmental knowledge certainly impinges on individuals' attitudes to the environment, and may affect people's inclinations and perhaps their intentions; however, environmental knowledge alone does not determine people's behaviour. People may say that they support protecting the environment but still live unsustainable lives, as if *their* actions do not *really* affect the environment.

Læssøe (2010) drew on three empirical studies to suggest that there are two paradigmatic approaches to teaching sustainability: *prescriptive* and *participatory*. The prescriptive approach, based on didactic, top-down instruction, was shown to reduce both critical analysis and creativity when solving sustainability problems. The conclusion was, therefore, that there is a need to develop participatory forms of the teaching of sustainability. However, there is more to learning about sustainability than participating in problem solving activities (Said, Yahaya, & Ahmadun, 2007). It would appear that some people easily understand that their actions have environmental effects, whereas others do not understand, or do not care about, the consequences of their actions. Cohen (2000) puts this into perspective in his theory of environmental knowledge orientations referring to a different knowledge *system* when considering sustainability. An individual who has limited scientific knowledge, or trust in science, can still have a very strong ecological consciousness (Cohen, 2000). An individual's ecological consciousness may have a profound affect on their ability to understand sustainability issues.

Walker and Loughland (2003) demonstrated that young people are mainly concerned with the environment with which they have the greatest experience, and that the greatest local environmental concern across the school age range was litter; being of

greater concern than global warming. They concluded by requesting further research that rethinks and redesigns established practices, focusing on other educational sources such as: non school organisations, the family and leisure activities, placing environmental education within school students' everyday environments. It is this combination of information, awareness, ecological consciousness, and situational factors that can bring about lasting behavioural change.

3.2 Knowledge in pieces

The 'knowledge in pieces' (KIP) perspective (diSessa, 1988) has been used to help explain how students go about framing problems. Kapon and diSessa (2012) investigated students' reasoning when faced with questions about forces on static objects. Their study, based on an earlier study by Brown and Clement (1989), presented students with a book resting on various objects, such as: a table, a hand, and a spring. The students (six students aged between 14 and 17 years who had not taken previous physics classes) were interviewed, using epistemic interviewing techniques (see Section 4.2.1) to gain an understanding of their reasoning process rather than to understand their physics knowledge. During the interviews, the participants were asked to clarify and justify their views and also asked to relate any alternative views they may hold. Out of the original six students interviewed, three were selected for analysis; three participant interviews were dropped, as they did not meet the initial requirements (one was interviewed in another language, one had undertaken a previous physics course, and one was uncooperative in the interview situation - only seeking correct answers from the researcher and failing to articulate her own reasoning). The interviews were transcribed and segmented, firstly into themed segments and then into smaller segments where individual knowledge activations

could be detected. The researchers posit that the context is significant in the students' ability to activate prior knowledge.

The decision whether an element activated by the source can operate in the target depends on the explanatory primitives that the source evokes and their judged applicability to the target. (Kapon & diSessa, 2012, p. 303)

This prior knowledge may not be knowledge directly related to the problem under consideration. Kapon and diSessa highlight an example of this. They refer to a particular 'e-prim' (see Section 2.4.4) which they define as "some changes may be invisible" (p. 306) and relate this to students comparing forces when the book is resting on a table and when it is resting on a spring.

Knowledge resources may be available to a student but may not activate in a particular context. Conversely, inappropriate knowledge (for the current context) may activate inappropriately. That is not to say that the knowledge itself is inappropriate, rather that the knowledge activation, in the current context, is inappropriate.

In addition to studies of advanced topics (such as college level mathematics and physics), 'Knowledge in pieces' has also been used as a theoretical perspective in a number of studies that investigate primary and high school students' thinking and problem solving (Azevedo, diSessa, & Sherin, 2012; diSessa, Hammer, & Sherin, 1991; Izsak, 2005; Kapon & diSessa, 2012; Masson & Legendre, 2008). Izsak (2005) investigated mathematical problem solving abilities in a class of year 5 students (aged between 11 and 12 years). Observations were made of ten teaching sessions, where the teacher introduced multiplication to calculate area, which included students working on examples in pairs. Four pairs were selected for interviews, however only

two pairs were interviewed during each instruction session and the study focused solely on the one dyad that provided the most detail in their interviews. The results showed that students appeared to bring together appropriate prior knowledge and were able to refine their knowledge as they progressed through the problem solving exercise. That is, when the context allowed the identification of similarities and differences between the current problem and students' prior experiences, students were better able to progress towards finding solutions. Masson and Legendre (2008) investigated p-prim activation in a group of six students aged between 11 and 12 years. In their study, the students were presented with interactive, computer-driven virtual worlds that behaved according to different conceptions of movement (Aristotelian, Buridanian, and Newtonian). The research participants were interviewed, by the researchers, while considering different 'situations' (such as a heavy box sliding across the floor) and while using the interactive computer environments. From transcripts of the interviews, the activations of a number of p-prim were observed and these activations were compared across students, situations and different conceptions of movement. The researchers concluded that prior knowledge, such as conceptions of friction and resistance, both inhibited appropriate p-prim activation and encouraged inappropriate p-prim activations.

The KIP theoretical perspective has been used to investigate a number of issues in education; however, the majority of studies have involved physics and mathematics. Both of these domains have canonical, well-structured solutions to their problems. This study investigates the ill-structured domain of sustainability and seeks to apply a similar KIP theoretical perspective to these types of school-based socio-scientific problems.

3.3 Teaching and learning science

This section investigates three pedagogical approaches to the teaching and learning of science in schools. The publication of the US National Science Education Standards (National Research Council, 1996) promoted the notion of scientific inquiry as a desired pedagogical tool for school science. The section starts with a review of ‘inquiry’ science and then reports on two, recently developed, inquiry methods: Productive Failure (Kapur, 2008), and Learning by Design™ (Kolodner, Camp, et al., 2003), as illustrations of pedagogical approaches.

3.3.1 Inquiry Science

The introduction of ‘inquiry’ into science education stems from a variety of sources culminating in a symposium on Scientific Inquiry at the 36th Annual Meeting of the National Association for Research in Science Teaching in Washington in 1963 (Bruner, 1961; Gagné, 1963; Rutherford, 1964; Schwab & Brandwein, 1962). In 1996, the National Research Council, in The United States of America, published the National Science Education Standards (National Research Council, 1996). This 262-page report sought “to guide our nation [USA] toward a scientifically literate society” (p. 11). The report, aimed at school years K to 12, provided a number of standards: for the teaching of science, for the professional development of science teachers, and for the assessment of science students. At the heart of the report is a desire that “all students should develop abilities necessary to do scientific inquiry and understandings about scientific inquiry” (p. 143).

The idea of teaching science through inquiry is not confined to North America. For example: in Europe, Inquiry-Based Science Education (IBSE) is being promoted and implemented through the Profiles project (Bolte, Holbrook, & Rauch, 2012) and in Australia through the School Science Education National Action Plan 2008 – 2012 (Goodrum & Rennie, 2007). However, there has been some debate regarding the definition of ‘inquiry’. Anderson (2002) interprets inquiry by considering inquiry *learning* and inquiry *teaching*. Inquiry learning can be thought of as an active process, equating the learning of science to the nature of scientific inquiry, whereas, inquiry teaching is not well defined; “there is no precise operational definition and, even though the NSES has some specific teaching examples, the reader is left to create his or her own images of what constitutes this form of teaching” (p.3). Anderson (2002) does, however, summarize Wise and Okey's (1983) meta analysis of teaching techniques and identifies inquiry-discovery as “more student-centred and less step-by-step teacher directed learning” (p.3). Bybee (2004) outlines three perspectives of inquiry science, which are: “strategies for teaching science, models for learning science, and content for science education” (p. 11). He concludes that, perhaps, there has been an overemphasis on teaching strategies and not enough consideration given to the learning theory that underpins inquiry learning.

Keys and Bryan (2001) outline five ‘abilities’ that are required for scientific inquiry; these are, “identifying and posing questions, designing and conducting investigations, analysing data and evidence, using models and explanations, and communicating findings” (p. 632). Olson and Loucks-Horsley (2000) provide a further five ‘features’ that make up classroom inquiry; these are, engaging in scientifically oriented questions, giving priority to evidence, formulating explanations from evidence,

connecting explanations to scientific knowledge, and communicating and justifying explanations. These lists provide a starting point for teachers and learners to think about inquiry science, however, they do not provide a framework for lesson structures. For example, the essential feature ‘engaging in scientifically oriented questions’, could range from students framing the problem and creating appropriate questions, to becoming engaged in teacher prepared questions. Martin-Hansen (2002) summarizes four ‘types’ of inquiry science: open inquiry - student centred (W. Roth & Bowen, 1995; W. Roth, 1996), guided inquiry - teacher helps students to form questions and conduct the investigation (Polman, 2000; Schwarz & Gwekwerere, 2007), coupled inquiry - starts with a guided inquiry followed by an open inquiry (Dunkhase, 2003; Sadeh & Zion, 2009), and structured inquiry - limited to the following of the teacher’s instructions (see Colburn, 2000). There is a wide range of types of inquiry, from student centred to teacher centred and, within each type of inquiry, the level of freedom that students are given to ‘inquire’ is often determined by the teacher.

Authentic inquiry, in the science classroom, requires students to frame a problem, formulate questions, decide what evidence is required, collect evidence, analyse data, draw conclusions (based on evidence and prior knowledge), and report findings. White and Frederiksen (1998) developed an “Inquiry Cycle” (p. 4) (Figure 3.2), which was shown to students prior to embarking on an inquiry episode.

THE INQUIRY CYCLE

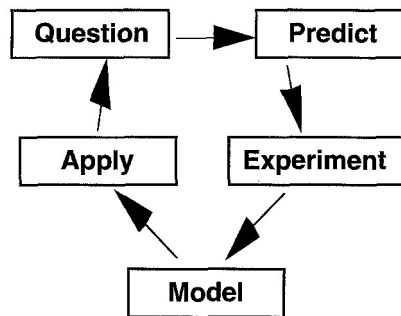


Figure 3.2 Model of the scientific inquiry process (White & Frederiksen, 1998, p. 5)

In their research, White and Frederiksen (1998) worked with 360 students aged between 13 and 15 years and asked the students to perform open inquiry into Newtonian physics, specifically the laws of force and motion. To aid the students with their inquiry, the research team provided support in two ways; the students were encouraged to take part in a “reflective-assessment process” (p. 8), and the research team provided computer models for the students to run ‘experimental’ trials. The reflective-assessment process was described to the students as “guidelines for judging your work”, and the students were asked to continually “reflect-and-try-again” (p. 50). Students were encouraged to “pursue a sequence of research goals in which they first formulate a question and then generate a set of competing predictions and hypotheses related to that question” (p. 4). This iterative model of refining predictions and hypotheses, along with on-going reflective assessment of their ‘research’ position, produced effective results. The experimental group of students (school years 7-9) was compared to a control group of older students (school years 11-12). The younger students produced lower scores in a pre-test; however, after instruction the

younger students outperformed the older students on qualitative problems based on Newtonian mechanics in real world situations. Another indicator that this pedagogical approach was successful was that, while less than 40% of the total year-7 student cohort took part in the inquiry sessions, students from the ‘inquiry’ group were awarded 77% of the prizes in an unrelated ‘science fair’ competition judged by scientists from their local community.

Learning school science through inquiry has been shown to produce effective results in both knowledge acquisition and knowledge transfer (see Waight & Abd-El-Khalick, 2011; White & Frederiksen, 1998; Windschitl, Thompson, & Braaten, 2008). However, an inquiry-based pedagogy, based on minimal instruction, may not always be beneficial. Kirschner, Sweller, and Clark (2006) put forward the argument that research “supports direct, strong instructional guidance rather than constructivist-based minimal guidance during the instruction of novice to intermediate learners” (p. 83). They state that research shows that direct instruction is as effective as minimal guidance and in many cases more effective, noting that minimal guidance pedagogies may cause negative effects by introducing misconceptions and “disorganized knowledge” (p. 84). This dissonance between supporters of *inquiry learning* and *direct instruction* is explored by Hmelo-Silver, Duncan, and Chinn (2007) who, rather than considering whether each pedagogical approach *works*, suggest considering; under what circumstances do these guided inquiry approaches work, what are the kinds of outcomes for which they are effective, what kinds of valued practices do they promote, and what kinds of support and scaffolding are needed for different populations and learning goals. (p. 105)

Rather than considering *inquiry learning* and *direct instruction* as opposing pedagogical approaches, they can be considered as different pedagogical approaches, often used together, that are used to achieve specific results. For example, direct instruction can, as Kirschner et al., (2006) state, provide “information that fully explains the concepts and procedures that students are required to learn” (p. 75), and inquiry learning can, as Hmelo-Silver et al. (2007) state, help students “learn content, strategies, and self-directed learning skills through collaboratively solving problems, reflecting on their experiences, and engaging in self-directed inquiry” (p. 100). These two goals are not mutually exclusive and various forms of direct instruction are used within inquiry learning. For example, Hmelo-Silver et al. (2007) provide examples of ‘just-in-time instruction’, ‘mini lectures’, and ‘benchmark lessons’ as ways in which direct instruction can be incorporated into inquiry learning.

Combining inquiry learning and direct instruction can be seen in various models for the teaching and learning of socio-scientific issues. Saunders and Rennie (2013) provide a “model for ethical inquiry into scientific issues” (p. 270) which highlights the need for students to obtain information about the science behind the issue along with opportunities to engage in the inquiry process (see also Saunders, 2010). Another example of combining inquiry with more formal instruction can be seen in Colucci-Gray, Camino, Barbiero, and Gray (2006); while their framework focuses on role-play as a method to develop “critical skills and sense of responsibility in relation to environmental problems of social relevance” (p. 242), it also calls for preparation to take on the role which includes an understanding of the scientific issues. The following two sections look in further detail at two inquiry methods: Productive Failure (Kapur, 2008), and Learning by Design™ (Kolodner, Camp, et al., 2003).

3.3.2 Productive Failure

To make sense of a new circumstance requires some level of prior knowledge. For example, consider the problem:

Train A, traveling 70 miles per hour (mph), leaves Westford heading toward Eastford, 260 miles away. At the same time Train B, traveling 60 mph, leaves Eastford heading toward Westford. When do the two trains meet? How far from each city do they meet? (Dr. Math ® Drexel University, 2013)

To make sense of this problem, a student requires prior knowledge, such as knowledge of trains, speed, direction, and distance. Without this prior knowledge, a solution would be impossible. The solution to this problem uses the formula “Distance = Rate x Time”. For many students, without adequate prior knowledge of ‘rate’ and ‘distance’, this formula becomes a means to solve the problem and requires memorization for future use. However, with adequate prior knowledge, the formula becomes part of the solution, not to be memorized, but to be used as a tool. Schwartz and Bransford (1998) consider direct instruction, referring to it as ‘telling’ and state;

When telling occurs without readiness, the primary recourse for students is to treat the new information as ends to be memorized rather than as tools to help them perceive and think. (p. 477)

They hypothesise that by providing opportunities for learners to consider contrasting cases, and to become able to differentiate between cases, learners can “become sensitive to information that they might miss otherwise” (p. 479). Providing opportunities to obtain differentiated knowledge prepares learners for future learning.

Schwartz and Martin (2004) pursued the idea of providing students with opportunities for the creation of differentiated knowledge, referring to it as ‘inventing to prepare for

future learning'. Drawing on insights from diSessa, Hammer, and Sherin (1991), Schwartz and Martin asked students to 'invent' solutions to problems, present those solutions and then undergo teacher led direct instruction. They conclude that the results indicate;

one way to prepare students to learn involves letting them generate original productions that are incorrect by normative standards. Although this production appears inefficient by itself, it has a later payoff when students find resources for learning. (p. 171)

Allowing students to explore ideas, even though these ideas may not be canonically correct and could be considered as *failure*, brought about *productive* learning after the combined direct instruction.

The idea of 'Productive Failure' has been further explored by Manu Kapur (Kapur & Bielaczyc, 2012; Kapur & Kinzer, 2009; Kapur, 2011; 2012). In various studies, Kapur has reproduced successful outcomes of Productive Failure experimental trails. For example Kapur (2012) investigated the effect of Productive Failure when students were undergoing instruction on the mathematical concept of 'variance'. One hundred and thirty-three students, aged between 14 and 15 years, took part in this study; students had already been assigned to four classes (two classes taught by one teacher, two by another). Pre and post tests were given to all students and one class of each teacher was assigned to be the experimental condition and taught using Productive Failure (the PF group); the other class for each teacher was given standard direct instruction (the DI group). The same amount of class time was given to both groups. In the experimental group, students were asked to 'invent' solutions to a complex problem; this was followed by direct instruction. The control group was given teacher

led instruction, followed by opportunities to work through teacher led examples. Both groups finished with a class of individual practice work and whole class discussions, led by the teacher. Kapur concludes “PF students significantly outperformed DI students on conceptual understanding and transfer” (p. 663).

The work on Productive Failure provides evidence that initial failure can result in productive learning. However, it may not be the ‘failure’ per se that increases learning, and ability to transfer knowledge, but rather the combination of providing opportunities for students to explore ideas and teacher-led instruction that creates success.

3.3.3 Learning by Design™

In 1969, Howard Barrows introduced Problem Based Learning (PBL) at McMaster University as a method for the teaching and learning of clinical issues in medicine (see Barrows, 1985; Neville, 2008). In 1986, Barrows developed a taxonomy of PBL in the medical profession and specifically extolled the benefits of including ‘design tasks’: “More of the students’ prior knowledge is activated in designing an inquiry strategy” (Barrows, 1986, p. 484). Around the same time, David Perkins introduced the idea that knowledge can be thought of as ‘design’; that is knowledge not isolated from context, but bound to purpose; he says, “we often treat knowledge as data devoid of purpose, rather than as design laden with purpose” (Perkins, 1986, p. 3). Learning can be thought of as the accumulation of facts (data devoid of purpose) or as an understanding of facts (design laden with purpose).

Using ‘design tasks’ as a pedagogical tool was being introduced in ‘problem-based learning’ and also in the field of ‘case-based reasoning’ (CBR) (see Kolodner, 1992; Leake, 1996). Gertzman and Kolodner (1996) developed “design problems for the curriculum that introduce students to technology and engineering while incorporating the math and science concepts” (p. 91). These design problems were crafted to assist students with their understanding of the mathematics and science concepts.

Learning by Design™ (LBD) has formed out of a blend of CBR and PBL. The idea is that students who progress through a ‘design activity’ develop important and desired skills (Kolodner, Crismond, Gray, Holbrook, & Puntambekar, 1998; Kolodner, Camp, et al., 2003; Thompson, Ashe, Yeoman, & Parisio, 2013). LBD has many important attributes that encourage scientific thinking and is based on an iterative design model (see Figure 3.3).

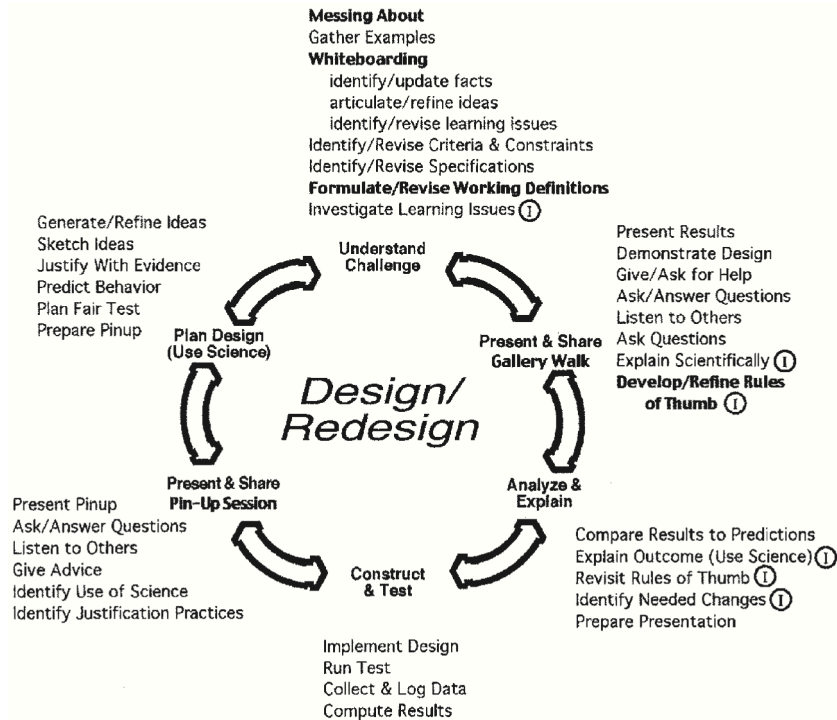


Figure 3.3 The design and redesign model (Kolodner, Camp, et al., 2003, p. 515)

Kolodner, Camp, et al., (2003) describe a sample LBD unit of study – Vehicles in Motion. It is an eight-week unit on forces and motion (Newtonian mechanics) where students are asked to design vehicles with propulsion systems. Students not only design, but also build models of their vehicles along with working propulsion systems. The students are presented with an imagined scenario where they have to design vehicles for an Antarctic exploration. This scenario provides the students with a number of design considerations which include design desires and design constraints. For example, the vehicles must be energy efficient, and need to be able to operate over hilly ground. The ‘design task’, which is based on a more manageable classroom activity, is to design a model of the vehicle that can travel over two hills and continue on, over flat ground, for as far as possible. During the LBD task, the teacher becomes “both a learner and a facilitator of learning” (p.496) and the teacher is placed “in the role of modeler and coach and articulator of process, gradually

having students take over these roles” (p. 498). Controlled group experiments show promising results; Kolodner, Gray, and Fasse (2003) report on the results of the ‘Vehicles in Motion’ unit of study. The experimental group (the LBD group) scored higher in performance assessments; they conclude:

That LBD students score higher than their comparisons means that they use their skills collaboratively more effectively than do non-LBD students. While we don’t have evidence that every child in every high-scoring group can remember and apply content and skills, we do have evidence that, when reminded, LBD students engage at a higher rate in using what they have learned. The data show that LBD students, on the whole, are further on their way to being able to reach full transfer as individuals than are their comparisons. (p. 162)

Learning by Design is another example of an ‘inquiry-pedagogy’ that uses iterative processes to enable students to reflect on their progress as they work through a unit of study.

3.4 Learning socio-science

Science education is a broad term and encompasses a wide variety of learning opportunities, which include: formal classroom science (experiments and formal definitions), visits to science museums (interactive exhibits), and everyday physical experiences (what happens when I throw a ball). Roberts (2007) proposes two ‘visions’ of scientific/science literacy, which he calls *Vision I* and *Vision II*. Vision I looks within science, and can be considered as “its [science’s] products such as laws and theories, and its processes such as hypothesizing and experimenting” (Roberts, 2007a, p. 9). Whereas, Vision II looks outward and considers where science has a role

in everyday lives; for example “decision-making about socio-scientific issues” (Roberts, 2007a, p. 9). When learning science, these two ‘visions’ can be thought of as learning how to be a scientist (Vision I) and learning to think about everyday situations as a citizen informed about science (Vision II). These visions are, as Roberts acknowledges, extremes and are often taught hand-in-hand. While becoming a ‘science informed citizen’ requires an understanding of scientific facts (from Vision I), it may not require an understanding of scientific processes (also from Vision I). However, when considering socio-scientific issues (Vision II), students are required to use a complex set of skills that include: recognition of the problem, activation of appropriate knowledge, appreciation of multiple solutions, consideration of appropriate evidence, creation of a plan, clarification of a particular position, and the making of value judgements (Zoller, 1992). These skills become increasingly more necessary as students move from thinking about environmental facts to considering themselves as part of, and having an effect on, the environment.

As discussed in Chapter 2, environmental education has gone through significant change. In the past students were required to learn *about* the environment; that is, to learn environmental facts. This has developed through several stages, such as learning *in* the environment, learning *for* the environment and learning *with* the environment (see Gough, 1997, chap 4). These three stages (‘in’, ‘for’, and ‘with’) are further discussed and illustrated with examples from the literature.

3.4.1 Learning ‘in’ the environment

Learning *in* the environment, as opposed to learning *about* the environment can be likened to learning outdoors as opposed to learning in a classroom setting. A number

of studies have shown that 'outdoor' education is beneficial; these are summarised in a review of research into outdoor education:

Strong evidence of the benefits of outdoor adventure education is provided by two meta-analyses of previous research. Looking across a wide range of outcome measures, these studies identify not only positive effects in the short term, but also continued gains in the long term. (Rickinson et al., 2004, p. 5)

It appears that being away from one's 'normal' environment brings experiences into sharper focus and individuals become more immersed in the experience and this, therefore, leads to increased participation in the experience (Gunter, 1987). Hattie, Marsh, Neil, and Richards (1997) conducted a meta-analysis of outdoor educational programs that included 'adventure', 'outward bound', and 'out-of-class' programs; they conclude "it seems that adventure programs have a major impact on the lives of participants, and this impact is lasting" (p. 70).

An example of outdoor education research is Palmberg and Kuru (2000). In this study Palmberg and Kuru followed 36 students (aged between 11 and 12 years, 24 boys and 12 girls) from three different schools as they prepared for and underwent an outdoor educational experience. The participants were first given a questionnaire, followed by individual interviews, their drawings were collected and observations performed during the outdoor activity. The participants were divided into two groups, those that had undergone numerous previous outdoor educational experiences and those that had only had minimal exposure to outdoor education. Palmberg and Kuru (2000) pointed to three major differences between the two groups.

- 1) Those students who had had multiple previous exposures to outdoor education had greater self-confidence and greater action skills. These students “knew their own limits and were spontaneously open-minded and cooperative”; whereas, the students with minimal exposure to outdoor education “were considerably more uncertain and needed a lot of help ... were anxious about trying new things ... were very quick to express their inability to do things ... and had more difficulties in working as a group” (p. 34).
- 2) Differences were found in the students’ relationships with the natural environment. They state, “comparing the pupils who were experienced in outdoor activities with the pupils who were not, it was found that the former seemed to have a strong and clearly definable empathetic relationship to nature” (p. 34).
- 3) While all participants expressed fragmented views about the environment and about human impacts on the environment, those students with greater outdoor educational experiences were better able to express feelings about nature and expressed stronger emotions that included feelings about other people and other organisms. They had “strong emotional reactions and a need to do something against man’s unfairness to nature and, especially, to animals” (p. 35). It was concluded that the

experienced pupils were better able to make moral judgments about ecological issues.

Outdoor education (learning *in* the environment) appears to increase students' ability to relate to the environment.

3.4.2 Learning 'for' the environment

The idea that students should not only have access to environmental facts (*about* the environment) and an understanding of themselves situated *in* the environment but also see themselves as both part of the environmental problem and part of the environmental solution, has brought about the idea of learning *for* the environment. This has led to the formation of 'socially critical environmental education' (Gough & Robottom, 1993). Students, learning about sustainability, are an integral part of the 'system' about which they are learning. Therefore, it would be appropriate for students to design sustainability solutions, with their role in the system taken into consideration.

Tilbury (1995) outlines a number of strategies that can be used when learning for the environment; amongst these are 'active learning' which "is a form of learning that empowers pupils to exercise responsibility for their own lives and for the environment", and 'critical skills' to "understand the complexity of environmental problems and solutions and the ability to participate individually and collectively in the resolution of environmental problems" (p. 204).

An example of an investigation into learning *for* the environment is the Aleixandre and Rodriguez (2001) study. In this study, Aleixandre and Rodriguez investigated the practices of teachers and students within both their primary classroom and during an out-of-school field trip. The participants were students aged between 9 and 10 years (18 boys and 7 girls); data were collected through interviews, group discussions, and observations. The students were assigned the task of first, constructing (or co-constructing) their own ‘behaviour code’ and second, implementing that code when on the field trip. For the behaviour code to be useful it was not sufficient for the students only to know *about* the environment or to be *in*, and relate to, the environment; the students were required to set up and modify their behaviour *for* the environment. The results of this study reflect a different kind of learning in that the researchers state that:

the pupils in the 4th grade were acting as a knowledge-producing community. ... they gave themselves a behaviour code and, once outdoors, behaved in a way that consistently reflected its values. (Aleixandre & Rodriguez, 2001, p. 19)

Learning *for* the environment places the learner as part of the environmental system and the learner becomes both part of the problem and part of the solution.

3.4.3 Learning ‘with’ the environment

Moving from learning ‘about’ the environment to ‘in’ and ‘for’ the environment has moved students from prescriptive to participatory forms of learning (Læssøe, 2010), but all of these have a focus on the link between ‘teacher’ and ‘learner’; the teacher is in some way guiding the learner on their learning pathway. The learner’s own perceptions of what is around them can become lost on their learning journey. Noel

Gough (1989) posits that learners' perceptions are important to the learning, but often ignored by the teachers. He states:

learners' own perceptions of their environments are often disregarded by teachers, who see such perceptions as distractions from the transmission of socially validated knowledge - a process within which the teacher's authority is central. Ecological theories of perception suggest that teaching which is centred on the teacher-learner relationship may inhibit learning because learners will be distracted, by teachers, from attending to what is before them in their environments. (Gough, 1989, pp. 228-229)

Learning *with* the environment requires a learning environment that allows students to both explore their own perceptions of what is going on around them, and to bring those perceptions to their own solution.

Learning about sustainability requires an integration of these stages of environmental education. Students are required to have environmental facts, be able to apply those facts in the environment, take their part in both the problem and the solution, and be allowed to attend to their own perceptions of the environment while solving these ill-structured problems. This learning *in* the environment, learning *for* the environment, and learning *with* the environment is illustrated by Tooth and Renshaw (2009) who investigate a narrative approach to learning for sustainability linked to experiences in nature. Their study followed eight primary schools as they undertook learning about sustainability. The learning took place *in* natural settings ("first-hand encounters with the natural world" p. 99), it focused on what can be done *for* the environment ("students and teachers are both audience and participants in stories about characters - real and fictional - living in harmony and in conflict with their environment" p. 99),

and the students explored their own relationships *with* the environment (“help students understand more about themselves and their own values” p.100).

3.4.4 Considering complex issues

Socio-scientific issues are inherently ill-structured and complex. In this section, three examples of complex issues are explored. These are cases that have been used to help students think about socio-scientific issues and are all ill-structured in as much as they have no well-defined canonical answers.

As the global population creeps towards the eight billion mark, agriculture has become a pressing issue. Feeding an increasing population puts strain on current agricultural practices and these issues, along with economic, social and political factors combine to create ill-structured problems, that have complex variables, with no fixed solution (Conway, 2012). Agriculture has been used as an effective platform to introduce primary students to environmental issues. Mayer-Smith, Bartosh, and Peterat (2007) worked with, and observed, primary aged school students (18 girls in the first two years, and then expanded to 84 students, aged 11 to 13 years, in the third year of the study) who, through farm visits, gained “hands-on experience cultivating and caring for the vegetables, herbs, and edible flowers” (p. 80). The students’ teachers decided when the farm visits would take place and which ‘farm’ activities would be integrated into their classroom practice. The researchers report that, over the course of the farm experience, the students’ relationship with the environment changed; the shift was from seeing the environment as external (a place or an object) to “a view characterized by the interconnectedness of humans and environment” (p. 82). This research showed that the participating students began to consider, not only

environmental facts in isolation, but also their own impact on the environment. This is illustrated by the words of one student reported in the research study:

Last time [when we talked] about environment ... I just thought we should not have any more buildings ... and I did not really have a reason. Now I have a reason and I think more about environment. And ... if we have garbage at our farm, the garbage will go inside our ... soil ... and the bad stuff in there. I think I really care about environment now. And I pick up garbage that I see, even if it's not mine [Student, Grade 4, 2006]. (Mayer-Smith et al., 2007, p. 82)

This student had been able to move from restating known environmental beliefs, “we should not have any more buildings”, without any justification, and without seeing any need for justification, to being able to justify the beliefs, “the garbage will go inside our ... soil ... and the bad stuff in there”. The student was also able to move from justification of beliefs to *action*, “I pick up garbage that I see, even if it's not mine”.

A second example of a topic used to introduce complex issues to students is that of dilemmas in human genetics. Along with scientific facts, human genetics is rife with complex and ill-structured problems. These problems do not have one single canonical solution and any potential solution, specific to an individual, will carry with it a host of personal beliefs and experiences. For example, consider finding a solution to this problem:

Rebecca and Joseph both have brothers whom are sick with Cystic Fibrosis (an autosomal recessive trait). Rebecca and Joseph got married and Rebecca is now pregnant. Should they abort the embryo? (Zohar & Nemet, 2002, p. 44)

Studying students' justifications of their solution to this problem, Zohar and Nemet (2002) stated that thinking about the inherent social issues connected the problem to students' out-of-school life experiences and this created an 'anchor' that aided learning.

The third example of a complex issue revolves around climate change. While there are scientific facts relating to climate change, an individual's own perspective has significant bearing on coming to a 'real-world' solution to a climate change problem (see Higham, 2013). This perspective not only incorporates prior experiences and personal beliefs, but also an understanding of the complex arguments that scientists (and the media) make about this topic (Bryce & Day, 2013). Sadler, Klosterman, and Topcu (2011) investigated students' socio-scientific reasoning when investigating issues relating to global climate change. In this study, the researchers focused both on scientific facts about climate change, and on different perspectives and how these perspectives alter solutions to a climate change problem. To do this, they first introduced the facts around the issue by presenting resources, including recent media reports, to the students. This was followed by an activity where the students considered five different special interest groups with distinct perspectives on the issue. The researchers were interested in the students' ability to recognise the complexity of the issue under consideration, think about the issue from different perspectives, understand that knowledge about the issue is changing, and challenge presented information i.e. an understanding that information may be 'biased'.

Each of these examples highlights a central theme in socio-scientific issues; that is, there are many possible 'right' solutions to these complex issues and any particular

‘right’ solution is determined partly by an individual’s perspective, formed from their prior knowledge, beliefs and experiences.

3.5 Empirical studies

This section provides an overview of empirical studies in the area of science education with a particular focus on studies concerned with the environment. It also extends to include other science education studies that particularly investigate prior knowledge, conceptual change and transfer. This review summarises the current research on learning in the areas of environmental education and sustainability; therefore, the scope of this review has been limited to studies that involve school students learning about the environment and about sustainable behaviour.

3.5.1 Justification for being included

The research for this review has been selected using clearly defined criteria. Only studies that contained empirical research were included; general guidance documents and reports that simply described environmental education programs were not included, however, relevant journal articles of this type were reviewed separately.

First, educational databases were searched, using relevant search terms, these included; ‘environment*’, ‘education’, ‘school’, ‘sustain*’³. Databases included: British Education Index, ERIC (via OvidSP) and Australian Education Index. Second, specific journals were searched, including: ‘Environmental Education Research’, ‘Applied Environmental Education and Communication’ and ‘The Journal of

³ The asterisk is used to include terms with multiple endings. Therefore, ‘sustain*’ included the words: sustain, sustainable, sustainability and sustainably.

Environmental Education'. Third, in 2001 the National Foundation for Educational Research (NFER) in the UK produced a thorough critical review of research on learners and learning in environmental education (Rickinson, 2001); articles identified by the NFER review are also included.

A summary list of empirical studies is provided in Table 3.1.

Table 3.1 Summary of empirical environmental education studies

| Authors | Focus | Sample | Method | Outcome |
|--|---|--|--|--|
| Aleixandre & Rodriguez (2001) | Students' pathway from <i>claims</i> to <i>action</i> | 18 boys, 7 girls, aged between 9 and 10 | Participant observation. Videotaped lessons/discussion. Conversation analysis | Learning activity created a change in behaviour |
| Avriel-Avni, Spektor-Levy, Zion, & Levi (2010) | 'Sense of place', and how this affects environmental attitudes | 78 students from 2 different locations, aged between 9 and 10 | Phenomenography. Analysis of students' drawings | Active learning creates greater awareness of the environment |
| Ballantyne, Fien, & Packer (2001) | The comparison of two school environmental education programmes | 152 students (79 primary, 73 secondary) | Questionnaire, short open-ended questions | Students reported changes beyond the classroom |
| Boyes & Stanisstreet (1997) | Investigation of the models students hold of the greenhouse effect and ozone depletion | 501 students aged between 13 and 14 years | Closed questionnaire (yes/no responses) comprising 27 questions about the ozone layer and greenhouse gases | Students confused the two phenomena and created robust models to support their conceptions |
| Ceaser (2012) | Environmental education should place a much greater emphasis on 'action' | Five groups of between 10 and 20 students aged between 16 and 21 years | Ethnography and group interviews | Students appeared to engage in behavioural change, but on-going effects were not assessed |
| Christidou, Koulaidis, & Christidis (1997) | The relationship between children's use of metaphors and their mental models of the ozone layer | 40 students (22 boys and 18 girls) aged between 11 and 12 years | Semi-structured interviews | The use of inappropriate metaphors hinders student understanding |

| Authors | Focus | Sample | Method | Outcome |
|--|--|---|--|---|
| Connell, Fien, Lee, Sykes, & Yencken (1999) | Environmental attitudes of young people | 24 group interviews with randomly selected students from 12 secondary schools | Focus group interviews | Students were pessimistic about the future and, as individuals, they could have little effect |
| Emmons (1997) | How non-formal field experiences may contribute to environmental sensitivity, attitudes and concerns | 10 students (all girls) aged between 15 and 20 years | Participant observation, interviews, and questionnaires | The field experiences produced positive outcomes and existing negative perceptions were not reinforced |
| Fisman (2005) | Students' awareness of place and how this affects environmental awareness | 82 students took part, data used from 47 participants who completed the tasks | Action research using questionnaires, drawings and interviews | Education programme brought about changes in awareness |
| Goldman, Assaraf, & Shaharabani (2013) | The effect of 'outsourcing' environmental education | 50 students aged between 13 and 14 years | Pre and post tests which included questionnaires and free drawings | Some benefits of the non-academic programme were observed but these were found not to be linked to existing school programmes |
| Gottlieb, Vigoda-Gadot, Haim, & Kissinger (2012) | The use of an 'ecological footprint' as a pedagogical tool | 333 students aged between 12 and 18 years | Questionnaires and student discussions | Greater student evaluation of their own actions and evidence of cross-curricula activity |
| Ivy, Road, Lee, & Chuan (1998) | The level of environmental knowledge, attitudes and behaviour of students in Singapore | 1256 students aged between 15 and 17 years | Questionnaire of 55 items covering environmental concerns | Students showed some factual knowledge, but were inadequately informed |

| Authors | Focus | Sample | Method | Outcome |
|--|---|---|--|---|
| Knapp & Poff (2001) | An <i>out of school</i> environmental programme and its affects on environmental ethic | 24 students aged between 9 and 10 years | Grounded theory with data collected during a series of semi-structured interviews | Some learning activities can lead to long term information retention |
| Kwan & So (2008) | Problem based learning and how this can lead to effective education for the environment | 21 students aged between 17 and 18 | Participant observation, reflective journals and group interviews | Increase in both problem solving and critical thinking skills |
| Lieflander, Frohlich, Bogner, & Schultz (2013) | The effect that students' 'connectedness' with nature may have on longer term pro-environmental behaviour | 568 students aged between 9 and 13 years | Pre and post tests while students were taking part in a four day environmental education programme | Environmental education is more than increasing environmental knowledge; benefits were observed when students felt more connected to nature |
| Mason & Santi (1998) | Students' conceptual change during discussions about the greenhouse effect and global warming | 22 students aged between 10 and 11 years | Individual interviews and teacher led discussions in both small and large groups | Socio-cognitive interactions enabled a gradual and progressive knowledge revision |
| Palmberg & Kuru (2000) | The effects of outdoor educational activities | 36 students, 24 boys and 12 girls, aged between 11 and 12 | Questionnaires, interviews, drawings, photographs and participant observations | Out of classroom experiences can assist students' environmental understanding |

| | | | | |
|---------------------|--|--|--|---|
| Powers (2004) | An environmental field trip and how the trip affects students' awareness and appreciation of natural resources | 133 students aged between 7 and 8 | Pre and post visit questionnaires with group interviews | Out of classroom learning needs to be associated with students' usual environment |
| Said et al. (2007) | Environmental education and its effects on environmental understanding, awareness and knowledge | 306 students aged between 15 and 17 | Questionnaire, comprising both multiple choice and open-ended questions | Current environmental education has increased awareness but not changed behaviour |
| Strommen (1995) | Young students' understanding about the environment and whether this deviates in any systematic ways from current scientific conceptions | 20 students aged between 5 and 6 years; 10 boys and 10 girls | Analysis of students' drawings and structured interviews | Student knowledge appears to be concrete and discrete; they had difficulty in structuring their prior knowledge about the environment |
| Volk & Cheak (2003) | The impacts of an environmental education programme | 101 students, aged between 10 and 12 | Standard tests to measure critical thinking and literacy, followed by interviews and text analysis | The programme increased students' environmental literacy |

3.5.2 Effects of environmental education programmes

There have been a number of studies that focus on the impact of environmental education programmes. Of these, many focus specifically on environmental awareness (Avriel-Avni et al., 2010; Fisman, 2005; Lieflander et al., 2013; Powers, 2004; Said et al., 2007). Others focus on several different aspects of student awareness, such as information retention (Knapp & Poff, 2001), understanding

(Palmberg & Kuru, 2000) and environmental literacy (Volk & Cheak, 2003). A further area of research is that of behavioural change (Aleixandre & Rodriguez, 2001; Ballantyne et al., 2001; Ceaser, 2012; Said et al., 2007).

Four of the studies in Table 3.1 specifically investigate pedagogies and learning methods and assess the outcomes of those methods. These pedagogies are problem based learning (Kwan & So, 2008), outsourcing (Goldman et al., 2013), environmental action (Ceaser, 2012), and using an environmental footprint (Gottlieb et al., 2012). The conclusions on these various pedagogical methods were mixed. Kwan and So (2008) interpreted their results as being successful if the desired outcome was to increase problem solving skills; their study makes little reference to whether this learning approach was successful in bringing about any lasting environmental knowledge. Goldman et al. (2013) suggest that neither school-based programmes nor 'outsourced' programmes are completely effective and that there is a need for some method of combining these two approaches. Ceaser (2012) detected strong student desire for behavioural change but noted that, as the activity took place outside of the usual school environment, sustained change may only come with changes to the formal education arena. Gottlieb et al. (2012) did report observed successes; students had a greater understanding of their own actions, and there was an ability for the environmental programme to be followed across the academic curriculum. While there are different methods of introducing 'sustainability' into school life, it appears that there is still a problem with integrating formal knowledge, everyday experiences and individual perspectives (beliefs and ethics) when thinking about socio-scientific issues.

To gain a better understanding, these studies have been divided into two broad categories: *environmental knowledge* and *environmental practices*. Rickinson (2001) defines *environmental knowledge* as “young people’s factual knowledge about environmental phenomena, their understanding and misunderstanding of such phenomena, and the sources of young people’s environmental information” (p. 219). *Environmental practices* are defined as “the outcomes of educational interventions in terms of the extent to which they bring about changes in students’ environmental knowledge, attitudes and/or behaviours” (p. 222). The environmental knowledge category refers to declarative knowledge (knowing *that*), whereas the environmental practices category refers to procedural knowledge (knowing *how*) and contextual knowledge (knowing *with*). These categories illustrate some of the difficulties students face when considering sustainability issues. In particular they shed light on difficulties that students have with misconceptions, structuring knowledge and understanding their own knowledge at a metacognitive level.

3.5.3 Learners’ environmental knowledge

The NFER Report (Rickinson, 2001) concludes that studies have shown students’ factual knowledge is low, students’ knowledge varies across topic areas and schooling appears to have a significant influence on knowledge. Of particular interest are three studies that investigate the difficulties students face and how these difficulties relate to the way in which knowledge is structured (Boyes & Stanisstreet, 1997; Christidou et al., 1997; Strommen, 1995). These three studies show that students may have misconceptions about environmental processes and an inability to apply their knowledge to those processes.

Environmental knowledge may be seen to be present and even perhaps strongly held, however, the scientific basis for that knowledge may not be correct. Boyes and Stanisstreet (1997) surveyed 501 school students, aged between 13 and 14 years. The students, from 22 classes across 8 randomly selected secondary schools, were each asked a set of 27 closed questions regarding global warming and ozone depletion. After analysing the responses, the authors concluded that students had very strongly held, but often inaccurate, models of environmental processes.

Furthermore, it is not only the processes that lead to misconceptions; the metaphors that students use can also cause difficulties. Christidou et al. (1997) considered the metaphors that students use to understand environmental processes. Their study used semi-structured interviews with 40 students (22 boys and 18 girls) aged between 11 and 12 years to ascertain which metaphors are used when considering ozone depletion. The metaphors fell into three broad categories: substances, objects, and persons. The use of these metaphors, in conjunction with the students' conception of the processes, was analysed. While appropriate metaphor use was shown to assist in the understanding of complex processes, the authors reported that the "use of inappropriate metaphors can enhance the construction of incomplete models which involve important alternative conceptions" (Christidou et al., 1997, p. 549).

The difficulties extend beyond misconceptions. Even when students have negotiated learning and understood the information, they still have difficulties applying their knowledge. Strommen's (1995) study, of 40 school students aged between 6 and 7 years, investigated students' knowledge of forest animals. While the students had good knowledge about the animals, they were unable to limit their answers to that

which they knew. For example, the students displayed rich knowledge about forest animals, but, when asked about the habitat of different animals, forest dwellers were correctly placed, however, non-forest dwellers (such as elephants and sharks) were also placed in the forest. It may be that a, perhaps incorrect, link had been formed between an animal's habitat and diet; for example, 'all carnivores live in the forest'. While the students had a significant quantity of accurate knowledge, they lacked structure to the knowledge, so that incorrect links were made which, in turn, produced nonsensical conclusions. Students may have been able to activate knowledge, but had significant difficulties in connecting the pieces of knowledge in a coherent and meaningful way.

3.5.4 Learners' environmental practices

Much of the research into environmental education focuses on environmental practices. The NFER Report (Rickinson, 2001) splits this area into two sections: school-based initiatives and out-of-school programmes. The conclusion is that there is evidence that both in-school and out-of-school initiatives can have a positive effect on environmental practices (p. 222). Two studies are of particular interest as these investigate the learning processes that led to changes in environmental practices.

Emmons (1997) considered learning processes when studying 10 female school students, aged between 15 and 20, on a 5-day field trip in Belize. The context of the learning environment invoked fear in the students, which in turn produced negative attitudes toward the environment. However, as the field trip progressed, fear and negative attitudes began to disappear. While one of the study's recommendations is that short field trips should be discouraged, to allow for fear of the unknown to be

overcome, this study also illustrates the possibility that some mental resources may become blocked by context; in this case, *fear* became a barrier to learning.

Students' metacognition was explored in a study investigating collaborative discourse reasoning with 22 school students, aged between 11 and 12 (Mason & Santi, 1998).

The students were asked to discuss two global environmental problems: the greenhouse effect and ozone depletion. Two aspects of the students' learning were investigated: their explanations of the two phenomena and their awareness of any metacognitive changes that occurred during the learning process. The findings

showed a "highly positive" correlation between students' understanding of the topic and their awareness of changes in their metacognitive representations of the topic.

How students think about the subject that they are learning, how they think about the learning process and how they think about knowledge can all have an impact on learning. Context may have an impact on any, or all, of these factors.

3.6 Theory and methods

In the previous section, a number of studies have been reviewed. These studies have the common theme of research into the teaching and learning of scientific concepts, with a particular emphasis on socio-scientific problem solving revolving around sustainability. Different theoretical perspectives and different methodological approaches have been used. The reviewed studies are now categorised in terms of methodological approach and methods used, and implications drawn for research based on a *knowledge in pieces* theoretical framework and, in particular, for this study.

The majority of the 26 studies reported used qualitative research methods to collect data; some of those that used quantitative measures also applied a mixed methods approach and collected qualitative data in addition to quantitative data (Goldman et al., 2013; Said et al., 2007; Volk & Cheak, 2003). Five of the studies had fewer than 10 participants (Azevedo et al., 2012; diSessa et al., 1991; Izsak, 2005; Kapon & diSessa, 2012; Masson & Legendre, 2008), and these five were also ones that specifically investigated student reasoning from a mental resource perspective.

This study seeks a better understanding of the processes students undertake when thinking about ill-structured socio-scientific issues. It takes a ‘knowledge in pieces’ (KIP) theoretical approach and is interested in observing how individual students approach solving complex problems. The studies reviewed in this chapter used a variety of techniques to collect data and these methods can be placed into the following five categories: 1) participant observation (e.g. Aleixandre & Rodriguez, 2001; Emmons, 1997; Kwan & So, 2008), 2) phenomenography (e.g. Avriel-Avni et al., 2010; Strommen, 1995), 3) interviews (Ceaser, 2012; Christidou et al., 1997; Connell et al., 1999; Mason & Santi, 1998), 4) questionnaires (e.g. Ballantyne et al., 2001; Boyes & Stanisstreet, 1997; Ivy et al., 1998), and 5) standardised tests (e.g. Goldman et al., 2013; Lieflander et al., 2013; Volk & Cheak, 2003). Research undertaken from a KIP theoretical perspective has used a number of methods for data collection. These methods include: epistemic (clinical) interviewing (Izsak, 2005), teaching interviews (Wagner, 2010), and participant observation (Reeve & Bell, 2009). There appears to be a significant overlap in methods used between the reported studies and studies that use a KIP theoretical perspective. This overlap includes

different types of interviews and observations. Building on this overlap, this research study also uses epistemic interviewing techniques along with participant observation.

3.7 Conclusions

This chapter has considered the teaching and learning of science and, in particular, socio-scientific issues such as sustainability. Various pedagogical approaches have been considered and each of the approaches (inquiry, productive failure through ‘inventing’, and learning through design activities) has a common thread of one form or another of an iterative process; students go about refining ideas and solutions. A number of both qualitative and quantitative research studies have been discussed with particular emphasis on those using a ‘mental resource’ perspective. Studies with both large and small numbers of participants have been considered and it has been noted that, when investigating student reasoning, from a mental resource perspective, small sample sizes have been used.

Students are encouraged to learn *about* the environment, *in* the environment, *for* the environment, and *with* the environment which presents complex issues that require students to combine both taught ‘facts’ about the environment with their own past experiences, prior knowledge and personal beliefs (which include moral and ethical dimensions). When faced with a sustainability problem, students are required to activate appropriate prior knowledge and to use that knowledge within the current context.

The various studies reviewed employed different research methods to collect data and these included participant observations, interviews (structured, semi-structured, and

epistemic), standard tests, questionnaires, and ethnography. Those studies that used smaller sample sizes, and collected rich qualitative data, used epistemic interviews, participant observations, and ethnography as the chosen method of data collection. The following chapter builds on these ideas and draws together appropriate methods for this study.

Chapter 4 Methods

This chapter outlines the study, including the methodology used to guide the study. It is divided into sections which: introduce the study, discuss the reasons behind the design of the study, provide details about the participants, detail how the data collection activities were conducted, introduce how the data were analysed, and discuss issues of both validity and reliability. Further details about specific methods are discussed in the empirical chapters (Chapters 5, 6, and 7).

4.1 Introduction

Throughout this study, a central focus has been to investigate how students activate and use knowledge. This incorporates how readily students are able to use appropriate prior knowledge (that is, to activate prior knowledge that has been useful in the past) and to frame and reframe a problem under consideration. Four aspects of context have been considered and this research attempts to investigate how the problem context, the knowledge context, and the physical context (including the students' own framing) affect problem solving when considering sustainability issues. The data collection activities were designed in a way that would allow the participating students an opportunity to demonstrate their prior knowledge and then to provide a new problem context where the students might have difficulty in activating their prior knowledge. Interviews were conducted to help understand both the facilitators and the inhibitors to the activation of appropriate knowledge.

4.2 Methodology

This study aims to gain a better, more nuanced understanding of the processes involved when students are presented with socio-scientific problems such as sustainability. The desire was to follow a number of students as they underwent a class-based unit of study about sustainability. To investigate the areas of interest (problem context, knowledge context, and physical context), various ‘problems’ were introduced for the students to consider and work towards solutions.

The methodology for this study draws inspiration from *case study* research. Yin (2009) defines case study as a methodology that can be used to answer ‘how?’ and ‘why?’ questions, in contemporary settings, where much of the environment is not controlled by the researcher. It provides opportunities for interviews with people and direct observations of both people and events. Yin further states that: “you would use the case study method because you deliberately wanted to cover contextual conditions - believing that they might be highly pertinent to your phenomenon of study” (Yin, 2009, p. 13). Orum, Feagin, and Sjoberg (1991) outline the case for case study methodology and state that case study “permits the grounding of observations and concepts about social action and social structures in natural settings studied at close hand” (p. 6). While this study is not primarily concerned with social action and social structures, it does investigate students working in natural settings (which incorporate social attributes) and is interested in fine detail that may only be observable *close at hand*. A qualitative research design was adopted for this study, employing epistemic interviewing (see Section 4.2.1) and participant observations (see Section 4.2.2) as methods of collecting data. These data collection techniques allowed detailed observations of the students as they went about their activities and provided a rich

data set for analysis. Although this study is predominately qualitative in nature, during the data analysis phases of the study, a number of the participants' responses have been quantified and statistical measures have been used to provide deeper insights into the qualitative data.

4.2.1 Epistemic Interviews

Interviews in traditional qualitative research have been regarded as opportunities for participants to 'tell their story'. Researchers are guided to allow the interviewee time and space to speak and to be careful not to influence responses. This can be seen in guides to interviewing techniques such as:

Be careful asking "why" questions. This type of question infers a cause-effect relationship that may not truly exist. These questions may also cause respondents to feel defensive, e.g., that they have to justify their response, which may inhibit their responses to this and future questions. (McNamara, 1999)

In contrast to this advice, epistemic interviewing takes a different approach. Rather than seeking to allow the participant to only reveal thoughts and ideas as they come to mind, epistemic interviewing seeks to challenge the participants' ideas, thereby encouraging them to think through their own ideas, to make sense of the current situation and explain their thought process. This, inevitably, requires the researcher to challenge the interviewee's responses, often with 'why' questions. The differences in these interviewing techniques are explained by Brinkmann (2007) as "doxastic" and "epistemic" interviews (pp. 1119 – 1126). Doxastic interviews are described as those that intend to reveal participants' experiences, whereas epistemic interviews are those that intend to reveal participants' knowledge. There is here a connection between

what an individual has experienced (doxa) and what the individual knows (episteme). While traditional qualitative interviewing techniques (Seidman, 2013; Silverman, 2013; Skinner, 2012) may be structured to allow the participant the space to reveal their experiences, epistemic interviews are designed to probe participants' knowledge, and to reveal their thinking, through asking them to justify their explanations. This may take the form of the interviewer appearing to work with the participant, helping the thought process by asking 'why' questions. Brinkmann (2007) refers to Socrates when outlining the epistemic interview methods:

Socrates is never content to hear what people believe or how they experience the world. He is always interested in examining whether people's beliefs and experiences can be justified, and his dialectical "method" (his *elenchus*) was developed to bring human beings from a state of being opinionated to a state of knowing. (p. 1135)

diSessa (2007) outlines the basis for 'clinical interviews'. In these interviews, diSessa poses problems and seeks solutions from the interviewees. The interview questions may pose problems and seek clarification of how the participant is making sense of the problem and how they are going about seeking a solution. The interview takes the form of a mutual voyage of discovery:

an interviewer and interviewee gradually negotiate an activity type that overlaps substantially with naturally occurring inquiry. In particular, the central goal of the interviewee is to make sense as best he or she can of the situations or problems proposed by the interviewer. A secondary goal for the interviewee is to help the interviewer understand the sense he or she makes. (diSessa, 2007, p. 557)

Using clinical interviewing as a basis, this study refers to epistemic interviewing as that which asks participants to relate their past experiences, and also to justify their opinions (Thomsen & Brinkmann, 2009). There is no clearly defined line between the different interviewing techniques. All interviews, and interviewers, in some way interact with an interviewee, thereby affecting the outcome of an interview (Fontana & Frey, 2005). In this study, that influence is accepted and, indeed, invited as the interviewer and interviewee embark on an inquiry experience; questions asked, answers given and then queried, and probed and justified.

With any question and answer session, it is hard to gauge whether the respondent is giving answers that reflect their knowledge. For example, consider a multiple-choice question, to which a respondent provides the answer “c)”. It could be that response “c)” was provided after careful consideration of the question and reflection on prior knowledge. Or, it could be that answer “c)” appeared to be the most reasonable of the choices. Or, it could be a complete guess. Or, it might be that the respondent thought the examiner wanted answer “c)” regardless of what the respondent really thinks. Simply collecting the response “c)” does not tell the observer much about the respondent’s knowledge. Piaget proposed five classifications of different ways individuals respond to questions: random choice, inventing a response, attempting to provide a desired response, and two which appear to come from knowledge, that which comes spontaneously and that which requires further reflection and deliberation (Piaget & Vonèche, 2007). To gain some form of understanding of knowledge held by an interviewee, it is necessary to move beyond simply recording responses; to challenge the responses and to probe for more information on how the response has been formed. It is through this challenging and probing that epistemic

interviewing attempts to distinguish between that which is said and that which is said from a position of knowledge.

4.2.2 Participant observations

The participant observations used in this study are based on ethnographic research methods. Up until the 1970s, ethnography was used to refer to social anthropology research, where a researcher would be immersed in a new, often foreign, culture for long periods of time. Bryman (2004) describes this immersion as observing situations and people, interviewing participants and collecting documents and other artefacts. On returning from a data collection activity, the researcher would write up an ethnographic record of the experience, thereby enabling others to gain a better understanding of the culture under investigation. Since the 1970s, the term ‘ethnography’ has been used in a broader range of situations where researchers are investigating (employing the same data collection techniques) cultures and contexts of particular groups (see Bryman, 2004, pp. 292-293). Delamont (2004) describes the term ‘participant observations’ as one “used to cover a mixture of observation and interviewing” (p. 206). This study incorporates both observing and interviewing year six school students as they go about solving problems revolving around sustainability.

Esterberg (2002) outlines eight stages in *participant observation*, these are: 1) immersion in the setting, 2) participating in various ways, 3) observing while participating, 4) taking notes, 5) interviewing, 6) taking more notes, 7) analysing the notes and 8) writing up the notes in a narrative (p. 60). These eight stages outline the data collection approach this study took.

4.3 Sample

In deciding on the criteria for participants in this study, consideration was given to the most likely point in the school curriculum at which the area of knowledge under investigation would be encountered. It was established, through consultation with teachers, that year six students (aged 10 to 12 years) would be ideal participants as they would be taking part in an environmental education program with a particular focus on sustainability. As the study had to fit in with existing school activities, only a limited amount of time could be dedicated to researcher led activities; this led to a concern that there may not be enough time, within the existing school science timetable, for the full data collection to take place. To help alleviate this issue, it was decided that data would be collected (observations made and interviews undertaken) at two separate schools.

The two schools chosen to participate in this study were similar in size, (school A: 1,800 enrolled students, school B: 1,200 enrolled students), they were both metropolitan independent schools and both had their year six science classes grouped according to ability. Based on teacher availability and timetable constraints, School A selected a participating class. To reduce additional variations, a class of similar ability was chosen at school B. The class from school A comprised 26 students of which 22 (10 female, 12 male) agreed to participate in the study. The class from school B also comprised 26 students of which 24 (13 female, 11 male) agreed to participate in the study. From these participating students, a number were selected by their teacher to participate in the interview phases of the study. The teacher from school A selected 10 students (7 female, 3 male) to be interviewed. The teacher provided no information regarding the method of selection (however, subsequent interviews revealed that some

extra-curricular activities, taking place during class time – such as music lessons, influenced the teacher’s decision); it is assumed that the selection process was random. The non-uniform ratio of females to males (7:3) was not of concern, as the research was not attempting to make claims based on gender differences. The teacher from school B was asked to choose 6 students to take part in the study, which resulted in 3 females and 3 males being interviewed. Again, there was no apparent method used by the teacher to decide which students were selected and therefore it is again assumed that the selection was random.

The students, while undertaking the ‘sustainability’ unit of work, worked independently. While working on their projects, at various points during the unit of study, the participating students were interviewed. These interviews, each comprising a single student and the researcher, were audio recorded and subsequently transcribed; the transcriptions of the interviews were then analysed. On two occasions, a number of the participating students were asked to work as a group. On the first occasion, the students (six in number) were brought together in a separate room from the rest of their cohort and given a number of tasks, first in dyads and then as a whole group. On the second occasion, which took place after the sustainability unit of study had completed, the students (four in number) were brought together in a separate room from their normal class cohort. On this occasion, the students were given both individual tasks and a group task to complete. These sessions were also audio recorded and transcribed for analysis.

4.4 Sample size

It is widely accepted that increasing the number of research participants can bring about higher levels of confidence in any generalisations of research findings (Berg, 2004; Patton, 1990, 2005). While generalisation in educational research can be important, it may not be an over-riding factor when embarking on a research project. In addition to generalizability, consideration must be given to the overall usefulness of the research in question. Bassey (1981) put forward the proposition that there may be a conflict between generalizability and usefulness in a teaching/learning environment. He states that “pedagogic research is a sub-set of educational research; it is research into the processes of teaching and learning, and as such necessarily focuses on individuals rather than populations” (p. 73). In attempting to discover a solution to this conflict, Bassey (1981) suggested that “the answer lies in research into single sets of events, in other words, case study research” (p. 86). This idea of small sample sizes is reflected in Bridges (2010); there are times when large sample sizes are necessary, for example

How many children begin school without being able to write their names?

What proportion of those entering Oxford and Cambridge have been educated in private schools? To what extent has the number of children being excluded from schools grown in the last 10 years? (p. 80)

But, in the complex learning environment of a typical classroom, reducing an experiment to a single variable may be difficult, and more likely impossible.

Therefore, discovering an instance of something working in one ‘case’ may be more useful and be able to help inform further pedagogical decisions. Bridges (2010) continues,

when we are designing a quantitative experiment we have to construct a story about what might (or might not) happen in a particular situation given certain limited different conditions; and when we report the research we feel greater confidence in telling a story about what did happen in those situations given certain (limited) conditions and what would be likely to happen in other similar situations. (p. 83)

Whereas large quantitative studies, such as Ivy et al. (1998) with their 1,256 participants, may provide a basis for generalizations, they may not provide useful insights into everyday classroom practice and corresponding pedagogical decisions. Smaller, in depth, and in-class studies, such as Izsak (2005) with four participants, do appear to be able to suggest pedagogical improvements, albeit with ‘situational’ parameters attached. For example, Izsak concludes,

the prevalence of elementary mathematics activities in which students attend to a single feature (e.g., manipulable cubes or drawn objects) suggests that other students with similar experiences might also face challenges when learning to attend adaptively to representational features. (p. 399)

In this ‘case’, students were seen to face challenges in certain circumstances and the inference is that other students, in the same circumstances, may face similar challenges.

This study aims to identify moments in students' progression towards solutions to ill-structured problems when the students are able to activate appropriate mental resources. From those moments, advances in pedagogy relating to socio-scientific education may become apparent. Therefore, this study seeks to investigate a small number of students in detail as they work through a unit of study. Sixteen students from two schools were initially selected to participate in this study; six of the original sixteen were followed in more detail during the unit of study and four students took part in a group session after the conclusion of their sustainability unit of study.

4.5 Pilot study

Before commencing on the data collection interviews reported in this thesis, a number of pilot interviews were conducted with a separate cohort. These were performed both as training interviews and to test different questioning techniques. The pilot interviews were conducted with four year 9 students who were studying ethics and particularly the ethics associated with scientific thinking. Data were collected from these interviews and, while these have not been analysed and play no further part in the study, the pilot study refined various techniques. The probing nature of epistemic interviews did not come naturally. Interviews tend to take the form of the interviewer asking a question designed to elicit a response and then listening to the interviewee's response before moving on. When conducting epistemic interviews, there is a desire to work with the interviewee, probing for justification of the responses. This requires a careful balance between 'prompting' and 'encouraging'. The pilot interviews helped the researcher understand this balance and provided an insight into how the interviews could be framed as a process of exploration where both the interviewee and the interviewer were on a joint voyage of discovery.

4.6 Data collection

Sixteen students were interviewed and observed for the data collection reported in this research study. This totalled 68 individual interviews (each lasting between 20 and 40 minutes), 15 hours of classroom observations and three hours of observed group activities. Not all of the observational data have been analysed in detail in this study. However, those parts that were not analysed in detail were used, in part, to guide and form other aspects of the study.

The data collection activities for this study had three distinct phases; each of the phases relating to one of the research questions. Students were presented with sustainability problems formed in different problem contexts, they were asked to solve problems using prior knowledge, and were asked to solve a sustainability problem, first as individuals and then in collaboration with their peers. Before the commencement of the data collection activities, the students were provided with formal instruction, which was followed by a series of interviews with participating students. These interviews, discussed in the following section, were to consolidate the formal instruction and to help gain a better understanding of the students' understanding of key concepts. The formal instruction was followed by the three phases of the data collection activities.

The theoretical perspective guiding this study, knowledge in pieces, suggests that as students encounter problems and seek solutions to those problems, prior knowledge resources will be contextually activated (diSessa, 1988; Izsak, 2005; Wagner, 2006). These knowledge resources activate (or do not activate) in conjunction with other mental resources, such as personal values, individual beliefs, and emotions. Within

the scope of this research study, the knowledge resources alone will be investigated; it should be noted that, while other mental resources are playing a part in the activation of any observed knowledge resources, they are not at this time analysed separately (See section 9.7.2).

This study seeks to investigate the relationship between different contextual prompts and the activation of appropriate prior knowledge. The formal instruction phase of the study was designed to ensure that students held relevant knowledge resources so that the activation of these resources could be detected in the data collection activities.

Expected knowledge resources are outlined in the following sections.

4.6.1 Formal instruction

Before the students were asked to start the problem solving activities, the whole class was given formal instruction. This instruction was followed by interviews where the students' understanding of the material was discussed.

The first stage of the formal instruction was to ensure that all students had access to the knowledge under investigation. This study is particularly interested in the ill-structured nature of sustainability problems and the way in which students access their knowledge to make sense of these complex problems. In this instance, taught scientific knowledge can be used, but this will necessarily be supplemented by knowledge formed from other out-of-school experiences. Some questions may direct students to consider a single source of knowledge. For example, asking the physics question "does motion require force?" the student may only consider taught Newtonian physics. Conversely, asking the question "which is harder, pushing a

heavy box up a hill or down a hill?” the student may only consider every day life experiences and not think about taught Newtonian physics. However, issues about sustainability may require students to consider multiple sources of knowledge such as prior ‘everyday’ knowledge formed from experiences along with formal ‘taught’ knowledge.

An underlying scientific ‘law’, relevant to sustainability was chosen: the law of ‘conservation of mass’. This law has been attributed to Antoine Lavoisier:

We may lay it down as an incontestable axiom that, in all the operations of art and nature, nothing is created; an equal quantity of matter exists before and after the experiment. (Lavoisier, 1793, p. 7)

This ‘law’ has stood the test of time and, over 200 years later, it is still used with two specific caveats. First, that special relativity and quantum mechanics are special cases where mass and energy interactions need to be considered. Second, that the law is only applicable to closed systems. This study investigates upper primary school students thinking when considering scientific issues. As these students had not been exposed to scientific instruction in the special theory of relativity or quantum mechanics, it was assumed that these exceptions would not enter into the thinking process nor would be likely to cause any confusion⁴.

⁴ At no point in any of the interviews or during any of the class observations did any student show any signs of knowledge of either the special theory of relativity or quantum mechanics.

For the purposes of this thesis, the Merriam-Webster definition of the law of conservation of mass is used:

The total mass of any isolated material system is neither increased nor diminished by reactions between the parts —called also *conservation of matter*. (“Conservation of mass,” 2013)

Instruction phase

All participating students took part in a learning session in which they were exposed to the idea of conservation of mass. The learning session took inspiration from Inquiry Based Science (National Research Council, 1996) and provided students with an opportunity to discuss observations before a more formal instruction session. The session comprised three parts: experimental observations, questions and discussions, and exposition.

- *Experimental Observations*

During the experimental observations, the students were asked to observe, and comment on, four experiments where different ‘things’ appeared to disappear.

These were:

1. A white powder stirred into a clear liquid (powdered sugar and water). The powder disappeared.
2. A second white powder stirred into a clear liquid (mixture of citric acid and sodium bicarbonate mixed into water). The liquid bubbled and the powder disappeared.

3. A candle was burned. The candle wax disappeared.
4. The students were told a story of a car on a journey and by the time the journey was over, the petrol had disappeared.

In each of these cases, something appeared to disappear.

- *Questions and Discussions*

Discussions took place, where the students considered what had happened to the various 'disappearing' things. These discussions took two forms: full class discussions - where students posed questions in the class, and small group discussions (mostly in dyads) - where students discussed their observations and reported back to the whole class. The researcher initiated the discussions, focusing on whether anything could be created from nothing and whether anything could be completely destroyed.

- *Exposition*

At the end of the discussions, the students received formal explanations of the law of conservation of mass; each of the items was discussed and the idea that the items had changed rather than disappeared was reinforced. Formal definitions of both the law of conservation of mass and sustainability (Brundtland, 1987) were provided.

The protocol for the instruction phase of the data collection activity was different at the two schools. At school A, the introduction to the law of conservation of mass took place over four separate lessons, each ‘experiment’ and ‘discussion’ taking about 15 minutes. At school B the introduction to the law, including each ‘experiment’ and ‘discussion’, was completed in one 60-minute session. This inconsistency was not by design; the research protocol was varied to fit in with existing lesson structures.

Interview phase

Following the instruction phase concerning the law of conservation of mass, the students were interviewed to provide them with an opportunity to discuss the instruction. This discussion enabled the students to articulate their understanding of the law of conservation of mass. These interviews took the form of questions and answers, where the students were reminded of the four ‘experiments’ and asked about the disappearing items. An excerpt from a typical interview (with Stephanie - a pseudonym) is provided:

Researcher: And all the things disappeared, didn't they?

Stephanie: Yes.

Researcher: Where did they all go?

Stephanie: Up into the air somewhere.

Researcher: Right. Do they still exist?

Stephanie: Yes.

Researcher: All of them?

Stephanie: Yes, but in a different form.

Researcher: In a different form?

Stephanie: *Yeah.*

Researcher: Is it possible to stop things existing? If you don't want it anymore, you just want to get rid of something – can you get rid of it?

Stephanie: *No.*

Researcher: No?

Stephanie: *I don't think so.*

The students were then asked to think of an episode when they had made something and tell the researcher what they had made. A wide variety of items were chosen, such as: models, paper airplanes, and food. In each case the students were asked to consider where the items needed to make the object had come from, and where they are now. The students were all able to articulate that the raw materials were in existence before the episode and remain in existence today, albeit perhaps in a different form. A typical response is provided from Stephanie:

Researcher: Okay. So if you've made something, imagine – can you think of something you might have made once, maybe a model out of a cardboard box, or a –

Stephanie: *Yeah, it was like a diorama of something.*

Researcher: Okay, perfect. Very good example. When you started making that, how did you make it?

Stephanie: *Well, it was a box with like – I just found a box in the cupboard somewhere and I just picked up some grass from the ground. I*

tried to burn it with a match but then it kind of didn't work. So I used a hot glue gun to put it all together and stuff.

Researcher: So all the bits in your diorama existed before you started.

Stephanie: *Yes, yeah.*

Researcher: Did you make anything that didn't exist before you started?

Stephanie: *No.*

Researcher: No. And where is your diorama now?

Stephanie: *I think – it was in my cupboard but then I think my Mum picked it up and put it somewhere, I'm not sure where.*

Researcher: And if there's something you did that's a bit old now, and you don't want it anymore, and you want to get rid of it, how can you get rid of it?

Stephanie: *Maybe put it in the bin or burn it.*

Researcher: Okay, and what will happen to it?

Stephanie: *It'll be in different form. It won't be there, but it will be in a different form.*

Researcher: So can you get rid of it?

Stephanie: *No. Well, kind of, but not really. Yes, but no.*

Researcher: Okay. So can you explain what you mean by "yes but no"?

Stephanie: *Well, it's kind of still there, but it's not really there because it's in a different form.*

These interviews took place a week after the instruction sessions. For school A, the interview took place four weeks after the first experiment observation and one week after the fourth experiment observation. In school B, as all experiment observations

took place in one 60 minute learning session, the interviews took place one week after all the experimental observations. Despite the extra time, in the first school, between the first experimental observation and these interviews, the students from both schools were able to articulate that the materials that were used were in existence before they were used and remain in existence after they had been used.

Participants were also given the opportunity to articulate their understanding of the term ‘sustainability’; the term having been introduced to the students during the ‘instruction’ phase. A typical interview interchange (with Susan – a pseudonym) is provided:

Researcher: Can you tell me what ‘sustainability’ means?

Susan: *Sustainability means like that something that is not, that won't waste the world's resources, something that won't waste the Earth's resources.*

Researcher: In what way can we not waste the world's resources?

Susan: *Well, like a lot of people have said that if you get a tree and you get a seed from that tree and then chop that tree down and plant the seed you are actually, the tree is still there, it's just a different tree like if you didn't chop down the tree, it'll still be the same that way.*

Once the students had provided their understanding of sustainability, confirmation of the definition of sustainability, along with a more formal definition of the term, was provided. The interview with Susan continued thus:

Researcher: I think that is a really good explanation of sustainability, well done. The definition is, how we define it is, when we are talking about the environment, how can we use the Earth's resources, like trees, but it doesn't have to be a tree, it could be anything that the Earth's got, how can we use that in such a way that we don't restrict future generations from also using the resources. And, what you said was really good, because you said that if we use a tree, if we plant another one, then people in the future will still have a tree that they can use.

Susan: Yes.

Relevant prior knowledge resources activated in this phase of the study were knowledge about the law of conservation of mass and knowledge about the meaning of 'sustainability'. All students were able to activate these prior knowledge resources.

4.6.2 Varying the problem context

The first data collection activity, for the participating students, was an attempt to solve two sustainability problems. The two problems were similar, in as much as they used the same underlying knowledge, however, the two problems differed in their problem context.

When considering these sustainability issues, the students were required to activate some prior knowledge resources. These knowledge resources may have been formed from previous everyday experiences or from more formal taught classroom experiences. In this case, the knowledge under investigation was the law of conservation of mass. Prior to this episode, all participating students had shown the ability to activate knowledge resources that included knowledge of the law of conservation of mass; that is, the knowledge that the total mass of a closed system does not change.

The problem context was varied. The first problem asked the students to consider the increasing population on Earth and whether the increasing population was increasing the overall mass of the planet. The second problem asked the students to consider all the ‘stuff’ that people make and use and, as the ‘stuff’ increases, whether there is an effect on the overall mass of the planet. Both problem contexts involved an element of the closed system increasing (first people, then stuff); this increase does not change the overall mass of the closed system. The students had previously exhibited the ability to activate the appropriate knowledge to be able to arrive at satisfactory solutions to these problems. This activity was designed to investigate whether the students were able to appropriately activate their prior knowledge or whether, in one or other of the problem contexts, the students would activate other, perhaps inappropriate, prior knowledge.

The activity took the form of a series of interviews, which were based on ideas of sustainability and the law of conservation of mass. Due to school timing constraints,

the school A interviews took place over a period of one week (see Table 4.1) and school B interviews took place over a four-week period (see Table 4.2).

Table 4.1 Data collection 1 – Interviews in school A

| Interview | Dates | Purpose |
|-----------------------|---------------------|---|
| A1 10 students | 27/03/12 - 02/04/12 | Post-instruction discussions; students asked to explain their understanding of ‘conservation of mass’. Questions about what sustainability is and why people might want to act sustainably. Questions that use the concept of ‘conservation of mass’ across contexts. |

Table 4.2 Data collection 1 – Interviews in school B

| Interview | Dates | Purpose |
|------------------|-------------------|--|
| B1 6 students | 22/5/12 | Post-instruction discussions; students asked to explain their understanding of ‘conservation of mass’. |
| B2 6 students | 24/5/12 – 31/5/12 | Questions about what sustainability is and why people might want to act sustainably. |
| B5 6 students | 14/6/12 | Questions that use the concept of ‘conservation of mass’ across contexts. |

Expected prior knowledge resources activated in this phase of the study were knowledge about the law of conservation of mass. While this knowledge would be appropriate for both problem contexts, the study investigates other, perhaps inappropriate, knowledge resources that were also activated.

4.6.3 Varying the knowledge context

The second data collection activity asked the participating students to consider the ‘sustainability’ of a number of everyday objects. This activity took place after both the ‘instruction’ and the ‘discussion of instruction’ described in the previous section. All participating students had received instruction in both conservation of mass and sustainability before this data collection activity took place. All participating students had previously articulated the knowledge that sustainability related to the ability of future generations to have access to the Earth’s resources.

When considering the sustainability of an object, students would need to consider a range of factors. Some of these factors may be based on science, some based on personal experiences and personal values. While the exact nature of the prior knowledge that would be useful for any particular student cannot be determined, any judgement on the sustainability of an object should take into account many factors. In these interview activities, different contextual prompts were used to investigate whether different prior knowledge would be activated. When asked to define ‘sustainability’ the student had previously responded along the lines of “something that won’t waste the world’s resources”. The students, in a first interview, were asked about the “sustainability” of a number of everyday objects and then, in a second interview, about the effect the objects had on the Earth’s resources.

This activity was designed to investigate whether an individual student’s coordination class, the information that students read from a problem (readout strategy) and the prior knowledge activated (causal net), is affected by the change in contextual prompts (see diSessa & Sherin, 1998). That is, to investigate whether the use of the term “sustainability”, rather than referring to an effect on the earth’s resources, would change the student’s readout strategy and causal net.

The students were interviewed on two separate occasions; separated by at least two weeks (see Table 4.3). The interviews all followed a similar pattern. The students were shown images of familiar, everyday objects and asked to comment on, in the first interview (B4), the ‘sustainability’ of each of the objects and to comment on, in the second interview (B7), the impact that the object has on the Earth’s resources.

Table 4.3 Interview schedule for data collection 2

| Interview | Dates | Purpose |
|------------------|-----------------|--|
| B4 6 students | 4/7/12 – 6/7/12 | Students were shown a series of images and asked to comment on the ‘sustainability’ of each of the objects. |
| B7 6 students | 21/6/12 | Students were shown the same series of images (as in B4) and asked to comment on the object’s impact on the earth’s resources. |

4.6.4 The framing and reframing of a sustainability problem

The third data collection activity again asked the participating students to consider the ‘sustainability’ of the same everyday objects; however, this activity differed from the previous data collection activity. In the second data collection activity, the students were shown one object at a time and asked to provide comments about the object. In this third activity, the students were given all the objects at the same time and asked to rank them according to a number of criteria. They were asked to do this first as individuals (all students working alone) and then asked to repeat the activity as a group (see Table 4.4).

The physical context of this activity was varied in two distinct ways. First, the task is similar to the previous activity in as much as the students were asked to make judgments on the sustainability of the thirteen objects under consideration; however, in this case, rather than seeing digital photographs of the images one at a time, the students were given physical copies of all thirteen photographs at one time. Second,

the task was run as an individual activity and then again as a group activity, thereby changing the physical context of the task.

Prior knowledge resources, activated during the activity, were investigated to gain an understanding of the effect of varying the physical context. Student responses were compared across activities (to detect changes due to the physical nature of the activity) and between the individual and the group activity (to detect changes due to the collaborative nature of the activity). Responses were also compared across students to gain an insight into similarities in students' coordination classes.

Table 4.4 Observation schedule for data collection 3

| Interview | Dates | Purpose |
|------------------|---------|--|
| B9 4 students | 27/5/13 | Students were given a series of images and asked to rank the objects according to various criteria. First, as individuals and then as a group. |

4.7 Data analysis

Once the interviews had been conducted, all interviews were transcribed, which enabled close scrutiny of the conversations. The interviews were split into 'interactions', that is, split according to the theme of the interaction (Chi, 1997).

These initial 'units' provided a starting point for the data analysis of each of the data collection activities. Further details of each of the specific data analyses can be found in the three empirical chapters (Chapters 5, 6, and 7).

4.7.1 Varying the problem context

These interviews, which were performed to gain an understanding of how the students went about solving sustainability problems set in two different problem contexts (see Chapter 5), were segmented at two levels of interactions. First, the interviews were segmented at an ‘interchange’ level (that is, when the researcher and student were focused on one question/answer). Second, the interviews were re-segmented at a finer-grained ‘resource’ level (that is, when the students were providing some form of explanation). The focus of this analysis was to discover under which circumstances students were able to activate their appropriate prior knowledge of the law of conservation of mass. The interactions were, therefore, coded according to both the problem and the students’ views on the applicability of the law of conservation of mass.

4.7.2 Varying the knowledge context

These interviews were designed to elicit spontaneous ideas from the students about both the sustainability of objects and the effect the objects have on the Earth’s resources. Unlike the interviews concerning the change in problem context, there were no preconceived notions about which factors the students would take into account when thinking about these issues. Therefore, the coding scheme emerged from the data. The interview interactions were segmented according to the object under discussion and an inductive thematic analysis was employed to establish relevant codes (Braun & Clarke, 2006).

4.7.3 The framing and reframing of a sustainability problem

The chapter investigating the framing and reframing of a sustainability problem, and how students make sense of the set sustainability problems, follows a different theme. The methods used for this chapter are based on participant observation. Therefore, the analysis of the data takes place in stage seven of eight stages proposed by Esterberg (2002); that is, having taken notes of the episode under investigation, to analyse those notes. The data are presented (in Chapter 7) as a narrative of an episode when the participating students undertook a series of problem solving activities. The analysis covers the manner in which the students arrived at satisfactory solutions to the set problems and also involves a statistical analysis of their solutions. These are presented in Chapter 7.

4.8 Validity and reliability

To ensure an adequate level of both reliability and validity, a number of design elements were introduced to both the data collection activities and to the data analysis activities. These elements draw from a positive approach to research and follow reliability and validity tests in case-study research (Riege, 2003).

4.8.1 Internal validity

This thesis reports on three separate empirical episodes where data has been collected. In each case, care was taken to ensure that participants were given sufficient opportunities to express their opinions and to think through their opinions. A potential threat to internal validity is that participants may have felt that single or fast responses would be adequate. Care was taken in all interactions with participants to provide

time, not only for responses but also for thinking and talking through ideas. Using epistemic interviewing techniques enabled both the participants to provide considered responses and the interviewer to ensure that participants had provided sufficient information for reliable data analysis.

Internal validity was also established by following a number of students through all of the data collection episodes. These episodes took place over a 14-month period and by maintaining a core of participants the researcher was able to verify that the findings were internally coherent.

4.8.2 External validity

The external validity or transferability is established by comparing participants both from within one school and across two schools. The findings from this study are compared with existing theory and existing pedagogies to establish congruence.

While many of the questions that were presented to the participants were predetermined, there was also sufficient leeway to allow the researcher to investigate issues as they were raised. This leeway was an essential factor within the epistemic interviewing protocol; therefore, within the interview settings, researcher self-monitoring was employed. To ensure accuracy of data analysis, rigid and documented procedures for the inductive thematic generation of codes, and for the coding of the data, were created.

4.8.3 Reliability

Initially a pilot study was undertaken to establish a protocol for the epistemic interviews. This enabled the researcher to be consistent when interviewing the participants. All interactions with the participants were recorded and transcribed verbatim. During the data analysis phases, multiple researchers were employed to establish the themes and codes (all researchers were late-stage PhD candidates who had previous experience in coding qualitative data). Again, multiple researchers were used to assign data elements to the established codes. Using multiple researchers within the coding processes provided support for the reliability of the findings and Cohen's kappa was used as a measure of inter-coder reliability (see Sections 5.4.2 and 6.4.3).

4.9 Summary

This study employed epistemic interviewing techniques and participant observations as methods to gain a better understanding of how and when upper primary school students were able to activate prior knowledge across contexts. Two schools were chosen, with one high achieving year six class participating from each school. Formal instruction was given in both the meaning of 'sustainability' and the 'law of conservation of mass'. The participants were then interviewed on a number of occasions, where the interviews enabled the students to express their conceptual understanding about sustainability across multiple contexts. The interviews challenged students to consider sustainability by changing both the 'problem context' and the 'knowledge context'. Through both individual activities and group activities, students were challenged to frame and reframe problems to enable them to reach a

solution. These interviews sought to provide an insight into the students' understanding of both sustainability and the law of conservation of mass and how that understanding varied as the context changed.

Chapter 5 Varying the problem context

This chapter reports on 28 interviews that took place with sixteen, year-six school students (aged 10 – 11) after formal instruction about both the law of conservation of mass and the meaning of ‘sustainability’. The definitions used throughout the interviews were based on the following:

Law of conservation of mass

The total mass of any isolated material system is neither increased nor diminished by reactions between the parts —called also conservation of matter. (“Conservation of mass,” 2013)

Sustainability

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland, 1987, p. 37)

For these interviews, the isolated material system was described as the planet Earth, along with everything that is in it, on it and in the atmosphere around it. Students were asked to consider the system to include the planet itself with the trees and other plants, the animals, the people and the air. Sustainability was defined as using the Earth’s resources in such a way that we can meet our needs without restricting future generations’ ability to meet their needs.

5.1 Introduction

This analysis investigates students' thinking when faced with problems related to the socio-scientific issue of sustainability and considers circumstances that enable students to activate their knowledge about the conservation of mass. Sixteen students were interviewed about the mass of the planet Earth. The interviews were recorded and subsequently transcribed. The transcripts were then analysed by coding the students' responses. The responses were studied for signs of the activation of knowledge about the law of conservation of mass; followed by a more fine-grained analysis that investigated the activation of mental resources along with observations of what may have facilitated those activations.

The purpose of this activity was to present the participating students with two similar issues, both of which may activate prior knowledge of the law of conservation of mass. The theoretical perspective, knowledge in pieces, suggests that students may appropriately or inappropriately activate prior knowledge and that those activations are highly contextual. That is, the change in the 'problem context' may cause the student to activate different mental resources. In both problem contexts, students' prior knowledge of the law of conservation of mass is entirely appropriate, however, other prior knowledge may also be activated while the students are considering the problems.

5.2 The interviews

Before commencing these data collection interviews, the students had undergone formal instruction concerning the law of conservation of mass and sustainability (see Section 4.6.1). At the end of the formal instructions, all participating students were interviewed. The students presented an understanding of the law of conservation of mass and were able to articulate an understanding of the term ‘sustainability’ that involved the idea of not restricting future generations’ ability to use the Earth’s resources.

These data collection interview questions were structured in such a way that the use of the law of conservation of mass would be entirely appropriate; however, some of the questions intentionally raised issues which had the possibility of activating different, inappropriate (in this context) knowledge that may, perhaps, cause the participants’ knowledge of the law of conservation of mass to remain dormant.

The individual interviews were not scripted, but followed a consistent theme. They all started with an introduction, during which the student was asked to report on one aspect of their class project. This introduction was intended as a ‘warming-up’ exercise, when the student could talk confidently about their on-going work. As the class project revolved around ‘sustainability’, this phase of the interview flowed into a discussion about sustainability and then onto the population of the Earth.

A ‘live’ population clock was used to illustrate how the population of the planet is changing (see Figure 5.1). This clock showed an estimation of the current world population, including the number of births, the number of deaths, and a net population

increase. It also illustrated the net increase for the particular day and also the increase since the start of the year.



Figure 5.1 Population clock⁵

The ‘Current World Population’ number was seen to be increasing and the students were asked to observe the rate of population increase. It was noted that the number was in excess of 7 billion. The students were asked to consider what the population of the planet was 50 years ago. The researcher was aged 49 at the time of the interview, so the question was framed “what do you think the size of the population of the Earth was when I was born”. After a little consideration the participant was told that the population of the Earth, 50 years ago, was a little over 3 billion people (actual number was 3.14 billion). The students then considered that the population had more than doubled in the past 50 years. A typical interaction, taken from an interview with ‘Lucy’ (a pseudonym), went as follows:

⁵ Retrieved from <http://www.worldometers.info/world-population> on 24th March 2013 at 22:03 UTC

Researcher: When I was born there were just over 3 billion people on the planet – 3 billion. On my iPad I've got a population clock so we can see how many there are today. So this is the current population of the world – 7, 047,039,093 – 94 – 97 – 99 –

Lucy: *Wow.*

Researcher: A hundred – 103 – 104 – 105 – so you can see the population is increasing and it's increasing very quickly. So when I was born there were just over 3 billion, now over 7 billion, so it's more than doubled just in my lifetime so far.

Lucy: *Wow.*

Researcher: And this is what's happening today. So just today, nearly 184,000 babies have been born, just today.

Lucy: *Wow.*

Researcher: They're all like twins, they've all got the same birthday. But 78,000 people have died today, and the difference between the two is 105,000. So just today, there are 105,000 more people alive than there were yesterday.

Lucy: *Wow.*

Researcher: Which is pretty amazing.

Lucy: *Yeah.*

Researcher: And this is this year – 60 million people have been born this year so far, 25 and a half million died, which gives us a net increase on the planet of 34 and a half million people just this year.

Lucy: *Yeah.*

Researcher: That's quite a big number.

Lucy: *Yeah, it's a big number, but with the deaths and births today – it's a big number, but then when you look at the world population it seems so small.*

Researcher: Well, let's think how big that number is. Thirty four million – the population of Sydney is about 4 million.

Lucy: *Wow.*

Researcher: So that's a lot of Sydneys just this year we've added.

Lucy: *But like how is there going to be enough space on the earth?*

Researcher: That is a very good question.

Once it was felt that the student had understood the rate of population increase, and that the population of the planet had more than doubled over the past 50 years, the main interview question was posed. The question was asked in a similar way to all participants, for example:

Researcher: My question is: Has the mass of the planet increased since I was born?

The actual question took several forms, depending on the student's prior knowledge regarding mass and weight. For example, the question may have been formed thus:

“Does the planet weigh more today than it did fifty years ago?”

In all interviews, the word ‘weight’ was used unless the student expressed knowledge of the differences between weight and mass in which case the differences were

discussed and the word 'mass' was then used. For example, one student (Jim) had a very clear understanding of the difference between mass and weight:

Researcher: So my question is: Does the earth weigh more now than it did when I was born?

Jim: *No.*

Researcher: Why not?

Jim: *Because it's in a – the earth is in space and in space is – like a – it's zero gravity, we just float there out there – if you – it won't really weigh more.*

Researcher: Okay. What about the mass of the earth, then? Because that's the difference between weight and mass. So if we're being very scientific about it, we'll talk about mass. Has the earth got more mass now?

Jim: *Yes.*

Once the term 'mass' had been introduced, it was then used in preference to the term 'weight' for the rest of the interview. To further avoid confusion, the term 'planet' and 'Earth' was also discussed during the interviews. This was to remove possibilities of the term Earth being limited to the geological structure of the planet. To avoid this, students were asked to consider the term 'planet' or 'the Earth' to describe not only the planet itself, but to include everything that is on and in the planet, including the atmosphere. This was typically described as:

Researcher: So let's say the Earth is – we include that, the atmosphere –

Lucy: Yeah.

Researcher: All the people, the plants, the buildings, the roads, the aeroplanes, the cars, all the earth, everything under the earth – we include all of that.

The interviews started with a focus on the population of the Earth and then led on to consider other factors that may have an influence on the mass of the planet. This was first introduced by asking if there were other things that might impact on the mass of the planet, for example:

Researcher: So if you think of the planet, which would include the atmosphere around it, everything inside there and all the people on it and everything else that's on it, has the mass of it increased since I was born?

Peter: Yes

Researcher: Can you explain why?

Peter: Because all those extra people are more people, and then there's more space occupied and more weight, or mass.

Researcher: Is it just the people?

Peter: No, there's the animals and there's the plants and there's the water, the air –

The interview progressed and, depending on the participant's responses, included follow-up questioning, such as "what about the things that people make?" and "what about all the stuff that people use and make?"

Once the participants had had an opportunity to present their views regarding the mass of the planet, they were reminded of the initial learning session and the four items that 'disappeared'. They were asked, again, to explain what had happened to the items that had disappeared.

Researcher: Okay. Thinking back, do you remember the four experiments we did the last couple of weeks with the powders and the candle?

Jim: *Yeah, yep.*

Researcher: Can you tell me about what happened to each of the things?

After reflecting on the experiments, the students were asked again about their views about the mass of the Earth. Therefore, these interviews had four distinct phases: 1) introduction, 2) ideas (about the mass of the Earth), 3) reflection (on the learning experience about the law of conservation of mass), and 4) further ideas (about the mass of the Earth). For example: 1) "How is your class project coming along?", 2) "Has the mass of the planet increased over the past 50 years?", 3) "Remind me about the disappearing things from the experiments we did and what happened to them.", and 4) "Does thinking about the experiments help thinking about the mass of the planet?"

Sixteen students were interviewed. The interviews were recorded and transcribed verbatim. The transcripts were read and re-read, while listening to the audio recordings to ensure correct transcription of the words and meanings.

5.3 Units of analysis

Each of the sixteen interviews was split up into separate interactions. Chi's (1997) verbal analysis protocol was employed to segment the data. For this analysis, two different levels of granularity were required. The main coding scheme used an "interchange" as the defining cut; in the subsequent 'resource' analysis an "idea" was used to delimit the verbal data (Chi, 1997, p. 284). The first segmentation (interchange) was intended to provide information about 'what' the students thought; the second segmentation (idea) intended to seek out 'why' the students thought what they did. To illustrate these two segmenting techniques, an example is given from an episode within an interview with Susan:

Researcher: So what I'm interested in is -- do you think the mass of the planet has increased since I was born?

Susan: *Yes.*

Researcher: Why do you think that?

Susan: *Because there's more people, and people weigh things.*

Researcher: Okay. What about things that people make or use or have?

Susan: *You'd make a little difference.*

Researcher: So for example, you know, this year alone, 34 million extra people, they're going to need houses to live in, hospitals to go

to, shopping centres to go shopping and more cities, more cars, more toys, more computers.

Susan: *Yeah – yes.*

Researcher: Is that making a difference to the mass of the planet?

Susan: *I think it is, yes.*

Researcher: Why does that make a difference?

Susan: *Because everything sort of weighs something when it's on earth, whether it's an ant or an elephant – but yeah, I think it would make a difference because even the animals, because there'd be more animals, and the more people, and people need more stuff. So yeah, I think it would make a difference.*

In the first 'interchange' segmentation, this episode was split into three interchange segments. These segments are described as either 'question and answer' or 'question and answer followed by an explanation'. Typically, the interviewer would ask a question which was answered by the participant. Often the response would lead to a follow-up question, which requested an explanation. These two types of interchanges were used to define the size of each interchange. For example:

Segment 1. Question and answer followed by an explanation

Researcher: So what I'm interested in is -- do you think the mass of the planet has increased since I was born?

Susan: *Yes.*

Researcher: Why do you think that?

Susan: *Because there's more people, and people weigh things.*

Segment 2. Question and answer

Researcher: Okay. What about things that people make or use or have?

Susan: *You'd make a little difference.*

Segment 3. Question and answer followed by an explanation

Researcher: So for example, you know, this year alone, 34 million extra people, they're going to need houses to live in, hospitals to go to, shopping centres to go shopping and more cities, more cars, more toys, more computers.

Susan: *Yeah – yes.*

Researcher: Is that making a difference to the mass of the planet?

Susan: *I think it is, yes.*

Researcher: Why does that make a difference?

Susan: *Because everything sort of weighs something when it's on earth, whether it's an ant or an elephant – but yeah, I think it would make a difference because even the animals, because there'd be more animals, and the more people, and people need more stuff. So yeah, I think it would make a difference.*

In the second 'resource' segmentation, the analysis particularly looks for explanations. The segments, therefore, appeared either within the participants'

answers or within their following explanations. This example episode, of the interview with Susan, was segmented into four resource segments. These segments do not encompass the entire dialogue, but are excerpts from the interchanges when Susan, during her explanations, explained a single idea. The four segments are as follows:

- Segment 1. “more people, and people weigh things.”
- Segment 2. “everything sort of weighs something when it's on earth, whether it's an ant or an elephant”
- Segment 3. “it would make a difference because even the animals, because there'd be more animals, and the more people”
- Segment 4. “people need more stuff”

These two segmentation techniques were used for the analysis of this interview data. The first ‘interchange’ segmentation, was used in the main coding of the data to investigate when students were able to activate their knowledge of the law of conservation of mass. The second ‘resource’ segmentation was used to provide a more fine-grained insight into the form of the activated knowledge and investigated under what circumstances knowledge of the law of conservation of mass was activated.

5.4 Coding scheme for ‘interactions’

The coding scheme, for the interactions, found in the interview data was developed after reading all the transcripts from the sixteen interviews. As each transcript was read, notes were taken of emerging themes (Hsieh & Shannon, 2005; Robson, 2011).

Participants had varying views about the mass of the Earth and these views were collated and used as initial codes.

5.4.1 Developing a coding scheme

Different students, at different times, expressed views that the mass of the Earth was increasing, decreasing or staying the same. These views were coded:

- U (Up) The mass of the Earth is increasing
- D (Down) The mass of the Earth is decreasing
- N (No change) The mass of the Earth is not changing

As well as their views on the way the mass was (or was not) changing, the students also had views on the causes of those changes. The causes for the changes fell into three broad categories:

- P (People) The increasing population has an (or has no) effect on the mass.
- S (Stuff) The things (stuff) that people make have (or do not have) an effect on the mass. Note, this included people using up the Earth's resources.
- O (Other) Other factors have (or do not have) an effect on the mass.

These three codes in each of the two dimensions were combined to give nine separate possible codes; these nine codes are:

UP, US, UO, DP, DS, DO, NP, NS, and NO

The first letter of these codes indicates the movement in mass (Up, Down, or No change) and the second letter indicates the cause (People, Stuff, or Other).

Once these codes had been identified, formal definitions were created with examples of how the codes would be used (see Table 5.1).

Table 5.1 Definition of codes

| Code | Description | Example interaction |
|---------------------|--|--|
| UP (Up People) | The increasing population on the planet has, over time, increased the mass of the planet. (Note: this code is used when the population is being considered, not the action of the people such ‘making more stuff’.) | “I’m not sure, actually. I think it might weigh around about the same because people die and give birth, but I think it might weigh slightly more because as the figures show, there are more people being born than dying.” |
| DP (Down People) | The increasing population on the planet has, over time, decreased the mass of the planet. (Note: this code is used when the population is being considered, not the action of the people such ‘making more stuff’.) | This code was not used in the analysis as no students expressed this view. |

| Code | Description | Example interaction |
|-----------------------------|--|--|
| NP (No change People) | The increasing population on the planet has, over time, made no difference to the mass of the planet. (note: this code is used when the mass of the people is considered, not the action of the people such as using up resources) | “Because when I'm born, like I may weigh a different amount, but then as I grow older I use resources and those resources are already on the earth, so as my weight increases, I use other things.” |
| US (Up Stuff) | Stuff on the planet, that people have made, (such as computers, buildings, cars) has, over time, increased the mass of the planet. Note, in the second example, while there is reference to “more people”, the participant is considering the extra “new stuff” that is being made; therefore, this is coded US rather than UP. | “There are more houses, more offices, more shops” Question: “Is that increasing the mass of the planet?” Response: “Yes.” and “Well, people are building machines, there's more people, you know, building new stuff.” |
| DS (Down Stuff) | Stuff on the planet, that people have made, (such as computers, buildings, cars) has, over time, decreased the mass of the planet. | Question: “And what about all the things people need to live?” Response: “ They're getting taken away because people are using the resources up and things like that.” |
| NS (No change Stuff) | Stuff on the planet, that people have made, (such as computers, buildings, cars) has, over time, made no difference to the mass of the planet. | “Well, I'm not actually sure because you're using up resources which makes the world weigh less but then you're putting them back into structure which makes them weigh just about the same as before.” |
| UO (Up Other) | Other factors have, over time, increased the mass of the planet. | Question: “Is it just the people that have increased the mass of the planet?” Response: “No, there's the animals and there's the plants and there's the water, the air ...” |
| DO (Down Other) | Other factors have, over time, decreased the mass of the planet. | This code was not used in the analysis as no students expressed this view. |
| NO No change Other) | Other factors have, over time, made no difference to the mass of the planet. | “Well, like the trees – people chop down – oh wait, but then they're still here...” |

5.4.2 Applying the coding scheme

Using the ‘interchange’ segmentation (described in Section 5.3), the 16 participant interviews were segmented into 95 separate interactions. As the delimiter for splitting segments was based on ‘question and answer’ and on ‘question and answer with explanation’ criteria, some interactions contained more than one ‘idea’. When this occurred, it was sometimes necessary to apply more than one code to a single interaction. The purpose of this data coding was to investigate possible differences between students’ thinking before and after reflection on their prior knowledge. It was, therefore, important to consider possible coding bias that might arise from knowledge of when, in the interview process, each interaction occurred. The interactions to be coded were listed in such a way that individual coders were not easily able to separate different participants or to separate interactions that happened before or after the period of reflection. This was accomplished by de-contextualising the interactions and randomizing the order in which they were presented to additional coders. The inter-coder reliability was especially important as an indicator that the first researcher, who was immersed in the data (and therefore, was aware of the order of the interactions), was not biased.

In total, there were 16 participant interviews; each interview was split into two phases of interest in the analysis, one phase before reflection and a second phase after reflection. This produced 32 separate instances (16 times 2) where the students’ thoughts were of interest. Two researchers initially coded all 95 separate interactions. Although there were only nine separate codes, as each interaction had the possibility of attracting multiple codes, the number of combinations of the nine codes was

significantly higher. Once the 95 interactions had been coded, it was found that, across both coders, 19 different combinations of the nine codes had been used.

The inter-coder reliability was calculated using Cohen's kappa as a statistical measure⁶. The first coding of the data, prior to any discussion, produced an 80% agreement of codes and an inter-coder reliability rating (κ) of 0.77.

Once the data had been coded and the differences between the coders' results had been investigated, it became clear that there were significant overlaps in the codes. It appeared that there were only minor differences between how the coders interpreted 'Stuff' and 'Other'. As this section of the data analysis was particularly interested in how students thought about the influence of 'People' on the mass of the Earth, it was decided to combine the 'Stuff' codes with the 'Other' codes. This reduced the number of codes from nine to six, the number of combined codes from nineteen to twelve, and produced an 88% agreement of codes between the coders. Cohan's Kappa was recalculated, again prior to any discussion, and produced an inter-coder reliability rating (κ) of 0.86.

The coders then met to discuss the discrepancies. After discussion and the removal of coding errors, the inter-coder reliability rating (κ) increased to 0.96. The remaining

| ⁶ Kappa Statistic | Strength of Agreement |
|------------------------------|-----------------------|
| < 0.00 | Poor |
| 0.00-0.20 | Slight |
| 0.21-0.40 | Fair |
| 0.41-0.60 | Moderate |
| 0.61-0.80 | Substantial |
| 0.81-1.00 | Almost Perfect |

(Landis & Koch, 1977, p. 165)

discrepancies comprised eight interactions. Of these eight discrepancies, five were caused by a misunderstanding of the definition of one of the codes and three were caused by a lack of context within the interactions. An example of this is the following interaction:

Stephanie: Because like – just say they cut down a tree. It would still be there, just chopped down, like – it's still the same weight, it's just chopped down, and then there are people just keep coming and more people come, then they die, so – yeah.

In this case Coder 1 gave the interaction the codes NS and UP, and Coder 2 gave the interaction the codes NS and NP. The discrepancy was that Coder 1 considered the student to be thinking that the population was increasing the mass of the Earth, whereas Coder 2 considered that the student was thinking that the population was making no change to the mass of the Earth. To resolve this issue, the context of the response has to be taken into consideration. The ‘question’ that Stephanie was answering was “Has the mass of the planet increased since I was born?”. In her response, she first considers the trees and then the people; she decided that the trees do not make a difference, but when she considers the people she finally responds with “so – yeah”. This is her final answer to the initial question, giving an indication that she does think that the mass of the Earth has increased over the past 50 years due to the fact that people “just keep coming”.

With a Cohen's kappa of 0.96, along with the rewording of one of the definitions and an understanding of the contextual importance of the remaining three interactions, there is a high level of confidence that the coding is both accurate and non-biased.

To make sense of the generated codes, the initial task was to list out all codes for the 16 students for the 32 instances (both before and after reflection) of the interview. This generated a list of codes for each student and for each instance, shown in Table 5.2. Out of the 32 instances shown, 20 were immediately detectable as consistent; that is, the student expressed only one set of views for either 'People' or combined 'Stuff and Other' in each instance. This left 12 instances where there were inconsistencies in the students' responses. The inconsistencies have been highlighted in Table 5.2. As an example, consider the responses from the participant named 'Anna'. Before reflection, her responses indicated that she held the belief that the increase in the population was causing an increase in the mass of the Earth, but was inconsistent in her thoughts about other factors; at one point saying that these factors were decreasing the mass and then saying that they were increasing the mass. Anna's inconsistency continued after reflection, as can be seen in Table 5.2.

Table 5.2 Codes ascribed to participants before and after reflection

| Student | Before reflection | After reflection |
|----------------|--------------------------|-------------------------|
| Jim | UP, US | NS |
| Mary | DS, NP | NS, UP |
| Michelle | UP, US | DS, NS, UP |
| Robert | UP, US | DS, NS, UP, US |
| Lance | UP, US, NS, NS | DS, UP |
| Jane | UP, US | NS, UP |
| Rachael | UP, US | NS, UP |
| Molly | UP, US | DS, NS |
| Anna | UP, DS, US | DS, NS, UP |
| Emma | UP, US | US, DS, NS |
| John | UP, US | NS, UP |
| Stephanie | UP, NS | NS, US, UP |
| Peter | UP, US | NS, UP |
| Susan | UP, US | NS, UP, NP |
| Paul | UP, NS, US | NS, NP |
| Lucy | UP, DS, US | NS, NP |

To make sense of the remaining 12 instances, where students had expressed apparently contradictory views about the mass of the Earth, it was necessary to revert back to the transcripts. By rereading the students' interactions, in context, it was possible, in some of the cases, to establish the students' line of thinking. As the interviews had been designed to probe the students' thoughts and to ask them to justify their statements, during the interactions, the students verbalised their thought process, which may have included contradictory thoughts as the student made sense of the situation. When this happened, and the students spoke their thought process aloud, multiple codes were generated. To illustrate this, an episode from an interview with Susan is given. Susan's interactions, after reflection, had been given the codes NS, UP, NP. This implies a contradiction in Susan's beliefs about the population, showing her holding both 'UP' (mass increases) and 'NP' (mass stays the same)

views at the same time about the same factor. During the interview, after reflection, Susan spoke her thoughts:

Researcher: Yes, that's very good, thank you for that. Now, what about the extra people? Because remember there were 3 billion, there's now over 7 billion people.

Susan: *I think – well – people aren't made of the earth's resources, they were born. So I think they would make a difference. That's just me guessing there.*

followed by:

Researcher: So does us growing and getting bigger change the mass of the planet?

Susan: *No. No.*

Researcher: No?

Susan: *No.*

Researcher: So my original question was do you think the mass of the planet has increased since I was born?

Susan: *No.*

Researcher: And now you're saying no – do you think it's the same?

Susan: *Well, I actually haven't thought about it, but when you talk to me about it and like give me some stuff to think about, then yeah, my answer changes.*

Researcher: Okay, that's fine. So can you explain to me now why you think the answer is no?

Susan: *Because everything is made of the earth's resources and even as we eat and stuff, like that won't change, because we're getting heavier but the earth is getting – but then that's getting lighter, so we sort of replace it with something.*

Here, when the segments were coded, Susan's response "people aren't made of the earth's resources, they were born. So I think they would make a difference" was coded as UP (the increase in population has caused an increase in the mass of the Earth). However, when Susan's statement is read in conjunction with what comes later, her thinking has developed. Susan concludes "Because everything is made of the earth's resources and even as we eat and stuff, like that won't change, because we're getting heavier but the earth is getting – but then that's getting lighter, so we sort of replace it with something". By this time, she has reached her conclusion that the population increase has not increased the mass of the planet; therefore, her population code, for after reflection, can now be given as NP.

This was not the case for all the discrepancies; in some cases, the student simply did not articulate their thoughts regarding one or the other influence ('People' or 'Other and Stuff') on the mass of the Earth. In one case, the student's responses were contradictory so it was not possible to identify a single consistent and reasoned conclusion. The results of the sense making of the final 12 instances are shown in Table 5.3. Note that Susan, after reflection, no longer contains the code UP, as this

code was only formed from Susan articulating her thought process as she was making sense of the situation.

Table 5.3 Final codes ascribed to participants

| Student | Before reflection | After reflection |
|----------------|--------------------------|--|
| Jim | UP, US | NS, Did not comment on population after reflection |
| Mary | NP, DS | NS, UP |
| Michelle | UP, US | NS, UP |
| Robert | UP, US | NS, UP |
| Lance | UP, US | DS, UP |
| Jane | UP, US | NS, UP |
| Rachael | UP, US | NS, UP |
| Molly | UP, US | NS, Did not comment on population after reflection |
| Anna | UP, DS | UP, NS |
| Emma | UP, US | Did not comment on population after reflection, inconsistent responses |
| John | UP, US | NS, UP |
| Stephanie | UP, NS | UP, but inconsistent with stuff |
| Peter | UP, US | NS, UP |
| Susan | UP, US | NS, NP |
| Paul | UP, NS | NS, NP |
| Lucy | UP, NS | NS, NP |

Once codes had been ascribed to each of the instances of the interviews, for each of the students, it was possible to assign a stance that each student took about both the increasing population and about other factors on the mass of the Earth, both before and after reflection on their prior knowledge (see Table 5.4). This illustrates individual student's stances of the effect of both the population increase and other factors on the mass of the Earth, and shows how (if at all) these changed before and after reflection on the law of conservation of mass.

Table 5.4 Students' ideas about effects of 'People' and 'Stuff' on the mass of the Earth⁷

| Student | Before Reflection | | After reflection | |
|-----------|-------------------|-------------|------------------|-------------|
| | People | Other Stuff | People | Other Stuff |
| Jim | Increase | Increase | - | No Change |
| Mary | No Change | Decrease | Increase | No Change |
| Michelle | Increase | Increase | Increase | No Change |
| Robert | Increase | Increase | Increase | No Change |
| Lance | Increase | Increase | Increase | Decrease |
| Jane | Increase | Increase | Increase | No Change |
| Rachael | Increase | Increase | Increase | No Change |
| Molly | Increase | Increase | - | No Change |
| Anna | Increase | Decrease | Increase | No Change |
| Emma | Increase | Increase | - | - |
| John | Increase | Increase | Increase | No Change |
| Stephanie | Increase | No Change | Increase | - |
| Peter | Increase | Increase | Increase | No Change |
| Susan | Increase | Increase | No Change | No Change |
| Paul | Increase | No Change | No Change | No Change |
| Lucy | Increase | No Change | No Change | No Change |

It can be seen that there was variation in how students expressed their ideas regarding the mass of the Earth. The law of conservation of mass would state that, as the Earth was being considered as a closed system, the net effect of any of these factors is zero. That is, none of the factors would change the mass of the Earth. All the students, with the exception of Mary, initially thought that the mass of the Earth was increasing as the population of the planet increases. Eleven of the sixteen students also thought that other factors, such as new buildings, and computers also were increasing the mass of the planet. After reflection on the formal instruction and the mass experiments, the majority of students changed their position on other factors, but maintained that the population was still increasing the mass of the planet.

⁷ 'Increase' indicates that the student expressed a belief that the mass of the Earth was increasing due to the factor at the head of the column, 'Decrease' indicates the belief that the mass was decreasing, and 'No Change' indicates a belief that the factor was not changing the mass of the planet.

It appears that these students are generally able to apply the law of conservation of mass to man-made objects, but mostly fail to be able to apply the law to the human population. While the science behind the problem is the same, the problem context has changed. Any increase in the ‘buildings’ comes from within the closed system but, it appears, ‘people’ are considered as a special case and, in this context, for most students, the law of conservation of mass did not activate.

Segmenting the interviews at the ‘interaction’ level provided an overview of students’ thinking when faced with these conservation of mass problems. To seek out ‘why’ the students did or did not activate their knowledge of the law of conservation of mass, the interviews were re-segmented at a fine-grained level to gain an understanding of specific ideas that students generated.

5.5 Fine-grained analysis

In the previous section, it was noted that students appeared to vary in their ability to activate their prior knowledge (the law of conservation of mass) in a new context. This section looks, in more detail, at the ideas that the students expressed when considering the mass of the Earth question and investigates what factors may have played a part in the students’ ability to activate the relevant knowledge.

To investigate the different ideas that students had during the interviews, each interview was segmented at a more fine-grained level. Each interaction was studied for evidence of individual ideas expressed by the students. To illustrate the process, an episode with Peter is given; the ideas expressed by Peter have been underlined.

Researcher: Okay, and where does all that [food we eat, the water we drink and the air we breathe] come from?

Peter: *The earth.*

Researcher: Yes, so does that change the mass of the planet?

Peter: *Yes.*

Researcher: How does that change it?

Peter: *Because we are – because we are very efficient, we can make more stuff than we put in, like – yeah. Well, maybe not, but – it's not like we were made out of the earth. It's kind of complicated.*

Researcher: It's complicated, it's exactly why I'm asking the question and it's very difficult to come to a real answer but I'm interested in how you think about getting to an answer, so tell me how you're thinking.

Peter: *Well, like I said, humans don't really like – I said we're efficient, so that leads me to think that our actual presence of taking up space is increasing the mass of the earth. But then I suppose we eat much more than what we weigh or – like – take up space in our lifetimes because then that's used up as energy. So over time yes, lots of humans would increase the mass, but one human or even like a hundred humans would only increase it a little bit.*

During this episode, Peter is 'thinking aloud'. While he is thinking, he verbalises some intermediate stages: "we are very efficient, we can make more stuff than we put in, like – yeah. Well, maybe not, but – it's not like we were made out of the earth. It's

kind of complicated.” In this segment, Peter verbalises his thought that people can make things out of nothing, but then quickly states “well maybe not”. In this instance he has noticed an error in his reasoning. While it would perhaps be unfair to allocate the idea of ‘we [humans] can make more stuff than we put in’ to Peter as he retracts the idea as soon as he has said it, it may be fair to assume that the idea that ‘humans can make things that are greater than their constituent parts’ is an idea that a year six student may express.

In seeking ideas from the sixteen students, attention was paid to the contexts in which the ideas were generated. The first pass, of investigating the ideas, did not seek to assign any ideas to any particular participants, but rather sought to identify possible ideas that the participants may exhibit while considering the mass of the Earth question.

The sixteen interviews were segmented into ideas, which generated 96 idea statements. Examples of these statements (taken from Peter’s episode) are ideas such as:

“we are very efficient, we can make more stuff than we put in”

“it's not like we were made out of the earth”

“our actual presence of taking up space is increasing the mass of the earth”

“over time yes, lots of humans would increase the mass”

An inductive thematic analysis (Patton, 1990) of the ideas was considered appropriate to gain an understanding of the categories of ideas that these year six students were expressing. Braun and Clarke (2006) provide a six phase process to conduct inductive thematic analysis: 1) familiarizing yourself with your data, 2) generating initial codes,

3) searching for themes, 4) reviewing themes, 5) defining and naming themes, and 6) producing the report. The 96 ideas, generated from the student interviews, were read and reread by two researchers, so as to become familiar with the data (phase 1). Braun and Clarke (2006) further suggest, “using ‘post-it’ notes to identify segments of data” (p.89). Following this advice the 96 ideas were printed out onto 96 ‘idea cards’ (phase 2). The two researchers initially re-read all the cards and created a set of possible categories (phase 3). All of the cards were sorted by the two researchers and placed, if possible, into the created categories. The remaining, unsorted cards were read again and new categories created (phase 4). Through a number of iterations, which included creating new categories, combining categories, and resorting the cards, the entire set of 96 cards was sorted into categories (phase 5) - see Figure 5.2. The two researchers reached full agreement on the categories and placement of the idea cards.

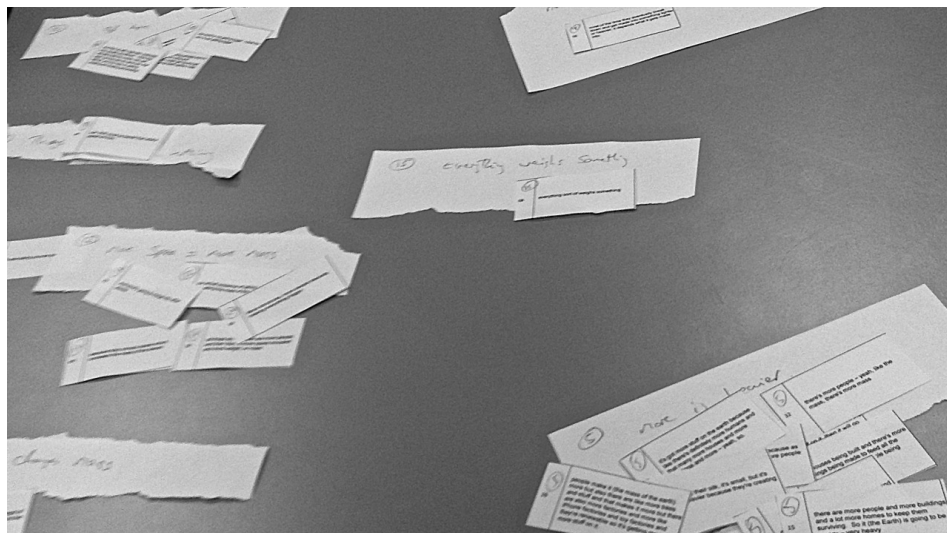


Figure 5.2 Sorting ‘idea cards’

The initial pass of creating categories from the ‘idea cards’ generated 15 separate categories for the ideas; these ideas (shown in Table 5.5) are listed with their frequency of appearance in the interviews.

Table 5.5 Idea categories

| | Category | Frequency |
|----|---|------------------|
| 1 | People weigh something | 9 |
| 2 | People are not made from the Earth | 10 |
| 3 | Mass is always conserved | 27 |
| 4 | Total mass depends on something | 1 |
| 5 | More is heavier | 12 |
| 6 | Things get used up | 4 |
| 7 | People do not weigh much | 9 |
| 8 | As things change they lose/gain mass | 6 |
| 9 | Things can disappear | 1 |
| 10 | Off topic | 4 |
| 11 | Things can appear/things can be made from nothing | 3 |
| 12 | More space equates to more mass | 6 |
| 13 | Force changes mass | 1 |
| 14 | People make more stuff | 2 |
| 15 | Everything weighs something | 1 |

These initial categories were examined and some amalgamated to produce eight final categories (Table 5.6). Category 10 comprised four ideas that were deemed to be off-topic: two of these concerned the sun, one concerned atoms, and one simply expressed confusion. For example: “eventually the sun might get big enough and just swallow the Earth before it dies”, and “molecules ... keep on splitting, doubling and doubling and doubling”. These off-topic ideas, along with the single item from

category 13 (Force changes mass), have been removed leaving 91 ideas to be categorised. These are listed in descending order of frequency of occurrences.

Table 5.6 Amalgamated idea categories

| | Category | Example of ‘idea’ | Frequency |
|---|--------------------------------------|---|------------------|
| 1 | Mass is always conserved | “It comes from the Earth. So, they’re not getting new stuff, they’re just using old stuff for a new purpose.” | 27 |
| 2 | More is heavier | “There are more people and more buildings and a lot more homes to keep them surviving. So, it [the Earth] is going to be a very – very heavy.” | 13 |
| 3 | As things change they lose/gain mass | “A tree is heavier than the wood that it makes.” | 13 |
| 4 | People are not made from the Earth | “It [the mass of the Earth] does get more when the people come – like the babies, they weren’t always there, like yesterday they weren’t there. They just came today.” | 10 |
| 5 | People do not weigh much | “I don’t think they [the people] make a huge difference because there’s like – all like buildings and structures and like the Earth and things which would weigh a lot more.” | 9 |
| 6 | People weigh something | “Everyone weighs something.” and “People obviously weigh something, they don’t weigh nothing.” | 9 |
| 7 | More space equates to more mass | “Our actual presence of taking up space is increasing the mass of the Earth.” | 6 |
| 8 | Things get used up | “People are using resources up.” | 4 |

These eight ‘idea categories’ are proposed as some of the knowledge elements that could activate when year six students consider the mass of the Earth question. These

knowledge elements are based on the students' prior knowledge and experience and, as such, appear to meet the definition of an 'explanatory primitive' (e-prim): "self-explanatory, unquestioned units of explanation, which students take as simply 'the way things are'" (Kapon & diSessa, 2012, p. 266).

5.5.1 Defining explanatory primitives (e-prims)

The e-prims identified appear to fit with diSessa's (1993) view of a knowledge system (see Section 2.4.4). They are elements of the system and they activate dependent on particular situations. They could develop over time and their activations, either alone or together, could also develop over time. The elements are not necessarily mutually exclusive and could function as part of a hierarchical system. To further investigate these 'resources' that students activate when thinking about the mass of the Earth question, diSessa's (1993) criteria for identifying mental resources are employed.

diSessa (1993) defined seventeen principles that can be used to uncover p-prims (fine-grained mental resources). Rather than seeking individual p-prims, this study attempts to define those explanatory primitives (e-prims) that students may activate when considering conservation of mass problems. diSessa's principles provide a method of ascertaining fine-grained primitives that individuals use and, while these are useful, they may not all be appropriate when considering e-prims which do not necessarily have such fine-grained nature. Combining the relevant principles for identifying e-prims, the following four characteristics are used as a guide to check whether the 'idea categories' can be considered as e-prims.

| | |
|----------------------------|---|
| Activation: | By definition, they must be able to be activated in certain situations. |
| Obvious and unproblematic: | When activated, they appear (to the individual) as being obvious, needing no further explanation and having been formed in an unproblematic manner. |
| Continuity: | The resources were formed from prior knowledge. |
| Coverage: | Resources may be activated in different situations. |

These definitions do not consider the grain size of the e-prim. Individual e-prim may be fine-grained, similar to p-prim, or could be coordinated sets of p-prim that activate together.

5.5.2 Identifying explanatory primitives (e-prim)

Taking these four criteria and referring back to the ideas generated by the students (Table 5.6), the eight ideas were considered to see if they would meet the definition of a resource. By definition, all of the eight ideas were activated by the students at points during the interviews; therefore, they all meet the first criterion of ‘activation’. Each of the ‘ideas’ were presented during the interviews and were verbalised in such a way that they did not require further explanation, nor did the participants show any apparent unease with the genesis of their ideas. These ideas came from prior knowledge and the multiple examples demonstrate that the ideas had wide coverage. To illustrate this, one of the ideas, ‘more is heavier’, is used as an example. During

the interviews, this idea was verbalised on 13 occasions by eight different students. The ‘more is heavier’ idea was used at different times, by different students, to describe many different factors. For example, different students used the idea when considering different aspects:

| | |
|--------------------------------|--|
| People : | Michelle, Robert, Jane, Rachel, Anna, Emma, and Susan |
| Buildings: | Michelle, Robert, Jane, Rachel, and Emma |
| Animals and trees: | Robert, Jane, Emma, and Susan |
| Other stuff (such as iPhones): | Jane, Rachel, Susan, and Paul |

Individual students also used the idea when considering different aspects:

| | |
|----------|--|
| Robert : | People, Buildings, and Animals and trees |
| Jane: | People, Buildings, Animals and trees, and Other |
| Rachel: | People, Buildings, and Other |

Therefore, the ideas had ‘coverage’ as they were generated when thinking about a variety of situations.

Some e-prims, that may be activated when a student is considering the mass of the Earth question, have now been defined. The e-prims themselves are not considered to be either correct or incorrect, but rather appropriately or inappropriately activated.

5.6 Appropriate e-prim activation

The previous section provides a list of ideas generated by the research participants (Table 5.6). These intuitive and explanatory ideas are eight examples of possible e-prim that may (or may not) have been activated when students were faced with the mass of the Earth question. There is no judgement over the accuracy or ‘truth’ of any of these knowledge resources. In some circumstances, many of these knowledge resources could be appropriate. However, when thinking about the closed system of the Earth, the activation of many of these knowledge resources would be inappropriate. For example, if the mass of a wooden table is considered and a wooden bowl is then placed on top of the table, it may be appropriate to consider that there is now ‘more’, so the mass has increased⁸. However, if the wooden bowl had been made from part of the table, in effect, the wood is simply being repositioned, then it would be inappropriate, in this instance, to consider ‘more’ as the wooden bowl is not ‘more’ but simply the same wood in a different position. In the same way, when considering the mass of the Earth, many of the activated resources can be considered inappropriate. Table 5.7 provides some examples.

⁸ This is akin to Ohm’s p-prim, the knowledge that increasing something results in a corresponding increase in effect (and conversely that decreasing something results in a diminishing effect).

Table 5.7 Appropriate and inappropriate resource activations

| | Resource | Explanation |
|---|--------------------------------------|--|
| 1 | Mass is always conserved | This resource would be appropriately activated as the mass is conserved in the closed system |
| 2 | More is heavier | While ‘more is heavier’ is often an appropriate resource, in the case of a closed system it is not possible to have ‘more’. |
| 3 | As things change they lose/gain mass | This may be appropriate if, as things change, they are being considered in isolation. However, in the case of a closed system, the entire system is being considered and the system itself cannot change mass. |
| 4 | People are not made from the Earth | This intuitive idea is not appropriate when considering the closed system. |
| 5 | People do not weigh much | This is an appropriate resource and can be used to help think about relative masses. In the case of a closed system it is not helpful. |
| 6 | People weigh something | This is an appropriate resource and can be used to help think about relative masses. In the case of a closed system it is not helpful. |
| 7 | More space equates to more mass | As things get bigger, they often increase their mass. It is understandable that this resource becomes activated; however, it is not appropriate in this case. |
| 8 | Things get used up | While this idea is valid, in a closed system the resources are being changed rather than being used up. |

Students appeared to activate e-prims that were (to the student) appropriate in the problem context being considered. These e-prims were activated alongside the students’ knowledge of the law of conservation of mass. There was often a conflict between an activated e-prim and the law of conservation of mass; however, the students did not appear to be aware of the conflict nor were they troubled by the conflict.

5.7 Discussion of results

This chapter reports on a series of interviews that took place with sixteen year-six school students when considering the law of conservation of mass. The students were asked to consider the law in two separate problem contexts; that of an increasing population and that of increasing ‘stuff’. The interviews were analysed using thematic analysis using two levels of segmentation (interactions and ideas). The results of these analyses are now discussed.

5.7.1 Activating knowledge across problem contexts

Sixteen students were asked to consider the mass of the Earth taking into account two factors: 1) the increasing population and 2) the increasing amount of ‘stuff’ on the planet. The students were interviewed both before and after reflection on their prior knowledge concerning the law of conservation of mass. The Earth was being considered as a closed system and all students had previously articulated a good understanding of, and the ability to apply, the law of conservation of mass. It could be expected that all students would hold the view that both the increasing population and the increasing amount of ‘stuff’ has no effect of the mass of the Earth. None of the sixteen students held this view; however, three students (approximately 20%) did hold this view after reflection on previous knowledge that included formal instruction on the law of conservation of mass.

All students, bar one (Mary), started with an initial view that the increasing population was increasing the mass of the planet. Mary was an unusual case as she

also considered the population increase to be increasing the mass of the Earth, but was somewhat in conflict over this view. Mary's interview transcript illustrates this:

Mary: *Let me think for a second. Well the earth itself does not get any heavier. In fact I think it gets lighter because people are taking away minerals and resources. The people – there's like obviously a lot more people and that – I don't think the amount of people have any effect on this.*

Researcher: Why don't they have an effect?

Mary: *So it like – it must have got heavier because there's more stuff in it, but like I'm not sure if the earth can get heavier because it's like earth, and if it gets too heavy it will throw it off course. But it's not off course yet so that – therefore it can't be too heavy.*

Mary's conflict was not that her intuitive view conflicted with the law of conservation of mass, but that it conflicted with her prior knowledge that the earth is balanced in its orbit. The extra mass would “throw it off course” and therefore she balanced the resources being used up with the extra mass of the people, to keep the planet in orbit. This ‘balancing’ would have been appropriate if she had expressed the view that the population growing was enabled by material already on the Earth, but Mary never made this connection.

Approximately 20% of the participating students initially responded with the belief that the increasing ‘stuff’ did not affect the mass of the planet. This rose to

approximately 90% of students (who expressed an opinion) after reflecting on the prior formal instruction. Note that two students (Emma and Stephanie) did not express an opinion. Only one of the sixteen students (Lance) continued to express the opinion that the mass was changing after reflection; this appears to be an anomaly as he expressed the opinion that the conservation of mass experiments were also losing mass. Generally, most students who did not already apply the law of conservation of mass, at the start of the interviews, were able to do so after reflection when, and only when, considering ‘stuff’ on the planet as distinct from the population.

When asked to consider the increasing population, the students were presented with much more difficulty. Nine of the sixteen students (approximately 55%) maintained their initial position, after reflection on the law of conservation of mass, that the increasing population was increasing the mass of the planet. Approximately 20% of the students did not express an opinion after reflection. These could either be considered to have not changed their opinion, or could be removed from the data set. Either way, approximately 70% of the students held onto their views that the increasing population was somehow outside of the system. People, it would appear, are considered (by the students) to be a special case and this appears to activate different knowledge resources.

Overall, the sixteen students interviewed expressed opinions about two problem contexts either before or after reflection. This created 64 opportunities for students to activate their knowledge of the law of conservation of mass. Of these 64 opportunities, students activated appropriate knowledge on 20 occasions, and of these,

the vast majority occurred after the students had been challenged to consider the experiments observed earlier.

5.7.2 Activating e-primis

The interviews with all sixteen students were analysed at a fine-grained, 'idea' level and eight e-primis were defined. These e-primis are the self-explanatory ideas that year six students may activate when considering the mass of the Earth problem. Of the eight discovered, one (mass is always conserved) is an appropriate e-primis for the students to activate in both problem contexts. The other seven e-primis all have their self-explanatory uses, but all are inappropriate when considering the problem contexts presented. Despite this, these e-primis were not only activated but also activated with significant frequency. Of the seven, three were directly related to 'people' ('people are not made from the Earth', 'people do not weigh much', and 'people weigh something'). Other e-primis (such as 'things get used up') were activated but, on reflection, dismissed; however, the 'people' e-primis were much more 'sticky'; that is, once they had been activated, even when seen to be in conflict with other more appropriate e-primis, they remained fixed and over-ruled the other e-primis.

5.8 Summary

This data collection activity followed sixteen students as they considered a question about the mass of the planet Earth. Before embarking on data collection interviews, all students underwent formal instruction about both the law of conservation of mass and the meaning of sustainability. The formal instruction took inspiration from ‘inquiry science’ and led the students through a series of ‘investigations’ where they attempted to discover what had happened to four items that appeared to disappear. The desired result of the inquiry session was that students would develop knowledge resources related to the law of conservation of mass. These knowledge resources would include knowledge that, in a closed system, nothing is either created or destroyed; things ‘change’. The participating students were interviewed about their understanding of the law of conservation of mass and all students were able to articulate a good understanding of the law. Students were also introduced to a formal definition of sustainability and were asked to explain their own understanding of the term.

The participating students were interviewed about the mass of the Earth and asked to consider the effect of 1) the increasing population and 2) the effect of all the extra ‘stuff’ the increasing population makes and uses. During the interviews, the students were asked to reconsider the ‘inquiry’ experiments they had observed and discussed in an earlier teaching session. They were again asked to comment on the mass of the Earth and any possible effects that the increasing population and increasing amount of ‘stuff’ may have.

Before reflection on the ‘inquiry’ lesson, most students intuitively thought that both the increasing population and the increase in the amount of ‘stuff’ did increase the mass of the planet. After reflection, most students changed their views about the increasing ‘stuff’ on the planet and now considered that any increase in the amount of ‘stuff’ that people make and use did not have any effect on the mass of the planet. However, the idea that the increasing population did increase the mass of the planet, for most students, stuck and remained even after considering the inquiry experiments and the law of conservation of mass. In most cases, the students did not remark on any conflict between the increasing mass of the earth, due to an increasing population, and the law of conservation of mass. It appeared that the students were happy to activate two conflicting knowledge resources at the same time.

The student interviews were re-segmented, at a finer-grained ‘idea’ level, to look for explanatory primitives (e-prims) – those intuitive and self-explanatory knowledge resources that students activate. Eight e-prims were identified and, while students appeared to be able to deactivate some of the e-prims when in conflict (such as those activated when considering all the extra ‘stuff’ on the Earth) other e-prims (such as those about ‘people’) remained activated even when in conflict with other, more appropriate, e-prims.

Chapter 6 Varying the ‘knowledge context’

In the previous chapter, a change in the ‘problem context’ was seen to change how students were able to apply their prior knowledge. However, activating appropriate knowledge is not necessarily dependent on the problem context changing. Students may or may not activate appropriate knowledge in a single problem context. Different students may ‘read’ different information ‘out’ of a situation and also use the information they have read in different ways (diSessa & Sherin, 1998). This chapter reports on an investigation into how six primary school students approached a sustainability problem and seeks to discover the differences in how students activate their prior knowledge.

Students approach the sustainability problems with their own prior knowledge and experiences. Unlike the previous chapter, this investigation does not seek to vary the problem context, but looks at how the variations in prior knowledge change the manner in which students approach and solve a sustainability problem. Students’ own variation in their prior knowledge varies the ‘knowledge context’ for this investigation.

6.1 Introduction

This chapter reports on how the use of the term ‘sustainability’ may affect the way year-six students think about socio-scientific issues. Throughout this year-six unit of study on sustainability the following definition was used:

Sustainability

Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland, 1987, p. 37)

However, the students’ dictionary defines the verb ‘sustain’ as:

Sustain

Cause to continue for an extended period or without interruption. (“sustain, v.,” 2014)

It was noted, early on in the data collection, that students, despite demonstrating a sophisticated understanding of the term ‘sustainability’, would often revert to a more literal meaning of the word and talk about ‘sustain’ – to last a long time. This confusion between the meanings of the two uses of the term is understandable. On the one hand, ‘sustain’ is used to refer to something that keeps going and, in everyday language, would usually refer to the object itself. On the other hand, ‘sustainable’ refers to the use of the Earth’s resources (and whether those resources will be sustained) rather than the object under consideration. This is well illustrated by one of the student’s (not one of the participants reported in this chapter) final ‘sustainability’

presentation. Philip (a pseudonym) had designed a new ‘sustainable’ skateboard. Philip’s sustainable design was made of plastic and, on one of his presentation slides, he illustrated his design alongside a more traditional skateboard made of wood. When questioned about the ‘sustainability’ of the new design, Philip answered that the plastic version would last much longer than the wooden one and therefore, was more sustainable. Further, informal questioning demonstrated that Philip had not considered the Earth’s resources in his determination of whether his product was ‘sustainable’, but had considered the life of the product and hence how long it would sustain.

It would not be possible to generate a definitive list of all aspects of ‘sustainability’. The sustainability of an object will depend on many factors. Maxwell and Vorst (2003) outline a number of factors that may be taken into consideration when developing ‘sustainable’ products. They refer to eco-efficiencies such as: “reduced volume of raw materials, eliminated and/or reduced hazardous raw materials usage, reduced energy usage, and eliminated/reduced waste generation” and also refer to product life, such as: “computers with an extended life”, and “office chairs designed ... to extend operational life” (Maxwell & Vorst, 2003, p. 891). During many interviews with the year-six students, it was noted that students appeared to place different weighting on different sustainability factors, with the lifespan of an object being given significant importance. This may be due to linking the term ‘sustainability’ to the verb ‘sustain’.

Even the lifespan of an object was a cause of confusion for some students. In a previous interview (B3 – see Appendix 2), the students were asked to think of an object that they owned and to describe the possession’s life. Of the six students

reported on in this chapter, three chose a computer of one type or another, one chose a soft toy, one a book, and one student chose his bed. When asked to describe the life of the object, most students started their object's life story at the point the object came into their possession. For example, these quotations are from the start of the students' descriptions of their object's life story: "my parents went into the Apple Store" (Stephanie), "I've owned it for a few years" (John), and "I got it for my birthday present" (Paul). One student was an exception to this; Lucy, when describing the life story of her book, started with a seed:

Researcher: Where are you going to start the life of your book?

Lucy: *I'm going to start the life of my book, I'm going to start with the paper, and I'm going to start as a seed.*

Placing significant weight on the lifespan of an object and considering an object to exist only for the time while it is a possession may be a factor in students' activating inappropriate mental resources when considering sustainability issues.

Before the interviews reported in this chapter took place, all students had undertaken a study program, within their regular science class, investigating sustainability. For the purpose of their study program, the term 'sustainability' had been defined. At the start of the interviews reported here, all six participants had confidently articulated their understanding of the term 'sustainability'. The researcher also took this opportunity of reiterating the difference between the verb 'sustain' and the term 'sustainability'. A typical example of this, taken from the interview with Paul (a pseudonym) is provided:

Researcher: Tell me what ‘sustainability’ means?

Paul: *Sustainability is like materials or things that won’t limit the new generations – like things we can use forever that won’t run out.*

Researcher: Yes, good. That’s a good explanation. The word ‘sustain’ means to continue, to carry on and when we are talking about the environment we are looking at the Earth’s resources and saying how we can use the Earth’s resources in such a way that we don’t restrict future generations – our children and their children and onwards, from also using the Earth’s resources.

In addition to the interviews reported in this research, a number of further interviews were conducted with the same students (see Appendix 3). These interviews established that the students were, when asked about sustainability, not simply reciting a formal definition of the meaning, but rather had a sound conceptual understanding of the idea. An overview of these interviews is provided:

- i) Students were asked about where they might go on holiday (using ‘like’, ‘should’, and ‘would’ questions). These questions were designed to gain an understanding of whether the students would activate any knowledge resources concerning the ‘sustainability’ of the activity. (Interview B6 – Appendix 2).
- ii) Students were asked about making a decision to purchase a laptop (again using ‘like’, ‘should’, and ‘would’ questions). The school operated a BYOD (Bring Your Own Device) policy and therefore, all students had

previously experienced this activity. Again, these questions were designed to gain an understanding of whether the students would activate any knowledge resources concerning the ‘sustainability’ of the activity (Interview B8 – Appendix 2).

- iii) Students were shown an image of a portion of a serving of hot chips and asked about the ‘sustainability’ of the product shown which included the chips as well as the packaging. (Interview B10 – Appendix 2).

In each of these interviews, the students displayed sophisticated understandings of the concept of sustainability.

Once the researcher was confident that each student had understood both the difference between ‘sustain’ and ‘sustainability’, and that the interview was about ‘sustainability’, the interviews continued.

6.2 The interviews

The purpose of these interviews was to establish whether a particular word (or phrase) would affect the way in which students think about socio-scientific issues. As students had appeared to place significant weight on the lifespan of objects when considering sustainability, it was hypothesised that the term ‘sustainability’ may trigger thinking about longevity in preference to thinking more holistically about the Earth’s resources.

The interviews employed ‘epistemic interviewing’ techniques (see Section 4.2.1) which enabled the student to feel that both the interviewer and interviewee were

embarking on a mutual inquiry experience. At various points, in the interview process, prompting questions (to help students think further about their responses) and summary statements (summarising the students' previous comments) were used.

To enable students to discuss their ideas about sustainability, a number of photographs of everyday objects were shown to the students (see Appendix 3). These photographs were shown one at a time and the students were asked about the 'sustainability' of what they saw in the image. To give a wide range of possible responses, the objects portrayed in the photographs were selected using two separate criteria: overall sustainability and lifespan.

A range of objects were selected that could be considered as being more sustainable or less sustainable. There was no attempt to be precise as to the sustainability of each of the objects; objects were chosen that could be thought of as being somewhere on a spectrum of sustainable to unsustainable. There are many products that may be considered to be 'sustainable', such as: reusable water purifiers, solar ovens, and composting toilets. There are also products that may be considered to be unsustainable, such as: plastic take-away food containers, new electronic gadgets, and over-sized cars. Each of these products falls somewhere on the spectrum from sustainable to unsustainable and its position on that spectrum will depend on many factors which are linked to the object and to the individual making the assessment. In addition to an object's sustainability, objects that we use in everyday life also have a lifespan. Some objects may only be used for a short time (for example, toilet paper); other objects may have a lifespan of many months or years (for example, a modern passenger aircraft is expected to have a lifespan in excess of 20 years).

To ensure that students had opportunities to articulate their thoughts about both the lifespan of an object and its sustainability, objects were required that the students may perceive as being more sustainable or less unsustainable, and perceive as having a longer or a shorter lifespan (see Table 6.1).

Table 6.1 Required mix of objects for students to consider

| | More sustainable | Less sustainable |
|-----------------------------|---|---|
| Lasts a longer time | Objects that are more sustainable and last a longer time | Objects that are less sustainable and last a longer time |
| Lasts a shorter time | Objects that are more sustainable and last a shorter time | Objects that are less sustainable and last a shorter time |

Thirteen objects were chosen that fitted into these categories (see Table 6.2). While the thirteen objects have been classified in the two dimensions, these are not meant to be definitive descriptions of either the sustainability or longevity of the objects. They are classified here as an example of how one individual may classify the objects. The example is provided to illustrate that individuals may classify different objects as being more or less sustainable and lasting for more or less time without the two dimensions being linked. That is, some objects can be considered to be sustainable and only last for a short amount of time and some objects can be considered as unsustainable and last for a long period of time. Which objects fall into which category is of lesser importance than that each object can be placed into one of the categories; the interviews did not seek to find correct answers but rather sought to discover the thinking behind arriving at a particular answer.

Table 6.2 Possible classifications of objects presented to the students

| | More sustainable | Less sustainable |
|-----------------------------|--|--|
| Lasts a longer time | Bus Bicycle | Aeroplane Laptop Computer Plastic toy |
| Lasts a shorter time | Pencil Toilet paper Disposable 'eco' coffee cup Packet of chips | Candle Disposable coffee cup Party balloon Plastic shopping bag |

To enable data to be collected that may highlight any differences that the use of the word 'sustainability' may make in students' thinking, when considering the sustainability of objects, two separate data collection activities were planned. Both of these data collection activities used photographic images of the thirteen everyday objects. In the first activity, after checking and reinforcing the students' understanding of the term 'sustainability', the students were asked to comment on the sustainability of each of the objects. In the second activity, the students were asked to comment on possible impacts, on future generations, that the objects may have on the Earth's resources.

6.2.1 Using the term 'sustainability'

The first data collection interviews started with a general discussion of the meaning of 'sustainability'. During this discussion, the students were reminded of the agreed definition of the term: "using the Earth's resources in such a way that we can meet our needs without restricting future generations' ability to meet their needs". An excerpt from a typical introductory discussion (with Lucy) is given.

Researcher: First question today... Tell me again, what is sustainability?

Lucy: *Sustainability is pretty much conserving things now so that in the future that they will still be available or equivalent will be available to people who live then.*

Following the introductory discussions, the students were shown the series of photographs, on a tablet computer, representing the thirteen objects outlined in Table 6.2. The students were asked to comment on the sustainability of the object in the image; the overarching question was “is this more or less sustainable?”. An example excerpt from one of the interviews with Lucy, discussing the photograph of the bus, follows:

Researcher: Is it sustainable or is it more sustainable or less?

Lucy: *I would say that it's partially sustainable because it's reusable, but also it's – because the materials that are making that, there's a lot of metals and a lot of plastics, and my brain is currently not thinking about how metal would be made; but with plastic, they make it with oil, so you've got quite a bit of oil, but I'm just thinking I don't know what they would do to that after it breaks, or – I know that they'd melt it down and make a new one, but I would say it's – it is, and it isn't – but I mean it would be less sustainable – no – more sustainable?*

Researcher: Can you think of any way that you could make it more sustainable?

Lucy: *Well, instead of – well, I don't know how it's powered, but I guess it would be powered off the battery inside the bus, the – stuff like that. So I guess what they could do is for during the day, they could use power – the light things, the light powers –*

Researcher: Solar panels?

Lucy: *Solar panels, that's the word. And then during the night they could use batteries so that they used less, they could have battery as a backup.*

Each of the thirteen objects was discussed with each of the six participating students.

6.2.2 Impacts on the Earth's resources

In the second set of interviews, rather than using the term 'sustainability', the students were asked for comments about the impact, on future generations, of the objects' use of the Earth's resources. To ensure a common understanding of 'the Earth's resources', each of the second set of interviews started with an introductory discussion about the Earth's resources. As students, especially in Australia, often hear about 'resources' in reference to mining operations (for an example, see Creighton, 2013) it was important to reiterate that the term "the Earth's resources" covers more than resources mined from the ground. This was outlined at the beginning of the interviews. An example is provided from an excerpt from an interview with Stephanie.

Researcher: Tell me, what are the Earth's resources?

Stephanie: *Well, things like trees, coal, anything that's natural that's the Earth's resources and – yeah.*

Researcher: Can you think of anything that's not, that we wouldn't consider an Earth's resources?

Stephanie: *It's all Earth's resources because it's made from natural stuff, so yeah.*

Researcher: And what about air?

Stephanie: *Air – that's Earth's resources.*

Researcher: And water?

Stephanie: *Yeah.*

Researcher: Yes. So everything we've got comes from the Earth's resources. So when I talk about what an impact things have on the Earth's resources there's lots of things to think about, because it's the impact on everything really.

Stephanie: *Yeah.*

Researcher: Not just oil, or not just coal but Earth's resources as a whole.

Stephanie: *Yeah.*

In the second data collection activity, the interview question was rephrased and only the definition of sustainability was used, not the word itself. The question was phrased along the lines of “what impact do these objects have on the Earth's resources?”. In the same way as the earlier interviews, no absolute definition of ‘impact’ was provided. Students were again given the freedom to make their own interpretations. An example of typical introduction to the interviews (with Stephanie) is given.

Researcher: Do you remember a while ago I showed you some photographs of different things?

Stephanie: *Yeah.*

Researcher: Today I'm going to show you the same pictures again, going to go through them again. What I'd like to do this time is just think about the earth's resources and the impact these have on the earth's resources, whether they have a big impact or a small impact, how they have an impact, and whether you can think of ways or things we could do that could reduce the impact on the earth's resources, could we use things in a different way or do things in a different way.

Stephanie: *Yeah.*

The second interview was kept as close as possible to the first interview with the only difference being that the agreed definition of the term 'sustainability' was used instead of the term itself. The interview with Stephanie continued thus:

Researcher: So what impact does a bus have on the earth's resources?

Stephanie: *Just using it up, like – maybe if it wasn't so big, but then if it wasn't so big then it couldn't carry more people, but – like some of those things you can't replace.*

Researcher: Right. So is this – is a bus good for the earth's resources or bad for the earth's resources?

Stephanie: *I think it's good.*

Researcher: And why is it good?

Stephanie: *Because it uses up some of the earth's resources, some of them you can replace, but it like helps the environment because if everyone has their own car and they drive it everywhere they make a lot of pollution for the environment.*

Researcher: And it would probably use up more fuel and more things.

Stephanie: *Yeah.*

Researcher: I think that's good. So overall good for the earth's resources?

Stephanie: *Yeah.*

Researcher: Is there any way we could make it better for the earth's resources?

Stephanie: *I know they have double decker buses so that it carries more people, but then that would probably take more fuel because it's heavier.*

6.3 Developing a coding scheme

The coding scheme for these interviews followed the same general processes that were discussed in Chapter 5. The phases outlined by Braun and Clarke (2006), when undertaking inductive thematic analysis, were used. First, the interviews were transcribed, read and reread to help with familiarization of the data. Initial themes emerged from the data; these started as segments of responses given by the students and were written down onto paper for manual sorting. Once the segments had been sorted into categories, a second researcher read all the interview transcripts and was asked to sort the segments into the categories. After considering all responses, a list of general categories was created. Students' responses appeared to fall into four broad

categories: ‘Reduce, Reuse, Recycle’, ‘General Environmental Concern’, ‘Longevity’, and ‘Earth’s Resources’ (see Table 6.3).

Table 6.3 Examples of students’ comments and proposed categories

| Object | Student comments | Proposed Category |
|-----------------------------|--|-------------------------------|
| Candles | “they burn up and they put stuff into the environment and so bad.” | General Environmental Concern |
| Party Balloons | “Because rubber is made out of sap of a rubber tree and rubber trees aren’t very eco friendly.” | General Environmental Concern |
| Toilet Paper | “No [not sustainable]. You can’t really reuse it as paper once it’s been flushed” | Longevity |
| Disposable ‘eco’ coffee cup | “... it’s not sustainable ... because it’s a hundred per cent compostable and people use it as compost and – and then it’s not being a cup anymore...” | Longevity |
| Plastic toy | “So I guess it lasts for a while, so – I mean it’s more sustainable that a candle or toilet paper. ... it lasts longer.” | Longevity |
| Plastic toy | “You can't really like reuse it unless you put it in the Vinnie's or something [charity shop/thrift store] for someone else to use.” “ Maybe just like reuse them and don't make as many, like if they stop making them so that people would recycle them.” | Reduce, Reuse, Recycle |
| Bicycle | “... it doesn’t have a fuel source apart from you, but food is more sustainable than fuel.” | Earth’s Resources |
| Toilet Paper | “I think it’s made from trees, so I think it’s sustainable because ... because if you chop down a tree, plant another one.” | Earth’s Resources |

There is considerable overlap between these categories. For example, recycling impacts on both the environment and the Earth's resources. However, although there is certainly overlap within the categories, there is also segregation. A well-made wooden table that may last for a long time could be considered as being sustainable and meets both the 'Earth's Resources' category and the 'longevity' category; a plastic toy could have longevity but may be considered bad for the Earth's resources. While overlaps may exist when considering each object against these categories, it was possible to code individual student comments into these proposed categories, albeit with some utterances producing multiple codes.

Once the proposed categories had been reviewed, the following five codes emerged:

- RRR (Reduce, Reuse, Recycle)
- GEC (General Environmental Concern)
- L (Longevity)
- ER (Earth's Resources)
- O (Other)

These codes were defined as shown in Table 6.4

Table 6.4 Description of code categories and examples of use

| Code | Description | Example |
|------|---|--|
| RRR | <p>When the student refers to one or more of the following: Reduce (reducing the use of something), Reuse (reusing something - for a different purpose, in its current state, rather than throwing it away), and Recycle (reusing an item in a new or changed state).</p> <p>Note: This code is used when the object is considered as being reduced, reused and/or recycled. If, however, the comment refers to the object being made from recycled materials, the code ER is used.</p> | <p>“Well, it's a hundred per cent compostable, so I suppose it's able to be recycled”</p> <p>“I mean yeah, it's nice, but I mean, if maybe you recycled the balloons, but like no one does, because they're like so small, and people are like oh, it couldn't matter, but it does.”</p> |
| GEC | <p>When the student refers to something affecting the environment, or as being ‘eco friendly’, or has other general environmental concerns about the image. Note, these comments could be either positive or negative.</p> | <p>“It's a toy truck – plastic, I guess. Lots of plastic. Plastic doesn't decompose well. It does after ages, but not well. So it's a bad thing for the environment.”</p> |
| L | <p>When the student refers to the length of time an object exists (note, this could be long or short.); also when the student refers to how long an object lasts. This code is used when considering how long the ‘made’ object lasts. It is not used when considering how long the Earth’s resources (that were used to make the object) may last. If the comment refers to how long the resources will/would last, then code ER is used.</p> | <p>“A balloon. I don't think it is very good for the earth's resources because like you kind of use it once, and it might pop, and then it might get never used again”</p> |
| ER | <p>When the student refers to using the earth’s resources in such a way that we don’t restrict future generations from accessing those resources (this has to be more than using the word ‘sustainable’ or ‘sustainability’).</p> | <p>“I think it’s made from trees, so I think it’s sustainable because ... because if you chop down a tree, plant another one.”</p> |
| O | <p>When none of the other codes are applicable</p> | |

6.4 Applying the coding scheme

The transcripts from the two data collection activities were coded according to the codes outlined in Section 6.3. Each interview was segmented and coded separately by two researchers to establish a level of coding reliability.

6.4.1 Segmentation of interviews

Based on Chi's (1997) procedures for the analysis of verbal data, the interviews were segmented according to the object being discussed. In total, there were twelve separate interviews (six students, each interviewed two times) and thirteen different object photographs; giving 156 separate segments. Basing the segmentation on the object being discussed provided a useful grain size for analysis. However, as the segmentation was created by the change in image being discussed, many of the individual segments contained multiple ideas. Therefore, provision was given for each individual segment to have one or more codes applied. Each of the segments was assigned codes according to the definitions outlined in Table 6.4. Many segments (33% of all segments) contained multiple ideas and therefore generated multiple codes. Each segment was read as a whole and all applicable codes assigned. Examples of how particular codes have been applied are shown in Table 6.5.

Table 6.5 Explanation of how codes have been applied

| Student comment (segment) | Code(s) | Explanation |
|--|----------------|---|
| <p>“it's made out of non-sustainable resources because there's not – the metal in the ground will eventually all go and there's not endless amounts of sand to make the glass, plastic and other things. So it's less sustainable.”</p> | ER | <p>The student is referring to the non-limitless supply of natural resources and equating these to a level of sustainability.</p> |
| <p>“Because plastic is definitely not eco friendly or that sustainable although it does take a long time to decompose; so it lasts a long time, but it's not eco friendly.”</p> | GEC, L | <p>There are General Environmental concerns (“not eco friendly”) but also reference to the length of time the items exists, which appears to be used to calculate sustainability.</p> |
| <p>“so probably less sustainable ... once it's used, it's used; so it's like a one timer, so then it doesn't be continued to be used.”</p> | L | <p>The item is only used for a short time and therefore perceived as less sustainable.</p> |
| <p>“Maybe, because it's more sustainable if it uses less energy to make.”</p> | ER | <p>The student has commented on the Earth's resources that go in to making this object.</p> |
| <p>“No. [not sustainable] ... Everything about it. Power – power is not going to last forever, like – factories – because then they make the metal that's not endless, the plastic is not endless – “</p> | ER | <p>Referring to the limited supply of the Earth's resources.</p> |
| <p>“They don't do anything, so – and they're made out of plastic and probably metal in the shafts, but – I mean, it will get used and then get given away, or – and eventually get thrown away. So I guess it lasts for a while, so – I mean it's more sustainable than a candle or toilet paper.”</p> | L | <p>Sustainability is here linked to how long the item will be in use. As it is used for a longer time than the other items mentioned it is deemed to be more sustainable.</p> |

6.4.2 Coding example

To illustrate how the codes were applied, two excerpts from the first interview with Peter are provided.

Excerpt one

In this excerpt, Peter was considering a photograph of an aeroplane:

Researcher: Yes. Okay, swipe along. An aeroplane.

Peter: *Definitely not sustainable.*

Researcher: Why not?

Peter: *They use tons of fuel and they need lots and lots of repairing.*

Researcher: So why does using lots of fuel make it not sustainable?

Peter: *Well, because the fuel is almost about to end, so – like – well, not that the fuel is about to end, but it's getting much more expensive because it's getting harder to find. And fuel is not a sustainable source. And getting all the repairs, as I said, all the metal – there's not endless amounts of metal and stuff, and it costs lots of money to do all that.*

The student has referred to resources coming to an end and there not being “endless amounts” of the resources; therefore, this segment was given the code ‘ER’.

Excerpt two

In this excerpt, Peter was considering a photograph of a coloured pencil discussing the coloured plastic coating:

Researcher: Other than the graphite is there anything else that might make it less sustainable, or not completely sustainable?

Peter: *The plastic coating on the pencils, or at least I think it's plastic.*

Researcher: Yes, might be.

Peter: *And then the paint.*

Researcher: Yes, there's probably some sort of paint, and probably it's based in plastic.

Peter: *Yeah. Because plastic is definitely not eco friendly or that sustainable although it does take a long time to decompose; so it lasts a long time, but it's not eco friendly.*

Peter here refers to plastic not being 'eco friendly'. He also remarks that the plastic is not "that sustainable" and "it lasts a long time"; this links sustainability with the length of existence. Therefore, his segment was given the codes 'GEC' and 'L'.

6.4.3 Inter-coder reliability

Two researchers coded each of the 156 segments independently. Although there were only five defined codes, many of the segments required multiple codes to be assigned. This led to a total combination of 14 different code configurations. On the first pass of the coding the two researchers' codes agreed on 112 of the 156 segments; giving a 72% agreement. However, when inter-coder reliability was calculated it produced a Cohen's kappa of 0.60. While this appears low, it can be explained by the relatively large segmentation of the data along with the assignment of multiple codes. In the cases where a segment's code combination did not match, it was usually that one

code, within a set of codes, was missing rather than different researchers assigning completely different codes.

The researchers met to discuss the cases where code combinations did not match. This resulted in some codes within the combination of codes for the segments being adjusted. After adjusting those segments where one or other of the researchers had only either a missing code or an extra code (not adjusting those where there was any fundamental disagreement on codes), the researchers agreed on 148 of the 156 codes (95% agreement); producing a Cohen's kappa of 0.93. The remaining 8 segments were further discussed. Of the 8 discrepancies, 6 were discrepancies over the use of combinations of the codes; for example, whether to assign only an 'ER' code or both an 'ER' code and a 'GEC' code; these 6 discrepancies were satisfactorily resolved through discussions. The remaining two segments, both of which contained the 'L' code were investigated further. Of particular interest in this analysis is the longevity code as the frequency and timing of this code may provide insights into possible activations of the verb 'sustain' rather than the term 'sustainability'. The researchers reconsidered these two segments. To ensure accurate coding, both researchers reread the entire interviews in which these segments appeared. The two segments were then independently recoded and the researchers met to discuss their applied code. Through this discussion, both of the discrepancies were resolved.

6.5 Results

To interpret the results of the interviews, the 156 segments have been represented as grids (see Tables 6.6 and 6.7). The thirteen object images are represented in the rows and the students represented in the columns. Table 6.6 represents the first set of interviews and Table 6.7 represents the second set of interviews.

Table 6.6 Coding of the first set of interviews

| | John | Stephanie | Peter | Susan | Paul | Lucy |
|---------------------|-------------|------------------|--------------|--------------|-------------|-----------------|
| Bus | RRR | ER | L, ER | ER | ER, L | RRR, ER |
| Bicycle | RRR | GEC, ER | ER | ER | L | ER |
| Aeroplane | RRR, ER | GEC | ER | ER, L | ER, L | RRR, ER, GEC, L |
| Pencil | L | ER | GEC, L | ER | L | ER |
| Candle | L, RRR | ER, L | L | ER | L | ER, L |
| Toilet Paper | L | ER | ER, L | ER | ER | ER |
| Coffee Cup | L | ER | ER | ER | L, ER | GEC, ER |
| Eco' cup | RRR | ER | RRR, L | ER | ER | ER |
| Laptop | L | ER | ER | ER | L, ER | ER |
| Toy | L | ER, RRR | L | ER | ER | GEC, ER |
| Chips | RRR, L | RRR | L, ER | ER | ER | O |
| Balloon | L | GEC, L | GEC, ER, L | ER | ER | GEC, ER |
| Bag | L, ER, GEC | L | ER, GEC | RRR, ER | ER | GEC, ER |

Table 6.7 Coding of the second set of interviews

| | John | Stephanie | Peter | Susan | Paul | Lucy |
|---------------------|--------------|------------------|--------------|--------------|-------------|-------------|
| Bus | ER | ER, GEC | ER, RRR | ER | ER | ER, GEC |
| Bicycle | ER | GEC, ER | ER | ER | ER | ER |
| Aeroplane | ER | GEC, ER | ER | ER | ER | ER |
| Pencil | ER, L | GEC, ER | O | ER | ER | GEC, ER |
| Candle | GEC, L | ER | O | ER, GEC | ER, GEC | ER |
| Toilet Paper | RRR | ER | O | ER | ER | ER, L |
| Coffee Cup | GEC, ER, RRR | ER, RRR | ER | ER | ER | RRR, ER |
| Eco' cup | RRR | ER | ER | ER | ER | ER |
| Laptop | RRR | ER, RRR | ER | GEC | ER | ER, RRR |
| Toy | RRR | RRR | ER | ER | ER | ER |
| Chips | RRR, ER | RRR, ER | ER | ER | ER | L, ER |
| Balloon | L | L, RRR | ER | ER | ER | ER, L RRR |
| Bag | RRR | RRR | GEC | ER | ER | ER, RRR |

These tables represent the codes that were applied to each of the interview segments.

Some segments had a single code applied; however, many segments produced multiple codes. As the longevity code is of particular interest, segments where the 'L' code has been applied have been highlighted. A visual inspection of the two grids immediately shows that the 'L' code was applied with greater frequency in the first set of interviews than in the second set of interviews.

6.5.1 Frequency of code applications

When the total frequency of each individual code is taken into consideration, across both interviews, it can be seen that there is a significant decrease in the application of the 'L' code in the second interview, however, the other four codes have remained relatively static.

Table 6.8 Frequency of code applications

| Code | Frequency occurring in Interview 1 | Frequency occurring in Interview 2 | z-value | p-value |
|-------------|---|---|----------------|----------------|
| L | 30 | 7 | -1.892 | .058 |
| RRR | 12 | 18 | -1.289 | .197 |
| ER | 55 | 63 | -1.511 | .131 |
| GEC | 12 | 12 | 0 | >.999 |
| O | 1 | 3 | 0.447 | .655 |

To better understand the significance of these changes in frequencies, statistical analysis was performed. As the dependent variable in each case was dichotomous (a participant's response either did or did not generate a particular code), a logistic regression test (Wilcoxon signed ranks test) was performed and corresponding p-values were calculated (see Table 6.8). At the commencement of the first interviews, the students articulated that sustainability was connected to our use of the earth's resources and ensuring that any use of the earth's resources should not compromise future generations; they then discussed the sustainability of the objects. In the second interview, students discussed the impact the object may have on the Earth's resources. It could, therefore, have been expected that students would have responded in similar ways in both interviews. This expectation was used as the null hypothesis. The alternative hypothesis is that students may change their thinking when the word 'sustainability' is introduced; that is, that students would respond differently in the two interview sessions. The p-value for the longevity code (.058), while not significant at $p < .05$, is low showing a tendency that, overall, the students did change the way they responded to the objects in the two interviews. However, the other four codes, having higher p-values, indicate that, in these areas, there were no significant differences between the two interviews.

6.5.2 Individual student differences

All six students produced different frequencies of the longevity code across the two interviews and there were differences between the students. Table 6.9 shows the frequency of the use of the longevity code for each of the students, for both interviews. Again a Wilcoxon signed ranks test was performed, calculating z-values and corresponding p-values; these indicate that the students' responses varied across the two interviews. All but one student (Lucy) reduced their frequency of use of the idea of longevity in the second interview and three of the students (John, Peter, and Paul) all reduced the use of longevity significantly (p values of .014, .005, and .008 respectively). These statistical measures are not being used to imply that there is any confidence that these results would be applicable in the general population, but rather to show that there is high confidence that, at least three of the students, had a significant change in their responses when considering the life of these thirteen objects. The anomaly is Lucy, whose use of the idea of longevity actually increased during the second interview session. This increase appears to go against the alternative hypothesis that the students would decrease their use of the longevity idea during the second interview. However, Lucy only used the longevity idea twice during the first interview and only three times during the second interview. The calculated p-value of .655 would suggest that there is no significant difference between Lucy's responses across the two interviews. Furthermore, Lucy used the longevity idea sparingly in both interviews, implying that she was, from the start, taking other factors into consideration. Therefore, observing consistency, rather than the absolute frequency, of the use of the longevity idea is more appropriate in this instance.

Table 6.9 Longevity code application – t and p values for students

| Student | Frequency Interview one | Frequency Interview two | z-value | p-value |
|----------------|--------------------------------|--------------------------------|----------------|----------------|
| John | 9 | 3 | -2.449 | .014 |
| Stephanie | 3 | 1 | -1.414 | .157 |
| Peter | 8 | 0 | -2.828 | .005 |
| Susan | 1 | 0 | -1.000 | .317 |
| Paul | 7 | 0 | -2.646 | .008 |
| Lucy | 2 | 3 | -0.447 | .655 |

To investigate the students' level of consistency, the mean deviation from their mean was calculated. This calculation provides a view of how far the use of the longevity idea, in either interview, deviated from the mean of both interviews for each student. A high mean deviation from the mean would show low consistency across the interviews and a low deviation from the mean would show high consistency across the interviews (see Table 6.10). The table shows that both Lucy and Susan were very consistent in their use of the longevity idea, whereas Peter, Paul, and John were less consistent.

Table 6.10 Use of the 'L' code across the interviews

| Student | Frequency of 'L' code in interview 1 | Frequency of 'L' code in interview 2 | Mean deviation from the mean |
|----------------|---|---|-------------------------------------|
| John | 9 | 3 | 3.0 |
| Stephanie | 3 | 1 | 1.0 |
| Peter | 8 | 0 | 4.0 |
| Susan | 1 | 0 | 0.5 |
| Paul | 7 | 0 | 3.5 |
| Lucy | 2 | 3 | 0.5 |

While all students displayed some variation between the two interviews, three of the students appeared to consistently activate the longevity code in the first interview but

not in the second interview. The other three students appeared to be very consistent in their activation of the longevity code across both interviews.

6.5.3 Variations across objects

The longevity code has been applied to student comments across the interviews when discussing all thirteen objects. At some point in the interviews, one or more students linked the lifespan of every object to its sustainability (see Table 6.11).

Table 6.11 Use of the ‘L’ code across the objects

| | Frequency of ‘L’ code in interview 1 | Frequency of ‘L’ code in interview 2 |
|--------------|---|---|
| Bus | 2 | 0 |
| Bicycle | 1 | 0 |
| Aeroplane | 3 | 0 |
| Pencil | 3 | 1 |
| Candle | 5 | 1 |
| Toilet Paper | 2 | 1 |
| Coffee Cup | 2 | 0 |
| Eco' cup | 1 | 0 |
| Laptop | 2 | 0 |
| Toy | 2 | 0 |
| Chips | 2 | 1 |
| Balloon | 3 | 3 |
| Bag | 2 | 0 |

During the first interview (when the term ‘sustainability’ was used), the ‘L’ code was, at some point by at least one student, generated for each object. During the second interview (when the term ‘sustainability’ was not used), the ‘L’ code was only generated during discussions concerning five of the objects (pencil, candle, toilet paper, chips, and balloon). These five objects do appear to have a relatively short lifespan and, therefore, it may be felt appropriate that the students considered the

lifespan to be an important factor in their sustainability. Despite this, it is again clear to see that the lifespan of an object was not considered as much when the students were asked to consider the impact that the object has on the Earth's resources as opposed to considering the object's sustainability.

6.6 Summary

During the interviews, the students expressed a variety of ideas about sustainability and the Earth's resources. These ideas fell into five broad categories, one of which has been called 'longevity', used when students commented on the lifespan of the object under consideration. The use of longevity as a factor when considering sustainability is not incorrect; the length of time an object is used may have a direct correlation to the sustainability of that object. It was entirely up to the student to discuss the lifespan of an object if and when he or she felt it was an important factor. At no point in either set of interviews were the students encouraged to discuss any particular aspect of sustainability; the students were only asked to discuss the 'sustainability' of the object or the impact the object may have on the Earth's resources. The results show that 'longevity' ideas were raised on more occasions during the first set of interviews when the word 'sustainability' was used as opposed to the second set of interviews when the word 'sustainability' was not used.

In the first set of interviews, one or more of the students raised the idea of longevity about each of the thirteen objects. In the second set of interviews, longevity was only raised during discussions about objects that do not last a long time. It appears that, during the first set of interviews (while the students were considering 'sustainability') the lifespan of objects, such as aeroplanes and buses, were considered to be an

important factor in the assessment of sustainability. However, when the students are asked to comment upon the agreed definition of 'sustainability', without the term itself being used, lifespan was of lesser importance for objects that have greater longevity.

Chapter 7 The framing and reframing of a sustainability problem

When students are faced with a sustainability problem, they first have to work out what is going on, what the problem is, and to consider their options on how to start to find one or more solutions. This chapter reports on four year-six students as they faced a problem about sustainability and looks for evidence of how the students went about making sense of the problem. The students were set a number of tasks individually and then a combined task to solve as a group. The activities were recorded and observations were made on the various processes that the students undertook on their way towards a solution.

7.1 Introduction

In the previous chapter, photographic images of thirteen everyday objects were shown to students (see Appendix 3). These images were shown one at a time and the students were asked to comment on the sustainability of the object represented in the photographs. Students were not asked to compare the images or to provide comparative assessments of their relative level of sustainability. This section of the study seeks to investigate the process students undergo when faced with the task of sorting the thirteen objects into various orders. There were two phases to the data collection activity; first the students worked alone and were asked to sort the objects. This was followed by a group activity that was intended to bring together the work the students had performed alone.

The participants for this data collection activity were four of the six students who had taken part in the earlier interviews. The activity took place several months after the students had last seen the images of the thirteen objects. Although the participants were able to remember the objects, when they saw the photographs, they could not remember details about their comments made during the previous interviews (reported in Chapter 6). Only four students were available for this part of the study; of the original six students, one had left the school and one was unwell on the data collection day.

This section of the research relied on participant observation, informed by ethnography (Delamont, 2004) and is presented using Esterberg's (2002) eight stages of participant observation (see Section 4.2.2). The chapter starts with a description of the setting and how the researcher participated in, and observed, the various activities. It provides a narrative account of the activities, and inferences are made from the narrative. These, along with the results from the previous two chapters, are discussed in Chapter 8.

7.2 Data Collection

Previously, when the students had viewed, and commented on, the images of the thirteen objects, they had viewed them on a handheld tablet computer. This time, as the students would be working individually and simultaneously, four sets of the photographs were printed out, one set for each of the participants. By having their own set, students could work at their own pace, independently of the other

participants. The physical nature of the photographs enabled the students to manipulate the images to home in on a solution to the set problems.

7.2.1 Working individually

The first phase of the data collection activity was a set of individual tasks and took place in a quiet classroom above the school library. The students were all asked to sit at separate tables some distance from each other and to leave all books, pens, bags and other paraphernalia at the door. Each student was wearing a microphone, connected to a voice recorder so that a record was kept of all verbal utterances. At each of the tables was a stack of thirteen photographs (identical at each table), which the students immediately recognised as the images they had seen on previous occasions. A set of instruction cards had been prepared for each student, with the student's name printed at the top (see Figure 7.1). These cards were used as directions for the task and were kept out of sight until the start of each task.

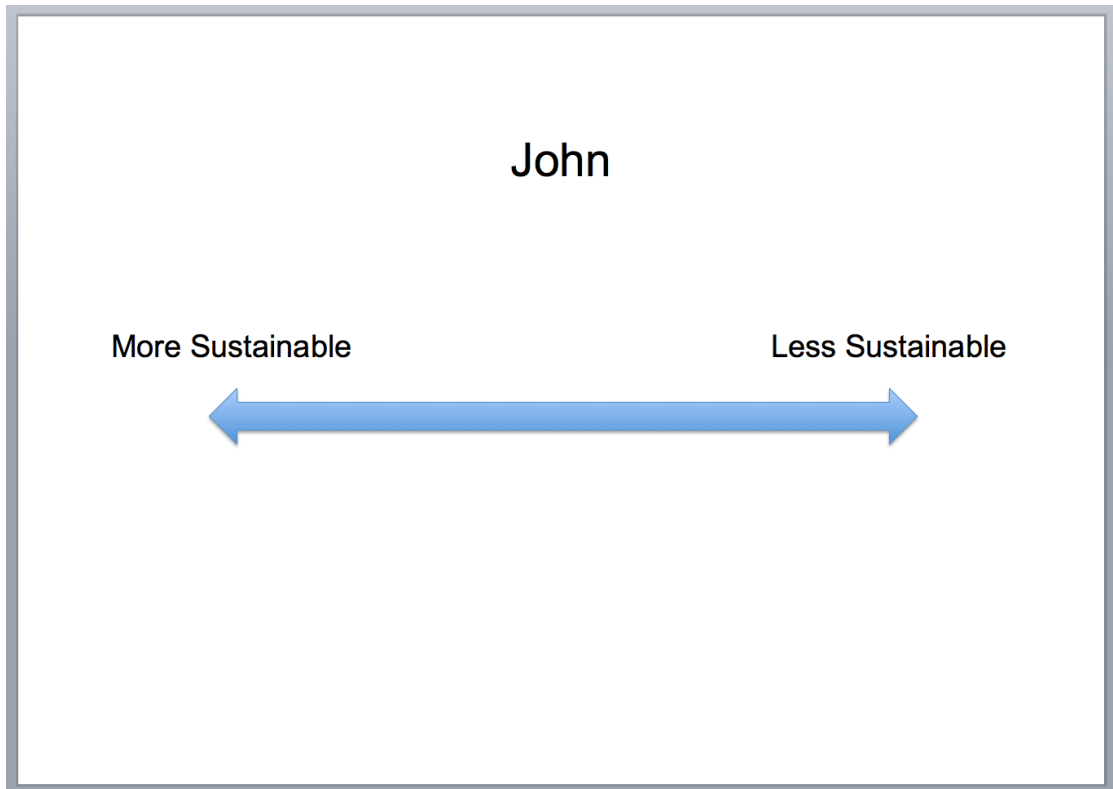


Figure 7.1 Sample instruction card for the individual activities

Once the students were sitting at their own tables, they were given instructions for the task. The instructions started with a reminder of the meaning of the term ‘sustainable’; an excerpt is provided from the transcript (note that, as all students were working in the same room, the entire group was reminded at the same time).

Researcher: Can anyone remember what sustainable means? [Susan raises her hand] Go on, tell us all...

Susan: *Sustainable is like, more like environmentally friendly, but not necessarily environmentally friendly...*

Researcher: Do you remember that we had a definition of sustainable?

Lucy: *I don't know the exact definition, but isn't it like about how it can be used again, like somethings how well they decompose – how well they decompose into the ground ...*

Susan: *Recycling...*

Researcher: Do you remember, we talked about sustainability is about future generations and about...

Lucy: *Oh yeah, saving things now so that they can have them in the future.*

Researcher: We want to make sure that the stuff that we use today, the Earth's resources are used in such a way that we don't restrict future generations from also using the Earth's resources.

Once the students had discussed sustainability, the formal individual tasks began. The four students were given their first work card (Figure 7.1) and asked to rank the images by placing them in order on the table; the order being specified by the direction of the arrows. At this point, students were also reminded that some questions do not have right or wrong answers. This activity was not to be seen as a test in which the students had an opportunity to pass or fail, but rather to be viewed as an individual task that is correct for the individual student. To help students understand this the following dialogue took place.

Researcher: Now, do you remember that there are some questions that don't have right or wrong answers? Can anyone think of a question that doesn't have a right or wrong answer?

Susan: *I know one, 'where would you like to go on holiday?'*

Researcher: Very good, if you said ‘I’d like to go to Bali’, how could I say that that was wrong? Because it’s not. There is no right or wrong answer and this is like that, there is no right or wrong answer. I have done this with lots of people and I don’t think anyone that I’ve seen has put them in the same order.

The first work card asked the students to rank the images from more sustainable to less sustainable. This task was similar to the activity reported in Chapter 6, however, on this occasion, the students were not only considering the sustainability of each object but were required to make a judgement regarding the relative sustainability between the objects. Students were not given any instructions on how they should go about arriving at a decision about the relative ranking of the objects. However, advice was given on a suggested procedural method that they may like to follow. This took the form of verbal instructions along with a physical demonstration of sorting three of the images:

Researcher: It is quite hard to sort these when you have got thirteen pictures to go through... The way that I like to do it is I pick up the first one ... one picture and I put it down then I pick up the next one and decide whether I think it is more or less than the first one and put it down. Then I take the next one and decide is it more or less or in between and decide where to put it.

Each student was given as much time as they needed and, once they had completed their rankings, a photograph was taken of the table depicting the order of the objects

along with the work card which identified which student and which task was being photographed (see Figure 7.2).

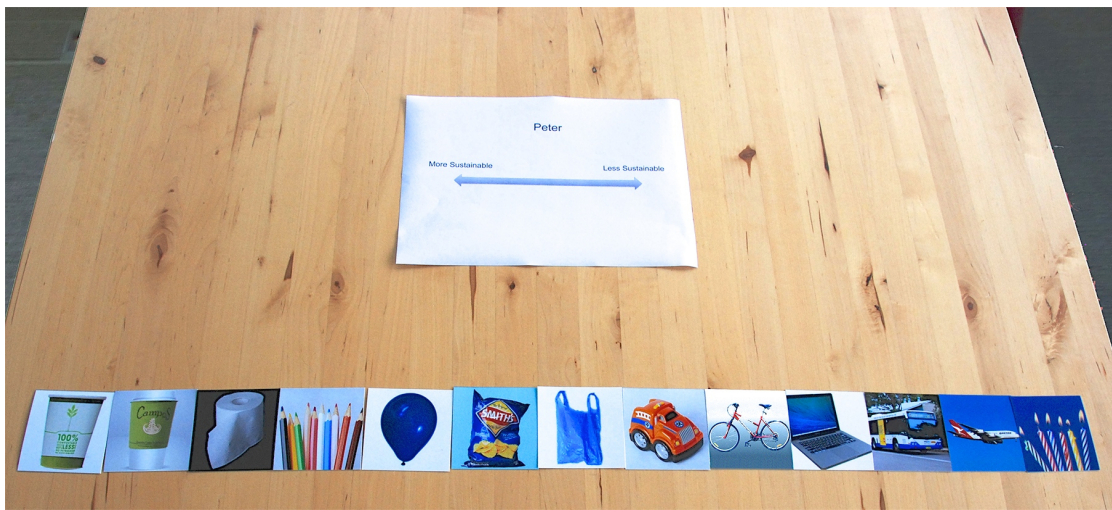


Figure 7.2 Example of the outcome of one of the sorting tasks

The sorting activities were based on the outcome of the students' comments during the interviews reported in Chapter 6. When thinking about sustainability, the students' comments fell into four main categories, these were 1) Reduce – Reuse - Recycle, 2) General Environmental Concerns, 3) Longevity, and 4) Earth's Resources. A total of five individual sorting activities were performed, these were: 1) more sustainable to less sustainable, 2) used for a longer time to used for a shorter time, 3) better for RRR to worse for RRR (Reduce Reuse Recycle), 4) more ecofriendly to less ecofriendly, and 5) lower impact on the Earth's resources to higher impact on the Earth's resources.

7.2.2 Working as a group

Once the students had completed their individual tasks, they were asked to move to a new table with all four students, and the researcher, sitting around the table. The previous, individual tasks were discussed and all of the factors (against which they

had sorted) were considered as having an effect on an object's sustainability. A new set of the same thirteen photographs of the objects was placed on the table and the students were asked, as a group, to perform the final sorting task. The final sorting task was to again sort the cards from more sustainable to less sustainable (the same as the first individual task). This time the group had already considered various factors that may affect an object's sustainability and now, as a group, they had to discuss where the objects were to be placed. The task was introduced as a complex problem:

Researcher: This is a hard thing to do. We have already established that it is very complicated to decide if something is sustainable or not. We have looked at lots of factors [gesturing to the individual tables with the photographs still laid out] and all probably have different orders. So, for you all to come to an agreement is going to be quite hard.

It was expected that the group-sorting task would take longer than each of the individual tasks. The group session lasted for about half an hour, compared to a time of about five minutes that each student had taken over the first sorting task.

7.3 Narrative report

Stage eight of Esterberg's (2002) stages of participant observation suggests "writing up the notes in a narrative" (p. 60). This section describes the data collection activities as a narrative, telling the story of the day. It is written from the viewpoint of the researcher (the observer) and it is included here to provide details about the activities that may not become apparent from a thematic analysis of the verbal interactions..

The entire session lasts for one hour and fourteen minutes and takes place in an unused classroom above the usually quiet school library.

7.3.1 The students arrive

I arrive at the school and am taken to a room above the school library. The room is used on an ad hoc basis for class discussions and for professional development. Today there are a number of tables scattered around the room, with three or four stools around each table. I spend the first ten minutes rearranging the furniture. I decide to leave the tables where they are but remove all but one of the stools from each of the five tables. These will be the tables for the individual activities. While I am setting up, the first participant, Peter, arrives. He tells me that the participants are not all in the same class, so the others are being rounded up from different parts of the school. We chat briefly and he helps me with the setup of the room. He remembers that, on other occasions, he has had to wear a voice recorder and goes about turning one on and attaching the microphone to his shirt. Once his recorder is working he continues turning on the other four recorders, ready for the other students, and reminds me to turn on mine. John is the next student to arrive and immediately clips on his recorder and microphone. The three of us chat about school and how they are enjoying their new classes. Several members of school staff wander into the room and interrupt us. Perhaps they are looking for a room in which to have a meeting and do not realise that there is a data collection activity taking place or perhaps they are curious to see what is going on. A quick chat explaining the forthcoming activities appears to satisfy them and they leave. We are still waiting for three more students, so we talk about current school assignments but steer clear of any talk about science related subjects or sustainability.

After seven minutes, Lucy and Susan arrive together (four here, one to come).

“Thank you for coming over.”

“Hello, we are so excited.”

They do indeed appear excited to have been removed from their regular classes and to be here to take part in the data collection activity. No one knows where the missing student is; none of them are in her class for this lesson, so we wait. Lucy and Susan get their microphones and recorders attached and we talk about the recordings:

“It might be embarrassing if we didn’t know it was recording.”

“I always tell people, but some people forget. Remember the only person who ever listens to it is me and anything you talk about that isn’t to do with what I am interested in, I just delete.”

A teacher comes in to let us know that the fifth student is absent today; she will not be taking part in the activity. Only four of the original six are present, two boys and two girls.

“I have a few tasks for you to do today; the first ones are going to be done on your own.”

They each pick a table to work at. The tables are far enough away so that the students cannot easily see what other students are doing, but not so far away that they cannot ask each other questions.

7.3.2 Working alone

I place a set of the thirteen photographs in front of each of the four students.

“I recognise these.”

“Yes, we looked at them before.”

“But, they were on your iPad.”

I explain the activity and give them each their first instruction card. The first activity is to sort the photographs from ‘more sustainable’ to ‘less sustainable’.

“You’ve got a card in front of you with your name on the top, check that you’ve got the right name.”

“Oh wow.”

“It also has an arrow that goes from more sustainable to less sustainable.”

We now chat about what ‘sustainable’ means. The students are hesitant at first. It has been many weeks since we talked about this. There is talk about recycling, about eco-friendliness, and about bio-degradability. In the end they talk about future generations and, like a wave, it all comes back to them. There is chat about the Earth’s resources and about ensuring future generations are not compromised. I explain about sorting the photographs and laying them out on the table and that, once they have completed the task, I will photograph their layouts. They start and they ask each other questions.

“This one, is it the chips or the packaging?”

“It’s the chips *in* the packets.”

“Is it foam or paper?”

“The cup is made of polystyrene foam with a plastic lid.”

“People just throw their computers away, that’s not even cool.”

“Is this like synthetic paper?”

“It is toilet paper, it’s run of the mill toilet paper.”

“Is this some kind of special bike?”

“It looks like a normal bike.”

Although the students are chatting it does not appear that they are influencing each other’s decisions about the order of the objects.

John and Peter finish the sorting task first and I photograph their layouts. Susan is the next to complete the task and Lucy cries “Wait, I’m not finished”. I tell her to take her time. She asks a question “Is it *this* pencil or pencils that have been used?” to which I reply “It’s the pencils that you see in the picture” and one of the other students chips in “It’s pencils in general”. After about five minutes on the task, all students have finished and I photograph the remaining layouts.

I hand out the second task and explain that they will need to resort the cards.

“Can we mix them all up again?”

“Yes.”

This time the students are required to sort the cards according to how long the item is used for in the form that it is currently in.

“Some things you might recycle and use for a different purpose; we are thinking about it in the form that it is in at the moment.”

“But, a paper cup could be used for a very long time if it is recycled.”

“But, then it would be in a different form. If it is recycled, it would be squashed and chopped up and turned into something else.”

“Then it’s not being used in the same form. But, if it is washed out and used again then it is being used in the same form. That’s OK.”

The students get down to the sorting task once more. There is again more chat about the objects and about the task.

“Buses are used for a long time.”

“What sort of toy is this?”

“Is it how long it is used for or how long it could be used for?”

“It’s how long it *is* used for.”

I ask them to remember to keep thinking about whether it is being used for the same purpose. Lucy has been sitting staring at the photographs and then shouts out:

“Oh, it’s not how long it lasts, it’s how long it’s used for”

This task again takes the students about five minutes to complete. As the students complete the task, I photograph their resulting layouts. They stack up the photographs ready for the third task, which I hand out. This card has arrows pointing between ‘better for RRR’ and ‘worse for RRR’.

“Do you all know what I mean by RRR? Who can tell me?”

A chorus of “reduce”, “reuse”, and “recycle” is shouted out. There is little doubt that they all know what the Rs stand for. I want to check that we all have a common understanding of the three words.

“Reduce is reducing the amount of stuff we use. Reuse would be reusing the item for another purpose. For example, if you use a paper cup and instead of throwing it in the bin you use it as a plant pot, that would be reusing it. And, recycling is turning it into something else.”

They start the task but Peter is concerned about combining the three Rs:

“But, is it ‘reduce, ‘reuse’, or ‘recycle’?”

“It is all three together.”

“But, they do different things.”

“If you can’t do it for all three, then choose one and tell me which one you have chosen.”

He is happy with this and continues to sort the photographs. The students continue to chat about the task; the talk is now more directed at the sorting task rather than the

objects in the photographs. They talk about what can and cannot be recycled and about recycling stations in shops. The discussions, taking place about RRR, appear to be helping the students come to their decisions about where to place the photographs, but do not appear to be ‘telling’ them where to place them. It is as if the discussions are helping the students to think through what they personally think about the issues before them. A discussion takes place about the pencils:

“You can’t reduce it, you either use it or you don’t.”

“When you sharpen it, you could sharpen it until it is just sharp or you could keep going, sharpening and sharpening and waste lots of the pencil”

“That’s what my sister does.”

Another discussion ensues about old aeroplanes:

“What do you do with old aeroplanes?”

“Jeremy Clarkson [a television presenter] has one in his garden.”

“Some people put old train carriages in their gardens.”

The discussions are quite wide ranging; one of the students is considering the photograph of the birthday candles and discusses the reuse of candle wax after the candle has burned. I remind the students of the original experiment we did at the start of the sustainability course unit, that used a candle, and the wax ‘disappeared’; it was not available for reuse.

“Oh yes, the wax went away.”

This leads on to further discussions about growing potatoes and photosynthesis.

Peter is the first to finish; while I am photographing his layout, I pick up on his earlier concern about integrating all three Rs.

“Did you do RRR or just one of them?”

“Oh, I did all of them”.

Susan is the last to finish this time; she appears to be having difficulty making final decisions and the other students encourage her. They do this without presenting advice on where she should place the photographs.

“Make a decision and stick to it.”

“I don’t know.”

“Now take your hands away and don’t touch it again.”

“But I know that it might not be the same as others.”

She stops and we all move on to the next task. One of the students expresses satisfaction with the tasks:

“I like the sorting tasks.”

But another replies:

“I’m not good at them.”

To which she responds:

“But, there’s no right way.”

It appears as if one of the pleasures found in the tasks emanates from the fact that there is not a right or wrong answer; the students are free to express themselves however they wish.

The penultimate individual sorting task is about eco-friendliness. The instruction card has arrows pointing between ‘more eco-friendly’ and ‘less-ecofriendly’. The conversation switches now and becomes much more about the details of the objects

represented in the photographs. The students want to know what the items are made of.

“Candles are not very eco-friendly are they?”

“They could be made from bees’ wax.”

“The pencils could be made from recycled wood”

To give some clarification, as questions are raised, I provide details about the items.

“The pencils are not made from recycled material, but the wood does come from sustainable forests.”

“The candles are made from paraffin wax which comes from oil.”

The students continue to discuss the objects.

“Coffee cups are not eco-friendly”

“[pointing to the eco-cup] This one is.”

This task has also taken about five minutes; the students are making their final decisions on where to place the photographs.

“Oh, I don’t know.”

“Remember that there is not a right or wrong answer.”

They have finished and all layouts are photographed again.

It is time for the final individual sorting task. This one is about the Earth’s resources and the effect the objects have on those resources. The students are getting the hang of it now. They start as soon as I hand out the instruction cards. We discuss what is meant by ‘the Earth’s resources’ and the students are moving the photographs round while the discussion is taking place. By the time the discussion is concluded, some of

the students are well on their way to finishing the sorting task; Peter finishes 90 seconds later. "I'm done." He says.

"Really?" says another student, "What is wrong with you?"

His layout is photographed and I ask him which task he found the easiest:

"This one, the last one was the hardest."

The other students continue to work and Peter joins in some of the discussions.

"Is aluminium made from oil?"

"No, it's a metal."

"We dig it up."

"It's an Earth's resource."

The students have all finished the final task and their layouts are photographed. They wander round the room looking at each other's layouts, chatting about the different orders. There is still a buzz of interest in the air. I had been fearful that, after five sorting tasks, the students' enthusiasm for the activity might be waning; however, they all appear keen to continue with the next activity.

7.3.3 Working as a group

We sit round a different table, in the middle of the room, leaving their individual tables still laid out with their final sorting task. I start this part of the activity by explaining how I devised the sorting tasks. I explain that I had listened to all the interviews, that I conducted with them, and typed up every word that they said. I have read and reread their words and found that generally, when they talk about sustainability, they talk about how long things last, how eco-friendly the objects are, about the three Rs, and about the effect the objects have on the Earth's resources.

These categories were used for the sorting tasks. These factors are all linked in many ways to sustainability.

I place a fresh set of the thirteen photographs on the table in front of the students and tell them that they have one final sorting task to complete but this time they will be completing it together. An instruction card is also placed on the table. This time the name at the top says 'Together' and the arrows point between 'more sustainable' and 'less sustainable'.

"I want to know how you as a group are going to decide which are more sustainable and which are less sustainable."

The students' first idea is to choose one item and put that in the middle and then to select another item. Peter quickly dismisses this idea; he wants to gather up all the 'sustainable' objects first. Before he can start, he seizes the photograph of the aeroplane and says:

"This is very unsustainable, do you guys know how much fuel it uses?"

John wants to start with the least sustainable object. A discussion starts.

"I'd put this one at the bottom."

"Let's just start with one."

"Well, it's not as sustainable as a polystyrene coffee cup or a plastic bag."

"The coffee cup should go here because the plastic bag takes ages to decompose."

"But, the coffee cup, lots of people use them."

"No, there's more material in that one."

"Let's put them quite close because they are quite similar."

“Pencils are sustainable because they are eco-friendly and they come from a replanted forest.”

“There aren’t that many of them.”

“They can be used quite a bit if they are looked after.”

“This one goes here.”

“That one is at least making an effort to be sustainable.”

“Computer – maybe here?”

“But, they use lots of minerals.”

“People recycle them.”

It is clear that each student has different priorities. Each item can be argued one way or the other.

They ask what the toilet paper is made from and I tell them that it is recycled. They laugh at the thought of recycling used toilet paper and agree that it is more likely to be toilet paper made from recycled paper.

Lucy and Peter, who both have strong views, are now dominating the discussion; Susan and John do still interject comments but John is now sitting at the edge of the group and beginning to look less interested. The discussion moves on to the plastic toy. John, having not taken much part in the discussions, has clearly been listening and immediately voices his opinion.

“It should be quite high up. Come on, when you pass it down to a little kid, they are never going to give it up, are they. When they are older they are going to pass it on to another little kid.”

John appears to be quite passionate about this and tries to get the toy car moved up the sustainability layout. He is somewhat successful but only gets it just over half way towards being sustainable. He gives up and continues to sit and listen to the others.

Just as I think they are all coming to a consensus, the discussion starts up again. One of them says, “we are going to end up changing them all”, and they chat some more about a final order. Finally, they are content to show me their combined layout. I get the feeling that Lucy and Peter are in general agreement; Susan is not too sure, but happy to go along with the solution, and John is still saying that he disagrees with some of the placements and wants to move some of the images. I photograph this version of their combined solution and ask them some questions about their decisions.

“You’ve put this [the eco-coffee cup] up at the top as the most sustainable. It is a disposable cup. People who want coffee use this and throw it away rather than using a cup that they can wash up and use again.”

The students attempt to justify their decision.

“But, it doesn’t use any petroleum.”

“It’s recyclable.”

“It says that it is 100% sustainable, I mean compostable.”

I ask them about the manufacturing process and about how it got from the factory to the coffee shop. They discuss whether they are still happy with the order of the other objects.

“I wouldn’t have put the bus so high up.”

The discussion focuses on thinking about each object as a whole, not just the object’s raw materials. They consider questions such as “how was it made?” and “did it need to be transported?” and “what happens to it after it has been used?”.

I ask the students to check that they are happy with the current order of the objects by asking:

“Let’s start at the top, are you all happy that this one [the eco-cup] is at the top?”

“Yes”

“One yes, anyone else?”

“No.”

“No, why ‘no’?”

“Because, to tell the truth, people don’t reuse it much. They use it and then they chuck it out. I mean, yes, it is compostable but it could turn into litter.”

The conversation starts again and the students continue to discuss where things should go. Lucy’s comment has triggered more talk, which brings the two coffee cups together.

“These are quite similar, they are different, but they are still quite similar.”

John is still canvassing to get the toy car moved up the sustainability rankings; he says that the toy car should go higher than the eco-cup and justifies this by saying:

“It is so reusable. Every kid who gets a toy car passes them on to someone else, like a little cousin.”

This is rebuffed with:

“Not everyone has someone to pass them down to, some just get thrown away.”

The discussion starts up again, and moves on to the relative merits of toilet paper and buses.

It is at this point that there is a sudden breakthrough in the conversations. Up to this point, there have been lots of opinions about individual objects, but very little to do with how any classification could take place. While the conversation has been continuing, Lucy has been quietly looking at the photographs and then makes a suggestion:

“What we could do is we could kind of make them, like maybe have three columns; one that is the worst version, one the kind of alright version and one that is the best version.”

This idea has an immediate effect of changing the activity from a linear (one dimensional) task where each item has to be ranked against the others, to a grid (two dimensional) task where each object is judged on its own merits against other, similar objects that may or not be represented in the photographs. Lucy’s three columns emerge on the table. On the left are items that the students consider the ‘best’ version of the object. The middle column contains items that are ‘alright’ versions of the object. The right column contains items that are the worst version of the object. The discussion now focuses on individual objects and the students’ opinions on whether they are the best, the alright, or the worst versions of the objects. This leads to the replacement of all the objects. The students now have a much more specific and constructive discussion about each of the photographs; whether better or worse versions of each of the objects exists and if so, what they are. For example, they discuss the coffee cups; looking at the eco-cup:

“A better version of this would be the ‘keepcup’ [a reusable takeaway cup]⁹”

“And, a worse version is this disposable coffee cup.”

⁹ <http://www.keepcup.com.au>

They move the eco-cup to the middle column and the disposable coffee cup to the right –hand column, leaving a space in the left-hand column where the ‘keepcup’ would go if they had a photograph of it to place. They do this with all the other photographs. They have photographs of both a bus and a bicycle and come up with ‘Bicycle – Bus – Car’ as the order from best to worst. They place the bicycle on the left and the bus in the middle. In the end, they have three columns containing items that they consider more sustainable, neither sustainable nor unsustainable, and less sustainable. This layout is photographed and we move on to a wrap-up activity.

Before we finish the session I want to get an idea of what factors the students now might consider when trying to assess the sustainability of an object. I ask them:

“Do you think that it is easy to decide how sustainable something is?”

There is a resounding ‘no’.

“No, it depends on so many things.”

“Everything starts from the Earth, gets made and used, and returns to the Earth.”

I introduce my ‘widget’. This is an imaginary object that I have invented and brought along to show them. I carefully mime taking the imaginary ‘widget’ out of my bag and place it on the table in front of the students.

“Here is my widget; it is my new invention.”

There is nothing on the table, but all the students are looking at where I placed the imaginary object.

“Did you make it?”

“What is it?”

I ask them to imagine it.

“What does it do?”

I tell them to use their imaginations.

“Here it is, now you have to decide whether this new widget is sustainable or not”

Peter immediately asks:

“First question, what is a widget?”

“It is here. Look, there it is, imagine that you are looking at it.”

Lucy responds:

“It’s just an invention.”

I carry on.

“What questions do you need to ask to find out whether this widget is sustainable or not?”

All four students start calling out questions at the same time.

“How is it made?”

“What is it made of?”

“How did it get to the state that it is in today?”

“What is its purpose?”

“How did they get the materials to make it?”

“How did it get here?”

“Does it use electricity?”

“Is it mass produced?”

“How long is it used for?”

“Can it be recycled?”

Once the students have exhausted their suggestions of questions, I ask them to assume that I have been able to answer all of their questions.

“How would you tell if the widget is sustainable?”

They talk about each of the questions and conclude that the answers to the individual questions point towards ‘sustainability’ or ‘unsustainability’ but they are unable to suggest any method of grouping all the factors together.

“I don’t think anything is either sustainable or unsustainable, it is...”

“...more sustainable or less sustainable.”

“Something could be more sustainable than something else.”

The students conclude that the only decision they can make is ‘a comparison between two objects about one factor’ and that they are unable to give any particular object a ‘sustainability score’. I photograph the layout of the three columns and thank all the students for taking part.

7.4 Results

The students performed five individual sorting tasks and one sorting task as a group. These two sessions are reported separately. The first section looks at the variation in the students’ decision making when faced with the individual task. The second section reports on the results of the group task and investigates the way the task changed as the students progressed through the activity.

7.4.1 The individual tasks

Each student was asked to sort the photographs of thirteen everyday objects according to five criteria. The criteria had been chosen as they corresponded to the categories formed from the previous analysis of the students’ interviews about the sustainability

of the same thirteen objects. The expectation is that the students' five layouts will all differ as each student has their own interpretation of sustainability. However, it may be expected that there would be some correlation between some of the factors, as these factors were defined by the students as being the ones they use when considering 'sustainability'. To help understand the differences both within the individual student's layouts and between students' layouts, each object was given a score (from 1 to 13) depending on where the student placed the object in the sorting task. For example, Peter's first activity (see Figure 7.2) placed the candles on the far right, these would be given a score of 1, and he placed the eco-cup on the far left giving it a score of 13. These scores were used to investigate the correlation between students' final solutions in each of the sorting tasks.

Four students sorted and ranked thirteen photographs five times, producing 260 data points to be analysed. To make sense of these data points, Kendall's (1955) 'Rank Correlation' was used. This rank correlation assesses the rank each individual has given to the objects and calculates the likelihood of the students' ranking going in the same direction (concordant) versus the likelihood of the ranking going in opposite directions (discordant). This method of correlation produces a value of τ (tau)¹⁰ representing the correlation (Abdi, 2007). A τ -value of zero would indicate no correlation between the students' solutions, a high positive value (close to 1) would indicate strong concordance and a high negative value (close to -1) would indicate a strong discordance between the solutions. Students who provide matching ranks would score a τ -value of 1 and students whose rankings are directly opposite (for

¹⁰ This nonparametric measure is used to provide an understanding of the level of correlation between the ranked responses from the students. It is not implying that these results are generalizable to a larger population. It is used as solely as an arithmetic measure to provide a sense of how closely a pair of rankings correlate.

example, 1,2,3,4,5 vs. 5,4,3,2,1) would score a τ -value of -1. The τ -values for each of the student pairings have been calculated for each of the five sorting tasks (Table 7.1). τ -values of 0.3 and above, representing some level of correlation, have been highlighted; those with τ -values of 0.5 and above, representing a higher level of correlation, have been shaded darker (τ -values are given to one decimal place).

Table 7.1 τ -values for student pairings

| | John Lucy | John Peter | John Susan | Lucy Peter | Lucy Susan | Peter Susan |
|--------------------------|--------------|---------------|---------------|---------------|---------------|----------------|
| Task 1 Sustainability | 0 | 0 | 0 | 0 | 0.5 | 0.5 |
| Task 2 Longevity | 0.7 | 0.7 | 0.7 | 0.6 | 0.7 | 0.5 |
| Task 3 RRR | 0.3 | -0.3 | 0 | 0.2 | 0.2 | 0 |
| Task 4 Eco-friendly | 0.5 | 0.5 | 0.7 | 0.1 | 0.6 | 0.3 |
| Task 5 Resources | 0.4 | 0.4 | 0.6 | 0.5 | 0.4 | 0.2 |

It appears that students' solutions have strong correlation when the students are thinking about longevity and there is a noticeable correlation between some of the pairs of students' solutions when considering eco-friendliness and the impact on the Earth's resources. There is, however very little correlation between the solutions when the students are considering the three Rs or any consistency in the correlation

when considering sustainability as a whole. The students' solutions do become more consistently correlated when they are asked to consider the impact the objects have on the Earth's resources rather than when asked to rank the objects' sustainability.

It is, perhaps, not surprising that there is limited correlation between different students' solutions as each student brings to the tasks different prior knowledge and different sets of ethical priorities. Similar τ -values were calculated to investigate the correlation, if any, for each student between overall 'sustainability' and the other factors (Table 7.2). Again, τ -values of 0.3 and above have been highlighted; τ -values of 0.5 and above have been shaded darker (τ -values are given to one decimal place).

Table 7.2 τ -values for individual students

| | Sustainability Longevity | Sustainability RRR | Sustainability Eco-friendliness | Sustainability Resources |
|-------|-----------------------------|-----------------------|------------------------------------|-----------------------------|
| John | 0.2 | 0.3 | 0.3 | 0 |
| Lucy | 0 | 0.3 | 0.4 | 0.4 |
| Peter | -0.4 | 0.8 | 0.6 | 0.8 |
| Susan | -0.5 | 0.6 | 0.4 | 0.3 |

Peter shows strong correlation between his understanding of sustainability and three of the factors identified in the earlier interviews. John shows the least correlation, in the group, between sustainability and any of the factors. None of the students showed any correlation between their ideas of longevity and sustainability.

7.4.2 The group task

A significant moment in the group task was when the students changed the activity from a one-dimensional, linear task into a two-dimensional grid task and formed their ‘best’, ‘alright’, and ‘worst’ categories. However, before this event, the students were able to come to an agreement on the joint linear sorting task. This was an identical task to the first ‘sustainability’ sorting task that they performed as individuals. To compare the two tasks, Kendall's (1955) ‘Rank Correlation’ was again used. This time, the results of each of the individual sorting activities, for each of the students, were paired with the results from the group task and τ -values calculated to determine correlation between these pairs (Table 7.3). Again, τ -values of 0.3 and above have been highlighted; τ -values of 0.5 and above have been shaded darker (τ -values are given to one decimal place).

Table 7.3 τ -values for comparing individual tasks with the group task

| | Group Sustainability paired with Individual Sustainability | Group Sustainability paired with Individual Longevity | Group Sustainability paired with Individual RRR | Group Sustainability paired with Individual Eco-friendliness | Group Sustainability paired with Individual Resources |
|-------|--|---|---|--|---|
| John | 0.3 | 0 | 0 | 0.8 | 0 |
| Lucy | 0.4 | -0.2 | 0.5 | 0.7 | 0.5 |
| Peter | 0.4 | 0.1 | 0.3 | 0.4 | 0.3 |
| Susan | 0.4 | -0.2 | 0.5 | 0.7 | -0.2 |

Strong correlation can be seen when comparing the group-sorting task with each of the students’ individual sorting of the objects in relation to their eco-friendliness.

During this group-sorting task, the students encountered a problem with the activity. They were unable to come to a conclusion that was acceptable to all members of the group. Ill-structured problems are problems that may have many solutions and, as such, it may become hard to determine when a solution has been reached (Churchman, 1971). In this case, sorting the photographs into a ranked 'sustainability' order was, for these students, an ill-structured problem; the task had many solutions and it became difficult for the students to know when, if at all, they had reached a solution. The students' first attempt at coming to a solution was to continue to move the images around and to discuss where they should go. This was an unsatisfactory method as: 1) when the students were asked to justify their solution, they immediately began to change the solution, and 2) at least one member of the group was, vocally, unhappy with the proposed solution. It became clear to the students, particularly to Lucy, that this ill-structured problem was not going to be solved by continuing to perform the task in the set manner. Lucy changed the task; instead of attempting to find a linear solution, she abandoned the task and invented a new way to solve the initial problem. Although the students had not been explicitly told that they needed to produce a linear solution, the instruction sheet (with its arrows), along with the previous tasks had made a linear solution the de facto method to solve the problem. Once Lucy had expressed the view that there could be an alternative method of solving the problem, the students were more constructive in their collaboration and quickly arrived at a solution that everyone was happy with (see Figure 7.3).



Figure 7.3 The final group solution

7.5 Discussion

The tasks reported on in this chapter were significantly different from the interviews reported on in Chapter 6. Both activities used photographs of the same thirteen objects and both activities asked the students to think about the sustainability of the objects. However, in this activity, students were given the freedom to manipulate the objects and asked to provide comparisons between the objects.

7.5.1 Longevity correlation

Comparing how the students ranked the objects according to the five different criteria (Table 7.1), there was good correlation between all of the student pairs when they were asked to consider how long an item lasts. Although none of the pairs agreed completely, the τ -values show that generally there is agreement in the rankings; that

is, in general, the students' rankings tended to go in the same direction. This is not surprising as, when faced with making a decision on how long something lasts there is less subjectivity than when considering an item's sustainability.

7.5.2 The relationship between sustainability and longevity

Chapter 6 showed significant weight, when determining sustainability, being placed on the longevity of an object. In contrast to the findings of Chapter 6, when the students were asked to manipulate and compare the objects, there was no correlation between longevity and sustainability. In fact two of the four students produced negative τ -values for this correlation, showing an indirect correlation between length of life and sustainability. On the face of it, this result is somewhat surprising. When asked about sustainability in an interview situation, longevity is of significant importance, but when asked to sort photographs, it appears that longevity is of little to no importance as a factor in assessing sustainability.

While the underlying task given to the students remained unchanged, the context had changed. In the 'interview' context, the students were asked to provide an immediate response and when providing the response they were given neither an opportunity to reflect on that response nor time to justify their response. However, in the 'sorting' context, the nature of the task not only provided an opportunity to justify the response, it forced the student to deliberate on where to place the image and thereby internally justify the response. The immediate, unchallenged response included the longevity of the object; however, when students were put in the position of having to justify their responses the longevity factor became of lesser importance.

It should be noted that these results are based on observations of four students and, as such, the findings are not presented, with confidence, as being applicable to the general population; they are presented here to help inform pedagogical decisions.

7.5.3 Individual student differences

With 260 separate data points, it is perhaps surprising that there was as much correlation as was found, shown in Table 7.1. Even if the longevity row is discounted, as this is a much more objective (a less ill-structured) issue, there is still significant correlation between pairs of students in both the levels of eco-friendliness and the effect on the Earth's resources. In contrast to this, the pairs correlate badly when considering the three Rs. When all the factors are combined and the students are asked to assess an object's 'sustainability' there is very little correlation between the student pairs. This may be due to the fact that the students could be placing a high significance on their assessment of the three Rs when considering sustainability, and this affects the overall correlation.

These conclusions are reinforced by the analysis of how well individual students correlated their factors with their overall sustainability assessment (Table 7.2). None of the students has any correlation between their ideas of longevity and overall sustainability. All students had some significant level of correlation between their ideas about the three Rs and overall sustainability; with two out of the four students showing high correlations. Students appear to differ on their opinion of the three Rs, but then use this opinion in assessing the 'sustainability' of an object.

Table 7.2 shows almost completely consistent correlations between the factors and sustainability for all students. There are two exceptions to this: 1) the longevity factor which appears to be completely uncorrelated with sustainability for any of the students, and 2) John's lack of correlation between the effect the object has on the Earth's resources and overall sustainability. This anomaly cannot be put down to the misunderstanding that John simply placed the images in the reverse order (from higher effect to lower effect) as this would have produced a negative τ -value; a τ -value of zero shows no correlation in either direction. It appears that John showed no link between an object's sustainability and the effect the object has on the Earth's resources. It may be thought that John only considered the effect the *use* of the object has on the Earth's resources rather than an overall effect; in which case his ranking would have been unlikely to correlate with his sustainability rankings. However, when considering student pairs, John's "effects on the Earth's resources" correlate reasonably well with all of the other three students' rankings (see Table 7.1). It is, therefore, assumed that John is using other factors when considering 'sustainability'.

7.5.4 The group task

Looking at the results of the group task, it can again be seen that there is no correlation between the individual students' assessments of longevity and the combined assessment of sustainability. Once longevity has been removed, both Lucy and Peter show good correlation between their individual assessments and the group's ranking. By the end of the first phase of the group task, both Peter and Lucy had taken control, with Susan listening and contributing occasionally and John sitting at the edge of the group, somewhat dissatisfied with the outcome. This is reflected in the

correlations; Lucy and Peter show correlations on all four factors, Susan shows correlations on three factors, and John shows correlations on two factors.

Once the longevity factor is removed, as this has been shown to be of little interest to any of the students when assessing sustainability, there are ‘reasonable to good’ correlations (τ -values > 0.3) for most factors for most of the students (see Table 7.3). It appears that, by working together and asking each other to justify their decisions, the students have been able to come to a compromise solution that satisfies most of their earlier individual ideas.

7.5.5 Reframing the problem

All students initially framed the problem in the same way; that is to produce a linear solution from high to low for each of the tasks. This was not surprising as the instructions, both verbally and on the cards, suggested this framing. For the most part, the initial framing of the problem functioned satisfactorily; the students were able individually to come to a solution with which they were content. This framing of the problem began to break down when the activity became a group task. The students started to approach the group task using their original framing and they made good progress towards finding a solution to the ill-structured problem. During the first phase, the students constantly asked each other to justify their decisions. These justifications appeared to produce changes to both the way the individuals were thinking and to the overall group layout of the photographs.

Once the students had come to what they believed was a satisfactory solution, they were challenged to justify their solution. It was during this challenge that the students,

led by Lucy, went through a reframing process. That is, they began to look at the problem differently. Rather than seeing the problem as a linear, straight comparison between objects, they reframed the task and began to think about each individual object, not in relation to the other objects represented but in relation to other objects that they knew existed outside of the photographs. This gave the students a new frame of reference for their comparisons. No longer were they trying to compare the relative sustainability scores of, for example, an aeroplane and some birthday candles. The reframing enabled the students to relate the sustainability of similar objects, used for similar tasks. For example, comparing the sustainability of going to the shops on a bicycle, in a car, or on a bus.

This reframing changed the task, changed the process, and changed the solution. In doing this, the final solution was very different from the anticipated linear ranking. However, the final layout still provided a solution to the original ill-structured problem. The students had not only provided a solution with which they were all happy, the process had also allowed them to conclude that providing an overall sustainability score was not possible; they were only able to make comparisons between objects based on single factors. For example, a 100% compostable disposable coffee cup is more sustainable than a plastic cup when considering the raw materials, but it may not be when considering the manufacturing and transportation processes.

7.6 Summary

This data collection activity had two distinct phases, the individual tasks and the group task. During the individual tasks, the physical manipulation of the photographs representing the objects under consideration appeared to change the students' views about sustainability. Whereas, in the interviews, students had shown links between longevity and sustainability, in the sorting context, those links disappeared. The activity of having to place the objects in a ranked order in some way asked the students (internally) to justify their positioning of the objects. This justification process appeared to lead to a more considered assessment of an object's sustainability.

The group task again provided multiple opportunities for students to be challenged on their solutions. The students themselves, by manipulating the images, were being challenged to consider where to place the objects. Other students were initiating, and responding to, discussions about the positions of the objects, and the researcher openly challenged the students about their combined solution. These challenges to justify their ideas appeared to prompt the students to reconsider interim solutions and to progress, looking for other possible solutions to these ill-structured problems.

The final challenge for the students was when one of the group, Lucy, reframed the problem, leading to a different method of solving the problem and hence a different solution. Once Lucy had articulated her reframing of the problem, all the students were able to collaborate more effectively and quickly arrived at an acceptable consensus of opinion.

Chapter 8 Activation, epistemic challenges and enquiry science pedagogy

This chapter starts with a look at the empirical evidence and relates the findings to the initial research questions. The findings are compared to existing pedagogical practices and current theoretical thinking, to gain an understanding of the processes these participants undertook during the data collection activities. It is hoped that gaining more nuanced insights, into the learning processes that students undertake when considering ill-structured socio-scientific problems, may lead to more effective pedagogical practices.

8.1 Empirical findings

This thesis reports on observations of, interviews with, and set tasks given to, a number of year-six primary school students. The findings have been categorised into three sections that cover changes in ‘problem context’, changes in ‘knowledge context’, and changes in the ‘physical context’ that affect how students frame and re-frame problems as they seek solutions. The findings from the empirical chapters are summarised in this section.

8.1.1 The problem context

Sixteen students were interviewed to gain an understanding of their thinking processes when attempting to solve two socio-scientific problems. These two problems both required the use of knowledge of the law of conservation of mass along with the student’s own understanding of the Earth as a closed system - that is, to understand that everything that we have on the Earth, and everything we make, comes

from the Earth. The students were asked to consider the effect that the increasing population has on the mass of the planet. Students were also asked to consider the effect of the increasing amount of 'stuff' on the planet. This 'stuff' was described as the extra material items that the increasing population requires such as houses, shops, roads, cars, and mobile phones.

In general, the students began the interviews articulating that the increase in the population was increasing the mass of the planet; this was despite acknowledging that the planet was a closed system. The majority of students also articulated the view that the mass of the planet was increasing due to the extra 'stuff' that all the extra people needed. However, after reflection on the previous experiments (that the students had observed) the situation changed. Most students then 'saw' that the planet was a closed system and that all the extra 'stuff' came from the planet and therefore did not change the mass of the planet. Despite acknowledging the fact that the planet was a closed system, the majority of students held on to the belief that the increasing population does increase the mass of the planet. This goes against their prior knowledge that the Earth is a closed system and therefore is unable to change its mass. There is little doubt that most of the students, when challenged to reflect on their prior knowledge, did understand the law of conservation of mass and were able to accurately apply the law to the question of increasing 'stuff'. However, the majority were not able to apply the same law, at the same time, when thinking about the population. It appears that, when thinking about 'people' students were able to dismiss their prior knowledge; some other knowledge (such as 'people are special') overrode their knowledge about the law of conservation of mass.

The combination of two knowledge resources, that appear to be in conflict, is not unique. The ‘people are special’ idea can also be seen in studies of evolution. Evans (2001) showed that beliefs about both animal evolution and creation, while in conflict, could be held simultaneously for different animals; “some participants ... endorsed evolution for nonhuman species while reserving creation for human origins” (p. 242). This observation is reinforced by the ‘did it evolve?’ question (Evans, 2008), where across the age range (from children aged 6 to adults), those who were happy to accept evolution for butterflies, frogs, and mammals were less happy to accept evolution for humans.

It appears that individuals are able to hold conflicting knowledge resources and activate those resources when appropriate, dependent on the context. In the cases investigated, it did not appear to be of concern, or indeed be noticed, if these knowledge resources proved to be contradictory or resulted in a lack of logical robustness. From the data reported in this thesis, in most cases, the knowledge that humans are special ‘trumped’ the law of conservation of mass. The ‘knowledge context’ activated a knowledge resource regardless of internal consistency.

The activation of knowledge resources was further investigated and eight explanatory primitives (e-prims) were defined. Of these eight, one was appropriate for the closed system of the Earth, and three were directly related to ‘people’. One of the e-prims, ‘people are not made from the Earth’ appeared to be particularly ‘sticky’ and tended to override other e-prims. This showed that students were able to hold and use conflicting e-prims as appropriate, without appearing to notice any conflicts.

Students appeared to be using knowledge formed in different circumstances; knowledge about the law of conservation of mass had been formed in a ‘taught’, school context and knowledge about the ‘specialness’ of humans may have been formed from more every-day experiences. In this instance, the students were required to integrate these two knowledge resources and, in many cases, this produced a logical inconsistency. The inconsistency appeared to go unnoticed by the individual students who were content to hold (and activate) both of the conflicting knowledge resources at the same time. Knowledge resources, rather than themselves being either correct or incorrect, are correctly or incorrectly activated; however, the activation of knowledge resources appears to be more complex, as inconsistent knowledge, perhaps formed in different contexts, may be concurrently activated without the logical inconsistency being noticed. Therefore, two or more knowledge resources that may be both appropriate and inappropriate can activate simultaneously.

Despite finding that students were able to activate inappropriate knowledge resources as the problem context varied, the data collection activity did highlight a significant change in students’ thinking after they had been challenged to reflect on prior knowledge. This reflection was, in effect, asking them to justify their statements in light of previous observations. When the students were asked to justify their knowledge their thoughts appeared to progress and, in the case of ‘stuff’ increasing on the planet, prior knowledge was appropriately activated. After reflection and justification, students activated and applied appropriate e-prims.

8.1.2 The knowledge context

Six students were interviewed to gain an understanding of whether students' prior knowledge of the verb 'sustain' compromised, in any way, their thinking about the 'sustainability' of everyday objects. In general, it was found that students talked less about the longevity of an object when the word 'sustainability' was not used. It appears that, by using the word 'sustainability', prior knowledge of the verb 'sustain' is activated and that this may have an influence on students' judgements about the overall sustainability of an object.

Students are being asked to integrate knowledge resources formed in different circumstances; knowledge about 'sustainability' was formally introduced in the 'taught' school environment and knowledge about the verb 'sustain' may have been formed from every-day experiences. The integration of these knowledge resources appears to cause a conflict and, in some cases, the every-day knowledge activated in preference to the 'taught' knowledge.

To gain a deeper understanding of the activation of this prior knowledge, the students could have been asked to justify their belief that the longevity of the object was important. While this would have led to richer data, it would also have compromised the second set of interviews as the students may have then been considering the appropriateness of their longevity comments.

8.1.3 The framing and reframing of a sustainability problem

The third data collection activity involved setting a group of four students a sorting task that was inherently ill-structured. The students first performed five sorting tasks individually and then one sorting task as a group. The main theme of the sorting was to compare everyday objects and to assess the relative sustainability of the objects. In addition to assessing the sustainability of the objects, the students were also asked to rank the objects according to other criteria. These criteria were factors that the students had previously identified as being important when assessing an object's 'sustainability'. The factors were derived from the analysis of the interviews described in Chapter 6 and presented one at a time to the students.

The initial finding was that, despite longevity being raised (in the previous interviews) as being an important factor in the assessment of the sustainability of an object, the students (when asked to sort the objects) appeared to ignore the longevity factor and it took little part in the students' decision-making. The sorting task involved moving photographs of the objects around on a table, providing time and space for students to reflect on their decisions. The students would place an object and then reflect on the reasons for placing the object in that particular position. After this reflection, the student would either leave the object or move the object to a more appropriate position. The students were going through an iterative justification process that was not present in the interview context. It is, perhaps, this justification process that enabled the students to dismiss the longevity of an object as a major factor in the assessment of sustainability.

While the students each managed to arrive at a solution for each of the sorting tasks, this was not achieved without problems. During the tasks, students vocalised their concern that they were not sure if they had finished or if they had got to an acceptable solution. This is understandable as the nature of the task was ill-structured which, by definition, implies that it has many solutions and would be hard for the students to determine when an acceptable solution has been reached. The problem of finding a final solution was exacerbated when the students were required to work as a group. The multiple solutions meant that students found it hard to accept other solutions proposed by other members of the group and the lack of a definite final solution left the students concerned that there was still work to be done in completing the task.

The group task was transformed after the students were asked to justify their solution. When the researcher asked for the reasons why the students had decided on the various positions of the objects, the students reframed the problem and found a new route to a possible solution. The requests for justification (of the form ‘why did you do it this way?’ and ‘are you happy with the solution?’) appeared to prompt the students to consider other possible ways of solving the problem and this led to a much more satisfactory discussion. The resulting discussion was more collaborative, involved the whole group, and became constructive; students were able to find solutions upon which they all agreed.

It is a limitation of this study that only one group of students was given the group task and therefore, no data exists to compare this group with other, similar groups. Due to this limitation claims cannot be made to the generalizability of these findings;

however, it can be surmised that similar groups in similar situations would be likely to respond, to the requests for justification, in similar ways (Bridges, 2010).

8.2 Epistemic challenges

In each of the empirical findings, students' progress towards final solutions was altered when challenged about their knowledge. In the first 'problem context', students were challenged to think about their solutions in light of the previous experiments. In the second activity, students appeared to activate the idea that longevity was linked to sustainability. However, when the students were given the opportunity to reflect on this link (in the third data collection activity) and their assumptions were challenged, the link between longevity and sustainability disappeared. In the third (group) activity, it was at the moment when students were challenged about their compromise solution that they were able to reframe the task and work towards an effective solution to the ill-structured problem.

Discussions in class, either led by the teacher or taking place between peers, are an established classroom practice and are often thought to lead to some form of cognitive conflict (see Section 2.4.3). This idea is highlighted by Day and Bryce (2011) who suggest that discussions may lead to "a cognitive conflict (disequilibrium) which may result in the pupil's thinking being either modified, in the light of views expressed during the discussion, confirmed or even completely overturned" (p. 1697). The challenges reported here go beyond classroom discussions and are aimed specifically to challenge the students' knowledge and to challenge students to justify their knowledge. The intention is not to provide cognitive conflict to facilitate new (to the

individual) knowledge, but rather to provide opportunities for individuals to activate prior knowledge that is applicable to the current problem under investigation.

Activating appropriate knowledge (problem context) and activating prior knowledge (knowledge context), along with beneficial re-framing of a problem (framing) all appear to come about, and be successful, when students are prompted (by a teacher/facilitator, by each other, or by the task) to justify their thoughts. These moments are here referred to as ‘epistemic challenges’; that is, challenges that relate to the students’ knowledge and the validity of that knowledge.

8.2.1 Problem context epistemic challenges

Reviewing the data collection activity that investigated the effect of varying the ‘problem context’ highlights significant moments when the students were presented with epistemic challenges. These challenges prompted the students to justify their responses and took the form of requests, such as: “explain to me why you said ...”, and questions, such as: “why do you think that?”. At times the challenges were more direct. For example, an excerpt from the interview with Molly:

Researcher: Did the weight of the earth go down because I burned the candle or did it stay the same or did it get more?

Molly: *I don't think it changed.*

Researcher: It didn't change – why not?

Molly: *Because it doesn't weigh enough to make a difference.*

Researcher: Okay, but did it – do you think it made a very, very tiny difference or no difference at all?

Molly: *It might have made like a really tiny difference, but ... I think air¹¹ does weigh something but like very, very little. So it might have made like a small difference.*

In this instance, Molly was asked to clarify her responses and in doing so was challenged to justify her responses. Molly first reported, “I don't think it changed” which can be interpreted as an initial stance of ‘no change’. However she was questioned “why not?”. At this point, her justification is that it does not weigh much. This response is not the same as ‘no change’; it can be interpreted as ‘very little change’. Molly is again asked to clarify this difference and she confirms the ‘very little change’ and justifies it with “I think air does weigh something but like very, very little”.

Providing epistemic challenges to the students, asking questions about their knowledge and about their justification of their knowledge appears to help students to consider multiple possible solutions and to form a solution in which they believe.

8.2.2 Knowledge context epistemic challenges

During the second data collection activity, epistemic challenges were not used. The data collected in these interviews were used to investigate how the use of the word ‘sustainability’ may affect students’ use of their prior knowledge about the verb ‘sustain’. Challenging the students during the interviews could have compromised the integrity of the data collection. Any epistemic challenges along the lines of “why do you think the length of time it lasts is important?” could have prompted the students

¹¹ When Molly refers here to ‘air’, she is referring to the gases released from the combustion of the candle

to attempt to justify their response and consequently have an effect on their ideas about sustainability.

During the third data collection activity, the students revisited the questions that they had responded to in the second data collection activity. However, in this case, the students were asked to manipulate images of the objects. This manipulation provided the students with an opportunity to reflect and make justifications about their ‘sustainability’ decisions, thereby, presenting the students with epistemic challenges. Once again, the epistemic challenges altered the students’ ideas about longevity and sustainability.

8.2.3 Epistemic challenges leading to reframing

The third data collection activity illustrated a change in the students’ method of working when they were presented with an epistemic challenge. Once the students had arrived at a seemingly successful solution to their group-sorting task, they were asked to justify their solution. This epistemic challenge could have had the effect of encouraging the students to change the agreed places of the objects under discussion. For example, the question “why did you put the eco-cup at the top, it is a disposable coffee cup?” could have resulted in the students moving the eco-cup down the ranking. However, this is not what happened. The students first attempted to justify their decision to place the eco-cup at the top of the rankings and then, after discussing more of the objects, reframed the problem. The reframing led to a complete change of tactics, which resulted in a new and more collaborative discussion which culminated in a solution that had the full agreement of the entire group. The epistemic challenges in this instance led to the students reframing the task. It was by looking at

the task differently (from a different perspective), that the students were able to progress.

The progress that the students made with this ill-structured problem is not unlike the process students undertake when working on design problems. Zimring and Craig (2001) put forward the idea that design problems have a “messy solution process” (p. 135) and can incorporate a large database of information. This information, when retrieved, may result in an “idiosyncratic structuring of the problem” (p. 135) and, as information is retrieved, the retrieval may then cause further restructuring of the problem. As designers go about seeking a solution to a design problem, they reflect on the process and evaluate the direction of their current solution. Dong, Kleinsmann, and Deken (2013) explain this thus:

When reflecting, designers question the direction their actions are taking them. Reflections evaluate the activities of the team in relation to the frame in which they are operating, for example ‘being stuck’. (p. 15)

Dong, Kleinsmann, and Deken (2013) continue to explain that at some point in the reflection, one participant may “adopt a different perspective” and this leads to a new frame being constructed. This reframing is seen in the research participants’ activity as they progressed through their group sorting activity. The linear method of seeking a solution had led the participants into the situation of ‘being stuck’. One participant questioned their route to a solution and this led to a new way of ‘seeing’ the problem. Like design problems, students considering ill-structured sustainability problems appear to make progress towards solutions by producing multiple solutions to a problem, being challenged about the possible solutions, and by considering how the individuals have framed the problem.

8.3 Inquiry Science

In Chapter 3 of this thesis, the teaching and learning of science through inquiry was explored (see Section 3.3). A number of features that form part of classroom inquiry were identified (see Keys & Bryan, 2001; Olson & Loucks-Horsley, 2000); these features included ‘communicating and justifying explanations’. The idea that students should be able to justify their explanations is not new. It is, however, now proposed that students’ justifications of their explanations play a more significant role in learning than simply being the final stage of a scientific enquiry process.

Throughout the data collection activities, reported in this thesis, it has been at moments of epistemic challenge, when students have been challenged about their knowledge and asked to justify that knowledge, that progress towards appropriate solutions has been made. The two examples, given in Chapter 3, of inquiry science in the classroom, Productive Failure (Section 3.3.2) and Learning by Design™ (Section 3.3.3), are now looked at in more detail and evidence gathered on those moments in the inquiry learning when epistemic challenges may be present.

8.3.1 Productive failure

Productive Failure (PF) is the notion that students, who are asked to study ill-structured problems (on which they are predicted to ‘fail’) followed by well-structured problems, will perform better (on subsequent ill-structured problems) than students who are given the same instruction through only well-structured problems. PF has been investigated and successful outcomes have been reported when students were initially presented with tasks that they were unable to successfully complete (see

Kapur & Bielaczyc, 2012; Kapur & Kinzer, 2009; Kapur, 2008; 2011; 2012). While it is clear that the experimental results have shown an increase in learning outcomes when students are presented with an initial ‘failure’ situation, it is not so clear why this effect is happening. Three aspects of PF are discussed to investigate if epistemic challenges may have an impact on the outcomes.

1. Design issues

In PF studies, two groups of students are followed as they undertake a learning episode. The control group (the Direct Instruction group) is provided with well-structured problems that have been created to assist the students in coming to a solution. The experimental group (the Productive Failure group) is first presented with an ill-structured task that has been designed so that the students will ‘fail’ to come to a satisfactory solution. Both groups of students are given similar problems to solve but, perhaps significantly, they are not given the *same* problem. To investigate whether ‘failure’ is, as PF supporters advocate, the key to success, the students could all be given the same initial ill-structured problem, with one group left to ‘fail’ and the other group given direct instruction on how to resolve the problem. This, however, is not done in PF trials. Instead, the control group is given a different initial problem to solve. The experimental (failure) group is provided with an ill-structured problem, which contains certain affordances for the students to engage in ‘design thinking’. It is, perhaps, this design thinking that affects the results, rather than the ‘failure’ per se. If all groups had initially been given an ill-structured problem, it may have been that the direct instruction group also would have engaged in ‘design thinking’. In which

case, all of the groups (regardless of which instruction method was used) may have performed equally well on the final task.

2. *Contrived ill-structured problems*

To create the ill-structured problems, the PF researchers took their well-structured problems (those that were given to the control group) and introduced areas of doubt. For example Kapur and Kinzer (2009) provide both a well-structured problem and an ill-structured problem about the same road traffic accident. In the well-structured version, the coefficient of friction is provided: “the coefficient of friction between the tires and the road was 0.6” (p. 43). In the ill-structured version, this coefficient is provided as a verbal comment from the car mechanic: “You see, the traction also depends on the condition of the road. The coefficient of friction between the car’s tires and the road is usually between 0.6 and 0.7” (p. 43). The type of ill-structured problems that PF uses are also made more ‘ill-structured’ by providing extraneous material, such as blood pressure and heart rate, which are not needed to arrive at a solution (see Kapur, 2008, pp. 420-421). These are not true ill-structured problems; they do not have multiple solutions and it is not hard to know when a solution has been reached. These are, at best, pseudo-ill-structured problems that introduce elements that may require groups to discuss the status of the problem and enter into an iterative process of refinement. This discussion and refinement may provide the students with epistemic challenges; that is, opportunities to challenge and justify their knowledge.

3. *Canonical solutions*

All of the examples provided in the PF empirical studies have canonical solutions. That is, regardless of whether the problems are classified as ‘well-structured’ or ‘ill-structured’, there are known solutions (known to the researchers) to the problems. Kapur (2008) states “the ill-structured problem also allowed for greater learner agency to propose and modify parameters in the problem statement” (p. 388). It is this agency, provided to the experimental group, that may be the significant part of this pedagogical method. It is, perhaps, this agency that creates the possibilities for ‘epistemic challenges’ that the well-structured group was denied.

To further investigate these epistemic challenges, the data coding of one PF experiment is considered. Kapur (2008) presents seven data analysis codes used to gain an understanding of the data. These are:

- PA: Problem Analysis
- PC: Problem Critique
- OO: Orientation
- CD: Criteria Development
- SD: Solution Development
- SE: Solution Evaluation
- NT: Non-Task (pp. 391-392)

The six on-task codes can be grouped into two categories:

1. Design thinking (PA, PC, and CD)
2. Linear solving (SD and SE)

(Note that the remaining code ‘OO’ is part of both design thinking and linear solving.)

The results showed that the groups that engaged in PA, PC, and CD were more successful than the groups that engaged in SD and SE. That is, those that engaged in design thinking were more successful than those that engaged in linear solving. The aspects of the tasks that engaged students in epistemic challenges, inherent in design thinking, were deemed to produce the most successful learning outcomes.

Kapur and Bielaczyc (2012) provide a guide for designing tasks for Productive Failure. This guide suggests that tasks should include idea generation, exploration, and consolidation. These include “affording opportunity for organising and assembling the relevant student-generated RSMs (multiple representations and solution methods)” (p. 49). Students, in PF tasks, are encouraged to consider ‘multiple representations and solutions’. Questions such as, ‘Are there any other ways you can think about this?’, and ‘Are there any other ways to solve this problem?’, which appear to have been provided to the experimental group students, challenge students to justify their knowledge.

PF states that, during the ill-structured initial phase, no specific instructional support was given to the students (Kapur, 2012), however, it is clear that other types of support (epistemic challenges) were provided to these students. Kapur (2010) provided some examples of the non-instructional support given to the students in PF groups; the students were asked to find a (single) solution to a mathematical problem “Can you design an index for consistency?” (7’ 15”). Moments later, Kapur states “we ask them [the students] to generate as many indices as possible” (7’ 27”). By asking the students to generate multiple indices, the students are provided with an initial understanding that there are multiple solutions to this problem and are

‘challenged’ to consider more than one solution. Kapur continues to state that, during the tasks, the researchers asked the students questions such as “What are you doing here?” (8’ 44”), “This is really good, this is how mathematicians would normally start, but we really want a quantified index” (9’ 10”), and “excellent idea, can you quantify it? Can you take it to the next level?” (9’ 35”). Each of these questions, while not providing specific instructional support, provides epistemic challenges to the students for them to enter an iterative process of design thinking.

Epistemic challenges can be seen at work in PF tasks, when students challenge each other. Kapur and Bielaczyc (2012) provide an example in their transcript of their students’ conversations:

HD3 Wait, what do you mean?

HD2 ...No, I don’t think this will work.

HD1 Why not? (p.69)

This verbal interchange arose during a collaborative exercise that prompted the students to challenge each other. Further evidence of epistemic challenges being provided to successful (PF) experimental groups can be observed; Kapur (2011) says that, while no additional support or facilitation was provided to the PF students, these students did receive “affective support for persisting in the problem-solving process” (p.565).

The success of PF may not be entirely tied to the ‘failure’ of the students in their first set of ill-structured tasks. The students who underwent the PF treatment were provided with significant opportunities for ‘design thinking’ and were also given on-going epistemic challenges. These opportunities, created through collaborative work

on ill-structured problems combined with teacher support, were not provided, to the same extent, to the control group. It could be surmised that these epistemic factors had a part to play in the PF success. Kapur (2008) concludes, “it might be fruitful to first investigate *conditions under which* ill-structured problem-solving activities lead to productive failure as opposed to just failure” (p.415, emphasis in original). It may be that the ‘conditions’ are the epistemic challenges that are created by the design and implemented by the instructor. The design of the ill-structured problems brings about conditions where students provide epistemic challenges to each other and the instructor supplements these with additional epistemic challenges when the students are encouraged to keep going and to find multiple representations and solutions.

8.3.2 Learning by Design™

Learning by Design™ (LBD) is a pedagogical method to help students develop scientific reasoning. As students undertake a ‘design activity’, they develop important and desired reasoning skills (Kolodner, Gray, et al., 2003). LBD has many important attributes that encourage scientific reasoning; these are outlined in Kolodner, Camp, et al. (2003) and are summarized here:

- i) LBD asks the teacher to be “both a learner and a facilitator of learning” (p.496). First, the teacher is put in the role of “modeller, coach and articulator of process” (p. 498); this role then diminishes over time as the students take on those responsibilities.

- ii) LBD has three foci:
 - a) to engage all learners
 - b) to help students to learn reasoning skills
 - c) to help students learn both skills and content and to be able to use this knowledge across contexts (p.498).
This is achieved through knowledge abstraction (p. 500); encouraging the encoding of a situation and the ‘labelling’ of relevant features, followed by retrieving appropriately labelled features when required (p 502).
- iii) LBD focuses on the outcome of the design process. It is important that students complete the process, producing a final artefact (pp. 498 & 510).
- iv) LBD refers to ‘failure’ as a prompt to find a solution (p. 502).
- v) LBD uses the notion of ‘rules of thumb’ to extract useful information from the students. These ‘rules’ are then shared amongst the group for implementation in designs (pp. 511-512).

Empirical studies have shown that LBD can be successful in promoting scientific reasoning (Bamberger et al., 2011; Gertzman & Kolodner, 1996; Kolodner, Gray, et al., 2003; Thompson et al., 2013). What is not so clear is how these successes are linked to the LBD pedagogical method. The significant attributes to LBD may be: the

iterative nature of the design task, the collaboration as students approach the task, and the epistemic challenges provided both by the students and the teacher/facilitator. It is, perhaps, not the end product (the artefact) or the achievement of the production of the artefact that is important, rather the opportunity to engage in a process of generating ideas, justifying ideas, testing, and refining that leads to a successful outcome.

The LBD method provides students with a design task and concentrates on the task and the output from that task; it encourages collaboration and, through the designed facilitation, inherently presents students with epistemic challenges. The five attributes (previously listed) of LBD need further consideration:

- i) While the teacher is asked to be a learner, as well as a facilitator, and take on a diminishing role within the learning activity, it appears that the teacher does much more than this. During the design activity, the teacher prompts the student in various ways, providing the ‘epistemic challenges’. While this is not explicitly mentioned in the LBD literature, it can be gleaned from descriptions of activity. LBD suggests “coaches guide student reflection on their problem-solving experiences” and “coaches question students to force them to justify their approach and explain their conclusions” (Kolodner, Camp, et al., 2003, p. 505). This is again evident in the suggested questions that the teacher may like to use such as “How can we give force to a car without using a ramp?” (p. 528) and in the

teacher's reflection on why he asked a student a particular question "He asked that, he says, because he did not understand what they were getting at" (p. 530). Teachers are explicitly instructed to learn with the students; that is, to embark on the learning journey with the students, to become co-learners. This is evident as teachers are asked to respect that the students are "learning partners" and that they should "together figure out what they need to learn more about" (p. 539), and "students and teachers learn together" (p. 541). LBD activities are orchestrated in such a way that the teacher provides epistemic challenges to the students and the students provide them to each other.

- ii) LDB concentrates on knowledge abstraction. Considering this from a 'knowledge in pieces' perspective, rather than abstracting and labeling decontextualized knowledge, students recognize similarities in the contextual elements and activate appropriate knowledge across context. Kolodner, Camp, et al., (2003) provide an example of an architect designing a new office building (p. 501). The example illustrates an iterative design process. The reasoning skills used are empathize, define, and ideate, and also include mental prototyping and testing. These reasoning skills are performed iteratively and, at each stage, the designer 'sees' similarities in context (between the new office and a previously built library and a courthouse).

- iii) LBD is about designing and it focuses on a design outcome. It is, perhaps, the design process itself, rather than the physical outcome that is important. By focusing too heavily on the outcome, LBD appears to have a tendency to revert to a linear model of instruction. While the emphasis is on iterative design, the teacher-led prompting tends to veer toward constricting students' thinking to a canonical solution. While this is understandable when the issue has a specific solution it is not an appropriate method of reaching a solution for socio-scientific issues. This linearization of instruction can be seen by the teacher "pulling out science concepts" (Kolodner, Camp, et al., 2003, p. 508), "opportunity for the teacher to identify student misunderstandings and misconceptions" (p.514), and when the teacher is asked to "help them extract and refine scientific principles" (p.516). By concentrating on design thinking and providing both epistemic challenges, and prompts for student/student epistemic challenges, the students are encouraged to continue on an iterative discovery path rather than being guided towards a canonical solution.
- iv) LBD has 'failure' as a prompt to move students towards more positive outcomes, and it has this in common with 'Productive Failure' (see Section 8.3.1). 'Failure' per se should not necessarily be a focus of 'design thinking' pedagogy. LBD states "it is difficult for students to differentiate between ...

failure that you can learn from and failure” (Kolodner, Camp, et al., 2003, p. 512) and, at the same time, suggests that after failure “the reasoner wants to explain so that he or she can be more successful” (pp. 502-503). This implies that the ‘failure’ was in some part a ‘success’ as the student wants to be more successful. This is, perhaps, an inevitable outcome of a design iteration; building on smaller successes to improve the design the next time round. The students have, in effect, been asked to justify their design and subsequently realize that a further iteration in the process is required. This is not failure - it is success.

- v) The LBD ‘rules of thumb’ are either ‘correct’ or ‘incorrect’. This may work well with issues that have canonical solutions (or for problems where students are given all the resources necessary to arrive at a solution), but it may not be so easy for a teacher to extract ‘rules’ for ill-structured socio-scientific issues. Rules of thumb have a linearizing effect as teachers direct students to desired ‘rules’. This can be seen in the design of LBD tasks (Kolodner, Camp, et al., 2003) when teachers are asked to correct misconceptions (p. 514) and asked to encourage students to extract scientific principles (p. 516).

The design of LBD tasks brings about conditions where students are asked to work collaboratively and provides opportunities for teachers to present epistemic challenges

to the students and for the students to challenge each other. It may be that the positive learning outcomes observed from LBD tasks are linked to the iterative processes of thinking, justifying and implementing; that is, linked to the ‘design thinking’ that the LBD tasks encourage.

8.4 Learning through epistemic challenges

Both Productive Failure (PF) and Learning by Design™ (LBD) appear to provide students with epistemic challenges that prompt design thinking which, in turn, leads to better learning outcomes. These ‘epistemic challenges’ may be playing a significant and, perhaps, previously unrecognized role in both of these pedagogical methods. Asking students to perform a collaborative design task sets them on a pathway that may lead to ‘design thinking’. Asking students to produce a final artifact may not, on its own, achieve ‘design thinking’. Asking students to ‘fail’ when attempting to find a solution to an ill-structured problem, may not lead to success. However, asking them (through challenges) to collaborate and work towards multiple solutions and to iteratively attempt solutions, may lead to ‘design thinking’. Designing a final artifact or going through a ‘failure’ experience may be the results of an effective pedagogical technique. However, these should not be the aims of the technique; the aims should be to engage the students in collaborative design thinking, and to promote the creation of multiple representations and solutions. These aims are achieved through providing epistemic support (through challenges) to the students.

The empirical studies reported in this thesis tend to reinforce the view that epistemic challenges can lead to design thinking. Students were able to activate their prior

knowledge about complex socio-scientific issues and, in many cases, were able to use their prior knowledge in different contexts. Individual tasks resulted in inappropriate prior knowledge being activated. Collaboration, when the activity afforded epistemic challenges, produced appropriate knowledge activation. The final, collaborative group task (see Sections 7.5.4 and 7.5.5) produced a situation where the students were able to challenge each other to justify their responses to the problem; they were able to cycle through possible solutions, and this culminated in the students reframing the problem in order to be able to arrive at an agreed solution.

Chapter 9 Conclusions

This study has illustrated that, in some circumstances, students benefit from being provided with opportunities to justify their knowledge. At numerous points in the activities, students appeared to progress with their thinking at moments when they were presented with epistemic challenges - that is, at those times when they were presented with challenges that related to their knowledge and the validity of that knowledge. The study was based on the premise that, while large numbers of participants may lead to more generalizable findings, classroom based studies (with a manageable number of participants) may prove more useful in terms of advancing pedagogical knowledge. Bassey (1981) states

that an important criterion for judging the merit of a case-study is the extent to which the details are sufficient and appropriate for a teacher working in a similar situation to relate his decision making to that described in the case-study. (p. 85)

It may not now be possible to say, based on the evidence here provided, that epistemic challenges would provide effective results in all socio-scientific learning situations. However, in classroom situations similar to those reported in this study, increasing epistemic challenges may be both appropriate and effective in helping students who are attempting to solve ill-structured problems.

The following six sections outline the conclusions of this study. They start by relating the findings to the research questions and then look in more detail at epistemic challenges, design thinking, and pedagogical implications. The final section

investigates future research and the steps that could be taken to further our knowledge about the effectiveness of these pedagogical techniques in socio-scientific education.

9.1 Problem context

How does the *problem context* affect school students when solving problems about sustainability issues?

It appears that the ‘problem context’ has a significant bearing on how students activate (and therefore use) knowledge when thinking about sustainability issues. In this study, the students were asked to use their knowledge about the law of conservation of mass in two different problem contexts; the problem context changed from considering more ‘stuff’ to considering more ‘people’. As the problem context changed, the students activated different sets of knowledge resources. When considering ‘stuff’ the students were able to appropriately activate the law of conservation of mass, but when considering ‘people’ they inappropriately activated prior knowledge resources that displaced the law of conservation of mass. It is noted that inappropriate activations were observed at moments when students were prompted to integrate knowledge formed in different circumstances. Multiple knowledge resources formed from the formal taught environment appeared to activate either appropriately or inappropriately and one displace the other. However, knowledge formed across different circumstances, such as knowledge from both taught and every-day experiences, also appeared to activate appropriately or inappropriately, but were able to be held simultaneously without displacement.

9.2 Knowledge context

How does an individual's *knowledge context* affect their problem solving abilities when considering sustainability issues?

The 'knowledge context' also affected how students activated knowledge resources. Students were observed activating inappropriate explanatory primitives during data collection interviews. However, the knowledge context also appeared to be affected by the task that the students were set. When set similar problems, first in an interview context and then again as a physical sorting activity, the students activated different knowledge resources. It appeared as if the different modes of activity enabled or disabled the activation of appropriate/inappropriate knowledge resource. It is surmised that, in the interview situation, students activated knowledge resources spontaneously without any requirement to justify those knowledge resources. In the second instance, when the students were required to sort physical objects, the act of placing an object in a ranked order forced the students to justify their knowledge and appeared to change the manner in which the students activated prior knowledge resources. Knowledge resources (e-prims) that were obvious and self-explanatory in the first 'interview' instance (such as 'the longer something lasts, the more sustainable it is') did not activate, to the same extent, in the second 'physical task' instance.

During the data collection activities, students were observed activating appropriate prior knowledge resources immediately after being confronted by challenges that related to their knowledge and the justification of their knowledge.

9.3 Framing

How does the physical context affect the way school students *frame and re-frame* their ideas when solving problems about sustainability issues?

Students made sense of sustainability issues in a variety of ways and the framing process appeared to play a vital role in enabling appropriate sustainability thinking. Parallels have been drawn between designers seeking a solution to a design problem and students seeking a solution to a socio-scientific issue. Both are faced with an ill-structured problem; there are multiple acceptable solutions and it is hard to know when an acceptable solution has been reached. Both may discover solutions that are different from their peers, but those solutions, while being different, may simultaneously be satisfactory. To arrive at a solution, an iterative process is undertaken; making sense of the problem, proposing possible solutions, and testing and refining. These iterations may lead to moments of ‘impasse’ when the original framing is reviewed and challenged. The original problem is then observed from a different perspective; reframing of the problem has occurred. This iterative process continues as students work towards a solution.

In these activities, students approached the tasks in different ways; the collaboration, in the group task, coupled with students being required to justify their knowledge, enabled students to progress with their framing and to move on towards finding a solution.

9.4 Epistemic challenges

It was observed that breakthroughs happened during moments of epistemic challenge. In the first activity, most students activated different knowledge resources after they had been asked to justify their knowledge in light of previous observations. In the second activity, students were deliberately not asked to justify their knowledge; they were not presented with epistemic challenges. However, in the third activity, students were provided with epistemic challenges through the physical, sorting nature of the task. These challenges led to the activation of a different set of knowledge resources. During the third activity, it was at the point of epistemic challenge (provided by the researcher) that the students were able to return to the original problem and reframe the issue; to look at the issue from a different perspective and continue on to a satisfactory solution.

The epistemic challenges observed in this research were formed in three distinct ways:

1. Epistemic challenges created by the researcher.

At various points in the data collection activities, the researcher posed questions and requests to the participants. These questions and requests were of the form, for example, ‘tell me more about that’, ‘why do you say that?’, and ‘can you explain why?’.

These facilitator/instructor led epistemic challenges can also be observed in reports from both the ‘Productive Failure’ (PF) and

‘Learning by Design™’ (LBD) literature. For example, “What are you doing here?” (Kapur, 2010, 8’ 44”) and the instruction that teachers should “question students to force them to justify their approach and explain their conclusions” (Kolodner, Camp, et al., 2003, p. 505).

2. Epistemic challenges created by the students.

The students themselves also created epistemic challenges for each other. This was most evident in the group-sorting task. The students were collaborating and the task itself provided opportunities for the students to question each other’s decisions. Two instances are of particular note: first when John attempts to have the plastic toy moved up the sustainability ranking and second, when the task changed through Lucy’s reframing. During the plastic toy discussion, the students were all challenged to justify their chosen position for the object. Through these challenges, John was partially successful at having the toy moved up the rankings, but not as high as he would have liked. During the reframing of the initial problem, Lucy attempts to justify her decisions to place objects in certain positions. She falters and, during this challenging moment, rethinks the entire problem; she vocalises her new idea and the discussion picks up along new lines. Without the justification challenge, minor adjustments may have been made to their agreed order of the objects, but a satisfactory solution (to the group) may not have been found.

While these student/student epistemic challenges are most visible in the group-sorting task, they can also be observed in the individual tasks as students discussed the various tasks and objects. Students discussed a variety of subjects, from a television presenter's garden ornaments to recycling stations in shops. These discussions appeared to help students think through what they personally felt about the issues, without providing 'instructional' support. The discussions did not 'tell' the students where to place the objects, but rather provided epistemic support, helping the students to make their own decisions.

Student/student epistemic challenges can also be observed in the collaborative nature of PF and LBD tasks. For example, Kapur and Bielaczyc (2012, p.69) provide a transcript of three students collaborating and challenging each other and Kolodner, Camp, et al. (2003) suggest that learners should "together figure out what they need to learn more about" (p. 539).

3. Epistemic challenges created by the activity

It has been observed in this research that the activity itself may provide affordances for epistemic challenges. When students were asked, in an interview situation, to comment on the sustainability of various objects, they appeared to comment without feeling the need to justify any of their responses. No external (researcher led) epistemic challenges were provided. However, when the same students were

asked to complete a similar activity with physical objects that needed sorting, they produced very different responses. It is surmised that the activity itself provided affordances for (internal) epistemic challenges. That is, the students were challenging themselves as to the validity of their decisions as they placed and manipulated each object.

It would be hard, with the evidence provided, to draw conclusions about similar PF and LBD activities. It is known that PF activities (such as the investigation into variance) used physical objects (pens, paper, graphs); LBD activities (such as the ‘vehicles in motion’ design task) also used physical models for the students to manipulate. It may be that these activities also provided affordances for epistemic challenges in a similar way to the activities reported in this study.

Students, when considering socio-scientific issues, and in particular issues about sustainability, appear to benefit from being provided with opportunities to discuss and justify their knowledge. These opportunities can be provided by creating moments of epistemic challenge through instructor led facilitation, student discussions, and through task design.

9.5 Design thinking

Students are currently expected to consider socio-scientific issues in a ‘school science’ way; that is, in a way that leads to a canonical solution. These issues are inherently ill-structured and as such do not lend themselves to canonical methods of reasoning. A ‘design based’ approach, that incorporates iterative design thinking, may

be more effective. It may be beneficial for a sustainability issue to be approached as a design problem rather than as a linear learning process. Students may benefit from a ‘cyclical’ design approach to help make sense of the issues under consideration.

9.6 Pedagogical implications

This thesis has looked at two inquiry pedagogies that are currently suggested to help students learn about ill-structured issues. Both of these teaching methods encourage the use of multiple representations and solutions. Productive Failure promotes an initial ‘failure’ where the students are asked, and encouraged, to explore their ideas and to produce as many possible solutions as they can. It is not expected, at this point, that the students will succeed in discovering a final solution; rather that the creation of multiple representation and solutions will help the students to learn more effectively once they enter a ‘direct instruction’ phase of their learning. Learning by Design™ promotes collaborative design tasks that enable students to iteratively explore different possible solutions and, through instructor led guidance, the students are then encouraged along a pre-determined learning trajectory. These two techniques appear to have the same significant drawback when dealing with socio-scientific issues; they both rely on there being a canonical solution to the problem under consideration. The ‘ill-structuredness’ of their issues comes, not from true ill-structured problems with multiple satisfactory solutions, but from ambiguities in the starting parameters. These ambiguities provide opportunities for students to iteratively create multiple representations and solutions; however, the end result of the learning exercise is a known (to the instructor) outcome. Both PF and LBD have reported positive learning outcomes from these collaborative pedagogies, brought about by students entering ‘design thinking’. These pedagogies do not sit well when students are faced with ill-

structured problems such as those associated with sustainability. Ill-structured problems do not have simple known solutions and different students, with equally valid arguments, may end the learning episode with very different (but equally valid) solutions. There are, in socio-scientific issues, no 'rules of thumb' that can be extracted for all students; there are no canonical solutions to the problems. However, much of the success of both PF and LBD can be seen in the results of this study. When students were presented with challenges where they were encouraged to consider other possible solutions, progression was made towards an acceptable solution.

It has also been observed that students appear to have difficulty displacing inappropriate knowledge formed outside of the formal taught (school) environment. That is, students appear to hold on to activated knowledge resources formed from everyday experiences even when these knowledge resources are in conflict with currently activated taught knowledge resources.

When embarking on a learning program that involves socio-scientific issues, the facilitators of the learning may benefit from recognising that the nature of these issues will require students to integrate both taught knowledge and everyday experiential knowledge. When this happens, students may activate conflicting knowledge resources that lead to confusing results. It is at these points that epistemic challenges, challenging the students to consider their knowledge and to justify that knowledge, may prove beneficial in helping the students sort out their own solutions to these complex issues.

Students appear to cope when conflicting knowledge resources are activated, without noticing any lack of logical robustness. These conflicting knowledge resources may go unnoticed by a teacher or facilitator. A student may use taught knowledge appropriately, giving the impression that all is well, but may simultaneously activate conflicting everyday knowledge that may be inappropriate. It would, therefore, be beneficial for instructors to be aware that students may be activating inappropriate prior knowledge, formed from everyday experiences and to seek to ensure that students are not holding onto 'sticky' e-prims that are currently inappropriate. For example, a student in this study could have appropriately activated the law of conservation of mass and inappropriately activated the 'people are special' e-prim, leading to erroneous results. By being aware of this potential pitfall, instructors would be able to help students activate appropriate e-prims. As with other areas of learning, multiple examples could help students to shift these 'sticky' e-prims, and these examples need to be sufficiently broad, spanning multiple knowledge sources, to enable e-prims formed from everyday experiences to either be reinforced or displaced by appropriate 'taught' knowledge resources.

The researcher in this study used epistemic interviewing techniques to help gain an understanding of the students' thoughts. The interviews were intended not only to discover what the student believes but also to ask the student to justify those beliefs. These epistemic interviews appeared to help the students think through their beliefs and move on towards finding a solution. The researcher attempted to learn with the student, joining the student on a mutual voyage of discovery, where the student was asked questions about their thoughts and asked to explain those thoughts to help the researcher better understand the issue under consideration. Providing epistemic

challenges in this way, through a mutual learning experience, was successful in the classroom observed in this study. Epistemic interviews, used as a pedagogical tool, may assist students to effectively think about sustainability issues.

9.7 Limitations and future research

This thesis has found encouraging evidence that, when faced with epistemic challenges, students are able to activate appropriate prior knowledge across contexts and students are able to work collaboratively to frame and reframe problems leading to sensible solutions. This was achieved when students were presented with true ill-structured problems that had multiple viable solutions. It is suggested here that the underlying cause of this success was the epistemic challenges that were introduced both by the researcher and by the tasks themselves. This fits well with existing ideas about inquiry learning.

9.7.1 Limitations of this study

The aim of this study was to investigate how various factors affected primary school students when solving problems associated with sustainability. From these investigations, it was hoped that lessons could be learned to assist classroom pedagogy when considering socio-scientific issues. A small number of participants were chosen for this study so that detailed data could be collected showing how these individual students went about solving set sustainability problems. The conclusions and inferences from the study must be considered in light of the limited sample size. The pedagogical techniques discussed were effective for these students in these classrooms considering only a small number of sustainability problems. From this,

practical advice may be provided to teachers who wish to embark on similar problem solving activities with primary school students; however, no more general conclusions are being inferred from this study.

Sustainability, along with other socio-scientific issues, presents students with complex problems that require ‘systems’ thinking – there is no one clear route to solution and there are many variables which all add to the complexity of a solution. In this research, many of the questions that were presented to the students were, to contain the scope of the project, reduced to more simplistic forms. For example, comparing the relative sustainability of different objects (Chapters 6 and 7) limited the students’ ability to consider the objects in a more holistic manner. To some extent this was lessened by the group task (Chapter 7) when the students were given the opportunity to discuss individual objects. Despite this limitation, valuable data was collected on how students approached these, perhaps artificial, issues. A further study focusing on students’ systems thinking would be able to add to these findings.

When considering the findings of this study in conjunction with other studies, such as those on Productive Failure and Learning by Design™, stronger inferences may be made about the effect of providing epistemic challenges across a wider variety of learning episodes. These, while speculative, can be investigated through further research.

9.7.2 Future directions

It was a limitation of this study that only knowledge resources were investigated. Along with knowledge resources, other mental resources (such as personal values, individual beliefs, and emotions) also play a part in a student's approach to sustainability issues. Future studies could investigate a broader range of mental resources and how mental resources interact to provide an interpretive frame when seeking solutions to these complex problems.

To further investigate the effect of epistemic challenges, it would be possible to build on many of the existing 'Productive Failure' and 'Learning by Design™' studies. Studies could be run to compare successful PF and LBD studies with similar studies that limit the amount of instructor-led epistemic challenges. This would help understand whether it is the 'failure' itself, or the design of a task that introduces situations where students are asked to justify their knowledge, that then leads to success.

Students were observed in this study activating conflicting knowledge resources that had been formed in different circumstances. Further investigations could be made to research this issue; seeking answers to when and why 'sticky' inappropriate e-prims are activated. This is especially important as, while inappropriate e-prim activations are sometimes obvious (the student gets things wrong), the student may be holding conflicting e-prims from different sources. He or she may appear to be activating appropriate knowledge resources but in fact be using simultaneously activated inappropriate knowledge resources.

The empirical data reported in Chapter 7 were collected during a student activity centred on the sorting of photographic images. In this instance the task, which was presented to the students, was designed to foster epistemic challenges by asking them to (internally) justify their responses – that is, to justify the order in which they placed the images. Further research could be carried out to investigate combinations of tasks and tools specifically designed to encourage epistemic challenges. This may lead to a better understanding of beneficial challenges to students created by the activity, by other students, and by the teacher/facilitator.

9.8 Concluding comment

It is hoped that this thesis may, in some ways, assist others by providing insights into the use of prior knowledge and especially the use of everyday experiences in more formal taught situations. Wagner (2006) discusses the difficulties that students encounter when attempting to transfer knowledge across contexts, and also the difficulties faced by instructors as they struggle to comprehend the difficulties that novice learners experience. He concludes

It seems that once we, as experts, have learned to see situations as similar or alike, it is difficult for us to imagine how they could be seen any differently.

(p. 68)

This statement is also valid when considering knowledge activations from both taught and everyday experiences. To paraphrase Wagner: it appears that once teachers have moved their everyday experiences into formal taught knowledge, it is difficult for them to imagine how conflicting knowledge resources could be activated simultaneously. This difficulty is further exacerbated by the fact that students may be exhibiting ‘correctness’ by having activated some appropriate knowledge resources,

but remain conflicted by other inappropriate prior knowledge resources. It is such difficulties that this thesis has addressed, advancing practical pedagogical techniques to help both teachers and learners as they struggle with complex socio-scientific issues.

References

- Abdi, H. (2007). The Kendall rank correlation coefficient. In *Encyclopedia of Measurement and Statistics*. Thousand Oaks, CA.
- ACARA. (2011). Year 6 science - Student portfolio summary. Retrieved from http://www.acara.edu.au/curriculum/worksamples/AC_Worksample_Science_6.pdf
- ACARA. (2012a). The Australian curriculum. *Version 5*. Retrieved from <http://www.australiancurriculum.edu.au/Download/F10>
- ACARA. (2012b). The shape of the Australian curriculum. *Version 4*. Sydney. Retrieved from http://www.acara.edu.au/verve/_resources/The_Shape_of_the_Australian_Curriculum_v4.pdf
- Adams, W. M. (2006). The future of sustainability: Re-thinking environment and development in the twenty-first century. *Report of the IUCN Renowned Thinkers Meeting IUCN International Union for Conservation of Nature*, 1–18.
- Aikenhead, G. S. (2003). STS education: A rose by any other name. In R. T. Cross (Ed.), *A Vision for Science Education: Responding to the Work of Peter J. Fensham* (pp. 59 – 75). Routledge Press.
- Aleixandre, M., & Rodriguez, R. (2001). Designing a field code: Environmental values in primary school. *Environmental Education Research*, 7(1), 5–22.
- Anderson, R. (2002). Reforming science teaching: What research says about inquiry. *Journal of Science Teacher Education*, 13(1), 1–12.
- Andrée, M., & Lager-Nyqvist, L. (2013). Spontaneous play and imagination in everyday science classroom practice. *Research in Science Education*, 43(5), 1735–1750.
- Australian Academy of Science. (2006). Marvellous micro-organisms: Stage 3: Life and living. In *Primary connections: linking science with literacy* (p. 74). Canberra: Australian Academy of Science.
- Avriel-Avni, N., Spektor-Levy, O., Zion, M., & Levi, N. R. (2010). Children's sense of place in desert towns: A phenomenographic enquiry. *International Research in Geographical and Environmental Education*, 19(3), 241–259. doi:10.1080/10382046.2010.496987
- Azevedo, F., diSessa, A., & Sherin, B. (2012). An evolving framework for describing student engagement in classroom activities. *The Journal of Mathematical Behavior*, 31(2), 270–289.

- Ballantyne, R., Fien, J., & Packer, J. (2001). School environmental education programme impacts upon student and family learning: A case study analysis. *Environmental Education Research*, 7(1), 23–37.
- Bamberger, Y., Cahill, C., Hagerty, J., Short, H., & Krajcik, J. (2011). Learning science by doing design: How can it work at the middle school level? *Journal of Education, Informatics and Cybernetics*, 2(2), 41–46.
- Barrett, B. F. D., Kuroda, A., & Miyamoto, K. (2002). Ecological modernisation, environmental knowledge and societal change: Attitudes and behaviour of young people in Japan. *International Research in Geographical and Environmental Education*, 11(3), 237–261.
- Barrows, H. (1985). *How to design a problem-based curriculum for the preclinical years*. New York: Springer Publishing Company.
- Barrows, H. (1986). A taxonomy of problem-based learning methods. *Medical Education*, 20(6), 481–486.
- Barsalou, L. (2009). Situating concepts. In P. Robbins & M. Aydede (Eds.), *Cambridge handbook of situated cognition* (pp. 236–263). Cambridge: Cambridge University Press.
- Bassey, M. (1981). Pedagogic research: on the relative merits of search for generalisation and study of single events. *Oxford Review of Education*, 7(1), 73–94.
- Bazire, M., & Brézillon, P. (2005). Understanding context before using it. In *The 5th international conference on Modeling and Using Context* (pp. 29–40). Chicago: Springer-Verlag.
- Behnke, F. (1961). Reactions of scientists and science teachers to statements bearing on certain aspects of science and science teaching. *School Science and Mathematics*, 61(3), 193–207.
- Berg, B. (2004). *Qualitative research methods for the social sciences*. Boston: Pearson.
- Billig, M. (2011). Writing social psychology: Fictional things and unpopulated texts. *British Journal of Social Psychology*, 50(1), 4–20.
- Block, J. (1982). Assimilation, accommodation, and the dynamics of personality development. *Child Development*, 53(2), 281–95.
- Board of Studies. (2011). Parents' guide to the NSW primary syllabuses. Board of Studies, New South Wales.
- Boddington, A., & Boys, J. (Eds.). (2011). *Re-shaping learning: A critical reader: The future of learning spaces in a post-compulsory education*. Chicago: Springer.

- Bolte, C., Holbrook, J., & Rauch, F. (2012). Inquiry-based science education in Europe: Reflections from the PROFILES project. In *First International PROFILES Conference*. Berlin.
- Boyes, E., & Stanisstreet, M. (1997). Children's models of understanding of two major global environmental issues (ozone layer and greenhouse effect). *Research in Science & Technological Education*, 15(1), 19–28.
- Boys, J. (2010). *Towards creative learning spaces: Re-thinking the architecture of post-compulsory education*. Routledge.
- Bransford, J. D., Brown, A., & Cocking, R. (2000). *How people learn*. Washington DC: National Academy Press.
- Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology*, 3(2), 77–101.
- Bridges, D. (2010). n= 1: The science and art of the single case in educational research. In P. Smeyers & M. Depaepe (Eds.), *Educational Research - the Ethics and Aesthetics of Statistics* (pp. 79–96). Dordrecht: Springer Netherlands. doi:http://dx.doi.org/10.1007/978-90-481-9873-3_6
- Brinkmann, S. (2007). Could interviews be epistemic?: An alternative to qualitative opinion polling. *Qualitative Inquiry*, 13(8), 1116–1138. doi:10.1177/1077800407308222
- Broudy, H. (1977). Types of knowledge and purposes of education. In R. C. Anderson, R. J. Spiro, & W. E. Montague (Eds.), *Schooling and the acquisition of knowledge* (pp. 1–17). Hillsdale, N.J.: Erlbaum.
- Brown, D., & Clement, J. (1989). Overcoming misconceptions via analogical reasoning: Abstract transfer versus explanatory model construction. *Instructional Science*, 18(4), 237–261.
- Brown, W. (1965). Science textbook selection and the Dale-Chall formula. *School Science and Mathematics*, 65(2), 164–167. doi:10.1111/j.1949-8594.1965.tb13383.x
- Brundtland, G. H. (1987). *Our common future*. Oxford University Press, Oxford.
- Bruner, J. S. (1961). The act of discovery. *Harvard Educational Review*, 31, 21–32.
- Bryce, T. G. K., & Day, S. P. (2013). Scepticism and doubt in science and science education: The complexity of global warming as a socio-scientific issue. *Cultural Studies of Science Education*, 9(3), 599–632. doi:10.1007/s11422-013-9500-0
- Bryman, A. (2004). Ethnography and participant observation. In *Social research methods* (pp. 291–317). Oxford; New York: Oxford University Press.

- Bybee, R. W. (2004). Scientific inquiry and science teaching. In L. B. Flick & N. G. Lederman (Eds.), *Scientific inquiry and nature of science* (pp. 1–14). Springer.
- Bybee, R. W., Powell, J. C., & Trowbridge, L. W. (2007). *Teaching secondary school science: Strategies for developing scientific literacy* (9th ed.). Pearson.
- Calmsley Hill Farm. (2010). Sustainable learning @ Calmsley Hill. Retrieved February 8, 2014, from <http://calmsleyhill.com.au/wp-content/uploads/Stage-2-and-3-Sustainability.pdf>
- Capps, D. K., & Crawford, B. A. (2012). Inquiry-based instruction and teaching about nature of science: Are they happening? *Journal of Science Teacher Education*, 24(3), 497–526. doi:10.1007/s10972-012-9314-z
- Carey, S. (1985). *Conceptual change in childhood*. Cambridge, MA: MIT Press.
- Carraher, T. N., Carraher, D. W., & Schliemann, A. D. (1985). Mathematics in the streets and in schools. *British Journal of Developmental Psychology*, 3(1), 21–29.
- Caton, E., Brewer, C., & Brown, F. (2000). Building teacher-scientist partnerships: Teaching about energy through inquiry. *School Science and Mathematics*, 100(1), 7–15. doi:10.1111/j.1949-8594.2000.tb17315.x
- Ceaser, D. (2012). Our school at Blair Grocery: A case study in promoting environmental action through critical environmental education. *The Journal of Environmental Education*, 43(4), 209–226.
- Ceci, S., & Roazzi, A. (1994). The effects of context on cognition: Postcards from Brasil. In R. K. Wagner & R. J. Sternberg (Eds.), *Mind in context : interactionist perspectives on human intelligence* (pp. 74–101). Cambridge: Cambridge University Press.
- Chi, M. (1997). Quantifying qualitative analyses of verbal data: A practical guide. *Journal of the Learning Sciences*, 6(3), 271–315.
- Chi, M. (2008). Three types of conceptual change: Belief revision, mental model transformation, and categorical shift. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 61–82). Hillsdale, NJ: Erlbaum.
- Chipman, S., Segal, J., & Glaser, R. (1985). *Thinking and learning skills: Current research and open questions*. Hillsdale, N.J.: Erlbaum.
- Christidou, V., Koulaidis, V., & Christidis, T. (1997). Children's use of metaphors in relation to their mental models: The case of the ozone layer and its depletion. *Research in Science Education*, 27(4), 541–552. doi:10.1007/bf02461479
- Churchman, C. (1971). *The design of inquiring systems: Basic concepts of systems and organization*. New York: Basic books.

- Cicourel, A. (1987). The interpenetration of communicative contexts: Examples from medical encounters. *Social Psychology Quarterly*, 50(2), 217–226.
- Cohen, M. J. (2000). Ecological modernisation, environmental knowledge and national character: A preliminary analysis of the Netherlands. *Environmental Politics*, 9(1), 77–106.
- Colburn, A. (2000). An inquiry primer. *Science Scope*, 23(6), 42–44.
- Colucci-Gray, L., Camino, E., Barbiero, G., & Gray, D. (2006). From scientific literacy to sustainability literacy: An ecological framework for education. *Science Education*, 90(2), 227–252. doi:10.1002/sce.20109
- Colucci-Gray, L., Perazzone, A., Dodman, M., & Camino, E. (2013). Science education for sustainability, epistemological reflections and educational practices: From natural sciences to trans-disciplinarity. *Cultural Studies of Science Education*, 8(1), 127–183.
- Connell, S., Fien, J., Lee, J., Sykes, H., & Yencken, D. (1999). If it doesn't directly affect you, you don't think about it': A qualitative study of young people's environmental attitudes in two Australian cities. *Environmental Education Research*, 5(1), 95–113. doi:10.1080/1350462990050106
- Conservation of mass. (2013). *Merriam-Webster.com*. Retrieved March 15, 2013, from [http://www.merriam-webster.com/dictionary/conservation of mass](http://www.merriam-webster.com/dictionary/conservation%20of%20mass)
- context, n. (2013). *Oxford Dictionaries*. Retrieved August 8, 2013, from <http://oxforddictionaries.com/definition/english/context>
- Conway, G. (2012). *One billion hungry: Can we feed the world?* New York: Cornell University Press.
- Creighton, A. (2013, July 9). Resources boom has years to run, says mining services chief. *The Australian*. Retrieved from <http://www.theaustralian.com.au/business/mining-energy/resources-boom-has-years-to-run-says-mining-services-chief/story-e6frg9df-1226676188961>
- Day, S. P., & Bryce, T. G. K. (2011). Does the discussion of socio-scientific issues require a paradigm shift in science teachers' thinking? *International Journal of Science Education*, 33(12), 1675–1702.
- DeBoer, G. (2000). Scientific literacy: Another look at its historical and contemporary meanings and its relationship to science education reform. *Journal of Research in Science Teaching*, 37(6), 582–601.
- Delamont, S. (2004). Ethnography and participant observation. In C. Seale, G. Gobo, J. Gubrium, & D. Silverman (Eds.), *Qualitative research practice* (pp. 205–217). London: Sage Publications.

- Dewey, J. (1910). Science as subject-matter and as method. *Science*, 31(787), 121–127.
- diSessa, A. (1988). Knowledge in pieces. In G. Forman & P. Pufall (Eds.), *Constructivism in the Computer Age* (pp. 49–70). Lawrence Erlbaum Associates, Inc.
- diSessa, A. (1993). Toward an epistemology of physics. *Cognition and Instruction*, 10(2/3), 105–225.
- diSessa, A. (2007). An interactional analysis of clinical interviewing. *Cognition and Instruction*, 25(4), 523–565. doi:07370000701632413
- diSessa, A., Elby, A., & Hammer, D. (2002). J's epistemological stance and strategies. In G. M. Sinatra & P. R. Pintrich (Eds.), *Intentional Conceptual Change* (pp. 237–290). Mahwah, NJ: Erlbaum.
- diSessa, A., Hammer, D., & Sherin, B. (1991). Inventing graphing: Meta-representational expertise in children. *Journal of Mathematical Behavior*, 10, 117–160.
- diSessa, A., & Sherin, B. (1998). What changes in conceptual change? *International Journal of Science Education*, 20(10), 1155–1191. doi:10.1080/0950069980201002
- Dong, A., Kleinsmann, M., & Deken, F. (2013). Investigating design cognition in the construction and enactment of team mental models. *Design Studies*, 34(1), 1–33.
- Dr. Math ® Drexel University. (2013). The two trains. Retrieved from <http://mathforum.org/dr.math/faq/faq.two.trains.html>
- Dunkhase, J. (2003). The coupled-inquiry cycle: A teacher concerns-based model for effective student inquiry. *Science Educator*, 12(1), 10–15.
- Emmons, K. M. (1997). Perceptions of the environment while exploring the outdoors: A case study in Belize. *Environmental Education Research*, 3(3), 327–344.
- Esterberg, K. G. (2002). Observation: Participant and otherwise. In *Qualitative methods in social research* (pp. 57–82). Boston, Mass: McGraw-Hill.
- Evans, E. (2001). Cognitive and contextual factors in the emergence of diverse belief systems: Creation versus evolution. *Cognitive Psychology*, 42(3), 217–266.
- Evans, E. (2008). Conceptual change and evolutionary biology: A developmental analysis. In S. Vosniadou (Ed.), *International handbook of research on conceptual change* (pp. 263–294). New York: Routledge.
- Ferreira, M. (2007). Education for sustainability: Defining the territory. In M. Robertson (Ed.), *Sustainable futures : teaching and learning : a case study approach* (pp. 38–48). Camberwell, Vic.: ACER Press.

- Festinger, L. (1962). *A theory of cognitive dissonance*. Stanford university press.
- Fisman, L. (2005). The effects of local learning on environmental awareness in children: An empirical investigation. *The Journal of Environmental Education*, 36(3), 39–50.
- Fontana, A., & Frey, J. (2005). The interview: From neutral stance to political involvement. *The Sage Handbook of Qualitative Research*.
- Fuchs, L. S., Fuchs, D., Prentice, K., Burch, M., Hamlett, C. L., Owen, R., ... Jancek, D. (2003). Explicitly teaching for transfer: Effects on third-grade students' mathematical problem solving. *Journal of Educational Psychology*, 95(2), 293–305.
- Gagné, R. (1963). The learning requirements for enquiry. *Journal of Research in Science Teaching*, 1, 144–153.
- Gero, J. S., & Smith, G. J. (2009). Context, situations, and design agents. *Knowledge-Based Systems*, 22(8), 600–609. doi:10.1016/j.knosys.2009.05.005
- Gertzman, A., & Kolodner, J. L. (1996). A case study of problem-based learning in a middle school science classroom: Lessons learned. In *Proceedings of the 1996 international conference on Learning sciences* (pp. 91–98). International Society of the Learning Sciences.
- Gibson, J. (1977). The theory of affordances. In R. Shaw & J. Bransford (Eds.), *Perceiving, acting, and knowing: Toward an ecological psychology*. New Jersey: Lawrence Erlbaum.
- Gibson, J. (1986). *The ecological approach to visual perception*. Lawrence Erlbaum Associates.
- Gick, M., & Holyoak, K. (1983). Schema induction and analogical transfer. *Cognitive Psychology*, 15(1), 1–38.
- Glaser, R. (1984). Education and thinking: The role of knowledge. *American Psychologist*, 39(2), 93–104.
- Goldie, P. (2004). Emotion, reason, and virtue. In D. Evans & P. Cruse (Eds.), *Emotion, evolution, and rationality* (pp. 249–267). Oxford: Oxford University Press.
- Goldman, D., Assaraf, O. B. Z., & Shaharabani, D. (2013). Influence of a non-formal environmental education programme on junior high-school students' environmental literacy. *International Journal of Science Education*, 35(3), 515–545.
- Goodrum, D., & Rennie, L. (2007). *Australian school science education national action plan, 2008-2012. Volume 1*. Canberra, ACT: Australian Government Department of Education, Science and Training.

- Goodwin, C., & Duranti, A. (1992). Rethinking context: An introduction. In A. Duranti & C. Goodwin (Eds.), *Rethinking context: Language as an interactive phenomenon* (p. 363). Cambridge: Cambridge University Press.
- Gopnik, A., & Meltzoff, A. (1997). *Words, thoughts, and theories*. Cambridge, MA: MIT Press.
- Gopnik, A., & Wellman, H. M. (1994). The theory theory. In L. A. Hirschfeld & S. A. Gelman (Eds.), *Mapping the mind: Domain specificity in cognition and culture* (pp. 257–293). New York, NY: Cambridge University Press.
- Gottlieb, D., Vigoda-Gadot, E., Haim, A., & Kissinger, M. (2012). The ecological footprint as an educational tool for sustainability: A case study analysis in an Israeli public high school. *International Journal of Educational Development*, 32(1), 193–200.
- Gough, A. (1997). *Education and the environment: Policy, trends and the problems of marginalisation*. Melbourne: Australian Council for Educational Research.
- Gough, A., & Robottom, I. (1993). Towards a socially critical environmental education: Water quality studies in a coastal school. *Journal of Curriculum Studies*, 25(4), 301–316.
- Gough, N. (1989). From epistemology to ecopolitics: Renewing a paradigm for curriculum. *Journal of Curriculum Studies*, 21(3), 225–241.
- Greeno, J. G. (1994). Gibson's affordances. *Psychological Review*, 101(2), 336–342.
- Gunter, B. (1987). The leisure experience: Selected properties. *Journal of Leisure Research*, 19, 125–130.
- Gupta, A., Hammer, D., & Redish, E. F. (2010). The case for dynamic models of learners' ontologies in physics. *Journal of the Learning Sciences*, 19(3), 285–321. doi:10.1080/10508406.2010.491751
- Hammer, D. (1996). Misconceptions or p-prims: How may alternative perspectives of cognitive structure influence instructional perceptions and intentions. *The Journal of the Learning Sciences*, 5(2), 97–127.
- Hammer, D., Elby, A., Scherr, R., & Redish, E. F. (2005). Resources, framing, and transfer. In J. P. Mestre (Ed.), *Transfer of Learning: Research and Perspectives* (pp. 89–119). Information Age Pub Inc.
- Hanks, W. (2006). Spatial frames of reference in language and thought. *Language in Society*, 35(02), 285–296.
- Hattie, J., Marsh, H., Neil, J., & Richards, G. (1997). Adventure education and outward bound: Out-of-class experiences that make a lasting difference. *Review of Educational Research*, 67(1), 43–87.

- Hershkowitz, R., Schwarz, B., & Dreyfus, T. (2001). Abstraction in context: Epistemic actions. *Journal for Research in Mathematics Education*, 32(2), 195–222.
- Higham, J. (2013). Climate change, discretionary air travel, and the “flyers’ dilemma.” *Journal of Travel Research*.
- Hines, J. M., Hungerford, H. R., & Tomera, A. N. (1987). Analysis and synthesis of research on responsible environmental behavior: A meta-analysis. *The Journal of Environmental Education*, 18(2), 1–8.
- Hmelo-Silver, C., Duncan, R. G., & Chinn, C. A. (2007). Scaffolding and achievement in problem-based and inquiry learning: A response to Kirschner, Sweller, and Clark (2006). *Educational Psychologist*, 42(2), 99–107.
- Hsieh, H., & Shannon, S. (2005). Three approaches to qualitative content analysis. *Qualitative Health Research*, 15(9), 1277–1288.
- Hungerford, H., & Volk, T. (1990). Changing learner behavior through environmental education. *Journal of Environmental Education*, 21(3), 8–22.
- Ivy, T. G.-C., Road, K. S., Lee, C. K.-E., & Chuan, G. K. (1998). A survey of environmental knowledge, attitudes and behaviour of students in Singapore. *International Research in Geographical and Environmental Education*, 7(3), 181–202. doi:10.1080/10382049808667574
- Izsak, A. (2005). “You have to count the squares”: Applying knowledge in pieces to learning rectangular area. *The Journal of the Learning Sciences*, 14(3), 361–403.
- Jenkins, E. (1999). School science, citizenship and the public understanding of science. *International Journal of Science Education*, 21(7), 703–710.
- Joint Information Systems Committee. (2006). Designing spaces for effective learning: A guide to 21st century learning space design. *Higher Education Funding Council for England (HEFCE) on Behalf of JISC*.
- Kapon, S., & DiSessa, A. (2010). Instructional explanations as an interface - the role of explanatory primitives. In *AIP Conference Proceedings* (pp. 189–192). doi:10.1063/1.3515195
- Kapon, S., & diSessa, A. (2012). Reasoning through instructional analogies. *Cognition and Instruction*, 30(3), 261–310.
- Kapur, M. (2008). Productive failure. *Cognition and Instruction*, 26(3), 379–424. doi:10.1080/07370000802212669
- Kapur, M. (2010). Productive failure. In *Learning Technology Research Fest 2010*. Sydney: Presentation 4th November 2010.

- Kapur, M. (2011). A further study of productive failure in mathematical problem solving: Unpacking the design components. *Instructional Science*, 39(4), 561 – 579.
- Kapur, M. (2012). Productive failure in learning the concept of variance. *Instructional Science*, 40(4), 651 – 672.
- Kapur, M., & Bielaczyc, K. (2012). Designing for productive failure. *Journal of the Learning Sciences*, 21(1), 45 – 83.
- Kapur, M., & Kinzer, C. K. (2009). Productive failure in CSCL groups. *International Journal of Computer-Supported Collaborative Learning*, 4(1), 21–46.
doi:10.1007/s11412-008-9059-z
- Kendall, M. (1955). *Rank correlation methods* (2nd ed.). Oxford: Hafner Publishing Co.
- Keys, C., & Bryan, L. (2001). Co-constructing inquiry-based science with teachers: Essential research for lasting reform. *Journal of Research in Science Teaching*, 38(6), 631–645.
- Kim, M., Tan, A., & Talaue, F. (2013). New vision and challenges in inquiry-based curriculum change in Singapore. *International Journal of Science Education*, 35(2), 289–311.
- King, P., & Kitchener, K. (1994). *Developing reflective judgment: Understanding and promoting intellectual growth and critical thinking in adolescents and adults*. The Jossey-Bas higher and adult education series.
- King, P., Wood, P., & Mines, R. (1990). Critical thinking among college and graduate students. *Review of Higher Education*, 13(3), 167–186.
- Kirschner, P., Sweller, J., & Clark, R. (2006). Why minimal guidance during instruction does not work: An analysis of the failure of constructivist, discovery, problem-based, experiential, and inquiry-based teaching. *Educational Psychologist*, 41(2), 75–86.
- Knapp, D., & Poff, R. (2001). A qualitative analysis of the immediate and short-term impact of an environmental interpretive program. *Environmental Education Research*, 7(1), 55–65.
- Kolb, A., & Kolb, D. (2005). Learning styles and learning spaces: Enhancing experiential learning in higher education. *Academy of Management Learning & Education*, 4(2), 193–212.
- Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, 8(3), 239–260.

- Kolodner, J. L. (1992). An introduction to case-based reasoning. *Artificial Intelligence Review*, 6(1), 3–34.
- Kolodner, J. L., Camp, P. J., Crismond, D., Fasse, B., Gray, J., Holbrook, J., ... Ryan, M. (2003). Problem-based learning meets case-based reasoning in the middle-school science classroom: Putting learning by design™ into practice. *Journal of the Learning Sciences*, 12(4), 495–547. doi:10.1207/S15327809JLS1204_2
- Kolodner, J. L., Crismond, D., Gray, J., Holbrook, J., & Puntambekar, S. (1998). Learning by design from theory to practice. In *International Conference of the Learning Sciences* (pp. 16–22).
- Kolodner, J. L., Gray, J., & Fasse, B. (2003). Promoting transfer through case-based reasoning: Rituals and practices in learning by design classrooms. *Cognitive Science Quarterly*, 3(2), 119–170.
- Krajcik, J., & Merritt, J. (2012). Engaging students in scientific practices: What does constructing and revising models look like in the science classroom? *Science Scope*, 35(7), 6–10.
- Kuhn, T. (1970). The structure of scientific revolutions. *Chicago and London, II*(2).
- Kwan, T., & So, M. (2008). Environmental learning using a problem-based approach in the field: A case study of a Hong Kong school. *International Research in Geographical and Environmental Education*, 17(2), 93–113.
- Læssøe, J. (2010). Education for sustainable development, participation and socio-cultural change. *Environmental Education Research*, 16(1), 39–57. doi:10.1080/13504620903504016
- Landis, J., & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33(1), 159–174.
- Lang, J. (2007). *How to succeed with education for sustainability*. Education Services Australia.
- Lave, J. (1988). *Cognition in practice: Mind, mathematics, and culture in everyday life*. Cambridge University Press.
- Lavoisier, A. de. (1793). *Traité élémentaire de chimie* (2nd ed.). Paris: Chez Cochet.
- Layton, D., Davey, A., & Jenkins, E. (1986). Science for specific social purposes (SSSP): Perspectives on adult scientific literacy. *Studies in Science Education*, 13, 27–52.
- Leake, D. (1996). CBR in context: The present and future. *Case-Based Reasoning: Experiences, Lessons, and Future Directions*, 3–30.

- Lieflander, A. K., Frohlich, G., Bogner, F. X., & Schultz, P. (2013). Promoting connectedness with nature through environmental education. *Environmental Education Research, 19*(3), 370–384.
- Lord, T., & Orkwiszewski, T. (2006). Moving From didactic to inquiry-based instruction in a science laboratory. *The American Biology Teacher, 68*(6), 342–345.
- Martin-Hansen, L. (2002). Defining inquiry: Exploring the many types of inquiry in the science classroom. *The Science Teacher, 69*(2), 34–37.
- Martínez, J., Borko, H., & Stecher, B. (2012). Measuring instructional practice in science using classroom artifacts: Lessons learned from two validation studies. *Journal of Research in Science Teaching, 49*(1), 38–67.
- Mason, L., & Santi, M. (1998). Discussing the greenhouse effect: Children's collaborative discourse reasoning and conceptual change. *Environmental Education Research, 4*(1), 67–85.
- Masson, S., & Legendre, M. (2008). Effects of using historical microworlds on conceptual change: A p-prim analysis. *International Journal of Environmental & Science Education, 3*(3), 115–130.
- Maxwell, D., & Vorst, R. Van der. (2003). Developing sustainable products and services. *Journal of Cleaner Production, 11*(8), 883–895.
- Mayer-Smith, J., Bartosh, O., & Peterat, L. (2007). Teaming children and elders to grow food and environmental consciousness. *Applied Environmental Education and Communication, 6*(1), 77–85.
- McNamara, C. (1999). General guidelines for conducting interviews. *Authenticity Consulting*. Retrieved February 3, 2014, from <http://managementhelp.org/businessresearch/interviews.htm>
- Minsky, M. (2006). *The emotion machine: Commonsense thinking, artificial intelligence, and the future of the human mind*. Simon & Schuster.
- Mohr-Schroeder, M. J., Jackson, C., Miller, M., Walcott, B., Little, D. L., Speler, L., ... Schroeder, D. C. (2014). Developing middle school students' interests in STEM via summer learning experiences: See Blue STEM Camp. *School Science and Mathematics, 114*(6), 291–301. doi:10.1111/ssm.12079
- Morton, A. (1980). *Frames of mind: Constraints on the common-sense conception of the mental*. New York: Oxford University Press.
- National Research Council. (1996). *National science education standards*. Washington DC, National Academy Press.
- Neville, A. (2008). Problem-based learning and medical education forty years on. *Medical Principles and Practice, 18*(1), 1–9.

- NSW Department of Education and Communities. (2010). Sustainability education: Developing a deeper understanding and supporting student learning. Retrieved April 1, 2014, from http://www.curriculumsupport.education.nsw.gov.au/env_ed/assets/powerpt/sustainabilityeducation.ppt
- NSW Environment & Heritage. (2013). What is sustainability? Retrieved July 9, 2013, from <http://www.environment.nsw.gov.au/sustainability/>
- Nutbeam, D. (2000). Health literacy as a public health goal: A challenge for contemporary health education and communication strategies into the 21st century. *Health Promotion International, 15*(3), 259–267.
- Oblinger, D. (2006). *Learning spaces (Vol. 2)*. Washington, DC: Educause.
- Olson, S., & Loucks-Horsley, S. (2000). *Inquiry and the national science education standards: A guide for teaching and learning*. Washington DC: National Academy Press.
- Orum, A., Feagin, J., & Sjoberg, G. (1991). The nature of the case study. In J. Feagin, A. Orum, & G. Sjoberg (Eds.), *A case for the case study* (pp. 1–26). UNC Press Books.
- Palmberg, I. E., & Kuru, J. (2000). Outdoor activities as a basis for environmental responsibility. *The Journal of Environmental Education, 31*(4), 32–36.
- Patton, M. Q. (1990). *Qualitative Evaluation and Research Methods* (2nd ed.). Thousand Oaks, CA: Sage Publications.
- Patton, M. Q. (2005). Qualitative research. In B. Everitt & D. Howell (Eds.), *Encyclopedia of Statistics in Behavioral Science*. John Wiley & Sons, Ltd.
- Perkins, D. (1986). *Knowledge as design*. Hillsdale, NJ: L. Erlbaum Associates.
- Perkins, D., & Salomon, G. (1988). Teaching for transfer. *Educational Leadership, 46*(1), 22–32.
- Perkins, D., & Salomon, G. (1992). Transfer of learning. In *International encyclopedia of education* (Vol. 2).
- Piaget, J., & Vonèche, J. (2007). *The child's conception of the world*. Rowman & Littlefield Pub Incorporated.
- Polman, J. (2000). *Designing project-based science: Connecting learners through guided inquiry. Ways of knowing in science series*. Williston VT: Teachers College Press.
- Popkewitz, T. (1972). The craft of study, structure, and schooling. *The Teachers College Record, 74*(2), 155–166.

- Posner, G. J., & Strike, K. A. (1982). Accommodation of a scientific conception: Toward a theory of conceptual change. *Sci. Ed.*, 66(2), 211–227. doi:10.1002/sce.3730660207
- Powers, A. L. (2004). Evaluation of one- and two-day forestry field programs for elementary school children. *Applied Environmental Education & Communication*, 3(1), 39–46.
- Pratt, R. (2010). Practical possibilities and pedagogical approaches for early childhood education for sustainability. In J. M. Davis (Ed.), *Young children and the environment: Early education for sustainability* (pp. 104–153). Port Melbourne, Victoria: Cambridge University Press.
- Reeve, S., & Bell, P. (2009). Children’s self-documentation and understanding of the concepts “healthy” and “unhealthy.” *International Journal of Science Education*, 31(14), 1953–1974.
- Rickinson, M. (2001). Learners and learning in environmental education: A critical review of the evidence. *Environmental Education Research*, 7(3), 207–320. doi:10.1080/13504620120065230
- Rickinson, M., Dillon, J., Teamey, K., Morris, M., Choi, M. Y., Sanders, D., & Benefield, P. (2004). *A review of research on outdoor learning*. London: NFER/Field Studies Council.
- Riege, A. (2003). Validity and reliability tests in case study research: A literature review with “hands-on” applications for each research phase. *Qualitative Market Research: An International Journal*, 6(2), 75–86.
- Roberts, D. A. (2007a). Promoting scientific literacy: Science education research in transaction. In C. Linder, L. Östman, & P. Wickman (Eds.), *Linnaeus Tercentenary Symposium*. Uppsala, Sweden.
- Roberts, D. A. (2007b). Scientific literacy/science literacy. In S. Abell & N. Lederman (Eds.), *Handbook of research on science education* (pp. 729–780). Mahwah, New Jersey.
- Robson, C. (2011). Observational methods. In *Real world research: A resource for users of social research methods in applied settings*. Chichester: Wiley.
- Roth, K., & Garnier, H. (2006). What science teaching looks like: An international perspective. *Educational Leadership*, 64(4), 16–23.
- Roth, W. (1996). Teacher questioning in an open-inquiry learning environment: Interactions of context, content, and student responses. *Journal of Research in Science Teaching*, 33(7), 709–736.
- Roth, W., & Bowen, G. M. (1995). Knowing and interacting: A study of culture, practices, and resources in a grade 8 open-inquiry science classroom guided by a cognitive apprenticeship metaphor. *Cognition and Instruction*, 13(1), 73–128.

- Ruddock, G., & Sainsbury, M. (2008). *Comparison of the core primary curriculum in England to those of other high performing countries.*
- Rutherford, F. J. (1964). The role of inquiry in science teaching. *Journal of Research in Science Teaching*, 2, 80–84.
- Sadeh, I., & Zion, M. (2009). The development of dynamic inquiry performances within an open inquiry setting: A comparison to guided inquiry setting. *Journal of Research in Science Teaching*, 46(10), 1137–1160.
- Sadler, T. D., Klosterman, M., & Topcu, M. (2011). Learning science content and socio-scientific reasoning through classroom explorations of global climate change. In T. D. Sadler (Ed.), *Socio-scientific Issues in the Classroom* (pp. 45–77). Dordrecht: Springer.
- Said, A. M., Yahaya, N., & Ahmadun, F.-R. (2007). Environmental comprehension and participation of Malaysian secondary school students. *Environmental Education Research*, 13(1), 17–31.
- Salomon, G., & Perkins, D. (1989). Rocky roads to transfer: Rethinking mechanism of a neglected phenomenon. *Educational Psychologist*, 24(2), 113–142.
- Saunders, K. J. (2010). Teaching and learning about controversial science issues. *NZ Science Teacher*, (125), 30–33.
- Saunders, K. J., & Rennie, L. J. (2013). A pedagogical model for ethical inquiry into socioscientific issues in science. *Research in Science Education*, 43(1), 253–274.
- Schwab, J., & Brandwein, P. (1962). *The teaching of science as enquiry and science in the elementary school. The teaching of science.* Cambridge MA: Harvard University Press.
- Schwartz, D., & Bransford, J. D. (1998). A time for telling. *Cognition and Instruction*, 16(4), 475–522.
- Schwartz, D., & Martin, T. (2004). Inventing to prepare for future learning: The hidden efficiency of encouraging original student production in statistics instruction. *Cognition and Instruction*, 22(2), 129–184.
- Schwarz, C., & Gwekwerere, Y. (2007). Using a guided inquiry and modeling instructional framework (EIMA) to support preservice K-8 science teaching. *Science Education*, 91(1), 158–186.
- Seidman, I. (2013). *Interviewing as qualitative research: A guide for researchers in education and the social sciences.* New York: Teachers college press.
- Shaffer, D. (2006). Epistemic frames for epistemic games. *Computers & Education*, 46(3), 223–234.
- Shelanski, V. (1979). To the reader. *Science, Technology & Human Values*, 4(3), i–i.

- Silverman, D. (2013). *Doing qualitative research: A practical handbook* (Fourth.). London: Sage Publications.
- Simon, H. (1979). Information processing models of cognition. *Annual Review of Psychology*. Retrieved from <http://www.annualreviews.org.ezproxy2.library.usyd.edu.au/doi/pdf/10.1146/annurev.ps.30.020179.002051>
- Skinner, J. (2012). *The interview: An ethnographic approach*. London: Berg.
- Strommen, E. (1995). Lions and tigers and bears, oh my! Children's conceptions of forests and their inhabitants. *Journal of Research in Science Teaching*, 32(7), 683–698. doi:10.1002/tea.3660320704
- sustain, v. (2014). *Oxford Dictionaries*. Retrieved from <http://www.oxforddictionaries.com/definition/english/sustain?q=sustain>
- Sweller, J. (1988). Cognitive load during problem solving: Effects on learning. *Cognitive Science*, 12(2), 257–285.
- TES Connect. (n.d.). Science investigation cards: Resources. Retrieved July 4, 2013, from <http://www.tes.co.uk/teaching-resource/Science-Investigation-Cards-3001731/>
- Thompson, K., Ashe, D., Yeoman, P., & Parisio, M. (2013). Phases of design: Following idea development and patterns of collaborative discussion in a learning by design project. In *International Conference on Computer-Supported Collaborative Learning*. Madison, WI: International Society of the Learning Sciences.
- Thomsen, D. K., & Brinkmann, S. (2009). An interviewer's guide to autobiographical memory: Ways to elicit concrete experiences and to avoid pitfalls in interpreting them. *Qualitative Research in Psychology*, 6(4), 294–312. doi:10.1080/14780880802396806
- Thorndike, E. (1906). *The principles of teaching: Based on psychology*. AG Seiler.
- Tilbury, D. (1995). Environmental education for sustainability: Defining the new focus of environmental education in the 1990s. *Environmental Education Research*, 1(2), 195–212.
- Tooth, R., & Renshaw, P. (2009). Reflections on pedagogy and place: A journey into learning for sustainability through environmental narrative and deep attentive reflection. *Australian Journal of Environmental Education*, 25, 95–104.
- Topcu, M., Sadler, T. D., & Yilmaz-Tuzun, O. (2010). Preservice science teachers' informal reasoning about socioscientific issues: The influence of issue context. *International Journal of Science Education*, 32(18), 2475–2495.
- Turner, J. C. (1991). *Social influence*. Thomson Brooks/Cole Publishing.

- Turner, J. C., & Oakes, P. J. (1994). Self and collective: Cognition and social context. *Personality and Social Psychology Bulletin*, 20(5), 454–463.
- UNESCO. (1997). Educating for a sustainable future. In *The international conference on environment and society: Education and public awareness for sustainability*. Thessaloniki, Greece: United Nations Educational, Scientific and Cultural Organization. doi:UNESCO: EPD-97/CONF.401/CLD.1
- UNESCO. (2006). *Framework for the UN DESD international implementation scheme*. Paris.
- Volk, T. L., & Cheak, M. J. (2003). The effects of an environmental education program on students, parents, and community. *The Journal of Environmental Education*, 34(4), 12–25. doi:463168421
- Wagner, J. F. (2006). Transfer in pieces. *Cognition and Instruction*, 24(1), 1–71.
- Wagner, J. F. (2010). A transfer-in-pieces consideration of the perception of structure in the transfer of learning. *Journal of the Learning Sciences*, 19(4), 443–479.
- Waight, N., & Abd-El-Khalick, F. (2011). From scientific practice to high school science classrooms: Transfer of scientific technologies and realizations of authentic inquiry. *Journal of Research in Science Teaching*, 48(1), 37–70.
- Walker, K., & Loughland, T. (2003). The socio-cultural influences on environmental understandings of Australian school students: A response to Rickinson. *Environmental Education Research*, 9(2), 227–239.
- Walpole, S. (1999). Changing texts, changing thinking: Comprehension demands of new science textbooks. *The Reading Teacher*, 42(4), 358–369.
- White, B., & Frederiksen, J. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, 16(1), 3–118.
- Windschitl, M., Dvornich, K., Ryken, A. E., Tudor, M., & Koehler, G. (2007). A comparative model of field investigations: Aligning school science inquiry with the practices of contemporary science. *School Science and Mathematics*, 107(1), 382–390. doi:10.1111/j.1949-8594.2007.tb17761.x
- Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education*, 92(5), 941–967.
- Wise, K., & Okey, J. (1983). A meta-analysis of the effects of various science teaching strategies on achievement. *Journal of Research in Science Teaching*, 20(5), 419–435.
- Yin, R. K. (2009). *Case study research: Design and methods* (4th ed.). Los Angeles: Sage Publications.

- Young, M. (1974). Notes for a sociology of science education. *Studies in Science Education*, 1(1), 51–60.
- Zeidler, D. L., Sadler, T. D., Simmons, M. L., & Howes, E. V. (2005). Beyond STS: A research-based framework for socioscientific issues education. *Science Education*, 89(3), 357–377.
- Zeidler, D. L., Walker, K. A., Ackett, W. A., & Simmons, M. L. (2002). Tangled up in views: Beliefs in the nature of science and responses to socioscientific dilemmas. *Science Education*, 86(3), 343–367.
- Zimring, C., & Craig, D. (2001). Defining design between domains: An argument for design research á la carte. In C. Eastman, W. McCracken, & W. Newstetter (Eds.), *Design knowing and learning: Cognition in design education* (pp. 125–146). Atlanta, GA: Elsevier.
- Zohar, A., & Nemet, F. (2002). Fostering students' knowledge and argumentation skills through dilemmas in human genetics. *Journal of Research in Science Teaching*, 39(1), 35–62.
- Zoller, U. (1992). The technology/education interface: STES education for all. *Canadian Journal of Education/Revue Canadienne de L'éducation*, 17(1), 86–91.

Appendices

Appendix 1: NSW Board of Studies K-6 Outcomes

Appendix 2: Interview schedule

Appendix 3: Images used for 'sustainability' interviews

Appendix 4: Ethics approval

Appendix 1: NSW Board of Studies K-6 Outcomes

| Strands and sub-strands | Early Stage 1 | Stage 1 | Stage 2 | Stage 3 |
|---|---|---|---|--|
| Patterns of Place and Location | ENES1 Gathers information about natural and built environments and communicates some of the ways in which they interact with, and can care for, these environments. | ENS1.5 Compares and contrasts natural and built features in their local area and the ways in which people interact with these features. | ENS2.5 Describes places in the local area and other parts of Australia and explains their significance. | ENS3.5 Demonstrates an understanding of the interconnectedness between Australia and global environments and how individuals and groups can act in an ecologically responsible manner. |
| Relationship with Places | Outcome ENES1 also applies here. | ENS1.6 Demonstrates an understanding of the relationship between environments and people. | ENS2.6 Describes people's interactions with environments and identifies responsible ways of interacting with environments. | ENS3.6 Explains how various beliefs and practices influence the ways in which people interact with, change and value their environment. |
| Resource Systems | SSES1 Identifies ways in which their own needs and the needs of others are met, individually and cooperatively. | SSS1.7 Explains how people and technologies in systems link to provide goods and services to satisfy needs and wants. | SSS2.7 Describes how and why people and technologies interact to meet needs and explains the effects of these interactions on people and the environment. | SSS3.7 Describes how Australian people, systems and communities are globally interconnected and recognises global responsibilities, cultural influences and their contribution to Australian identities. |
| Roles, Rights and Responsibilities | Outcome SSES1 also applies here. | SSS1.8 Identifies roles and responsibilities within families, schools and the local community, and determines ways in which they should interact with others. | SSS2.8 Investigates rights, responsibilities and decision-making processes in the school and community and demonstrates how participation can contribute to the quality of their school and community life. | SSS3.8 Explains the structures, roles, responsibilities and decision-making processes of State and federal governments and explains why Australians value fairness and socially just principles. |
| Built Environments | BEE1.1 Explores and identifies ways in which built environments suit their users. | BES1.1 Creates, modifies or models built environments to suit the needs of users. | BES2.1 Creates, models and evaluates built environments, reflecting consideration of functional and aesthetic factors. | BES3.1 Creates and evaluates built environments, demonstrating consideration of sustainability and aesthetic, cultural, safety and functional issues. |
| Living Things | LTES1.3 Identifies ways in which living things are different and have different needs. | LTS1.3 Identifies and describes ways in which living things grow and change. | LTS2.3 Identifies and describes the structure and function of living things and ways in which living things interact with other living things and their environment. | LTS3.3 Identifies, describes and evaluates the interactions between living things and their effects on the environment. |

| | | | | |
|-----------------------------------|--|--|--|--|
| Physical Phenomena | PPES1.4 Explores and identifies ways some forms of energy are used in their daily lives. | PPS1.4 Identifies and describes different ways some forms of energy are used in the community. | PPS2.4 Identifies various forms and sources of energy and devises systems that use energy. | PPS3.4 Identifies and applies processes involved in manipulating, using and changing the form of energy. |
| Products and Services | PSES1.5 Recognises the relationship between everyday products and people's needs. | PSS1.5 Grows, makes or processes some products using a range of techniques and materials. | PSS2.5 Creates and evaluates products and services, considering aesthetic and functional factors. | PSS3.5 Creates and evaluates products and services, demonstrating consideration of sustainability, aesthetic, cultural, safety and functional issues. |
| Earth and Its Surroundings | ESES1.6 Explores and identifies ways the environment influences their daily lives. | ESS1.6 Identifies and describes ways in which people and other living things depend upon the earth and its environments. | ESS2.6 Identifies some of the features of the solar system and describes interactions that affect conditions on earth. | ESS3.6 Recognises that the earth is the source of most materials and resources, and describes phenomena and processes, both natural and human, that form and change the earth over time. |
| Investigating | INVES1.7 Investigates their surroundings by observing, questioning, exploring and reporting. | INVS1.7 Conducts guided investigations by observing, questioning, predicting, collecting and recording data, and suggesting possible explanations. | INVS2.7 Conducts investigations by observing, questioning, predicting, testing, collecting, recording and analysing data, and drawing conclusions. | INVS3.7 Conducts their own investigations and makes judgements based on the results of observing, questioning, planning, predicting, testing, collecting, recording and analysing data, and drawing conclusions. |

Appendix 2: Interview schedule

| Interview | Dates | Purpose |
|-------------------|---------------------|---|
| A1 10 students | 27/03/12 - 02/04/12 | Post-instruction discussions; students asked to explain their understanding of ‘conservation of matter’. Questions about what sustainability is and why people might want to act sustainably. Questions that use the concept of ‘conservation of mass’ across contexts. |
| A2 6 students | 25/06/12 - 26/06/12 | A follow-up to interviews B4 and B7 with a different group of students |
| B1 6 students | 22/5/12 | Post-instruction discussions; students asked to explain their understanding of ‘conservation of matter’. |
| B2 6 students | 24/5/12 – 31/5/12 | Questions about what sustainability is and why people might want to act sustainably. |
| B3 6 students | 31/5/12 – 1/6/12 | Students were asked to describe something that they own and to draw and explain the life of the item |
| B4 6 students | 4/6/12 – 7/6/12 | Students were shown a series of images and asked to decide between “more” or “less” sustainable |
| B5 6 students | 14/6/12 | Questions that use the concept of ‘conservation of mass’ across contexts. |

| | | |
|-------------------|-------------------|--|
| B6 6 students | 15/6/12 – 21/6/12 | Interview about where the students might go on holiday; using ‘like’, ‘should’, and ‘would’ questions. |
| B7 6 students | 21/6/12 | Revisit of the images from B4. This time the word “sustainability” was not used. ‘Impact on the earth’s resources’ was used instead. |
| B8 6 students | 22/6/12 | Interview about making a decision to purchase a laptop; using ‘like’, ‘should’, and ‘would’ questions. |
| B9 4 students | 27/5/13 | Students were given a series of images and asked to rank the objects according to various criteria. First, as individuals and then as a group. |
| B10 6 students | 24/7/12 | Group session with six students, considering the sustainability of a serving of hot chips. Students worked individually, in pairs and as a whole group. |

Appendix 3: Images used for ‘sustainability’ interviews

| | | |
|---|---|---|
|  |  |  |
| <p>Bicycle</p> | <p>Eco-cup</p> | <p>Candles</p> |
|  |  |  |
| <p>Bus</p> | <p>Laptop</p> | <p>Aeroplane¹²</p> |
|  |  |  |
| <p>Toilet paper</p> | <p>Plastic toy</p> | <p>Disposable coffee cup</p> |

¹² Photographs are copyright of the author except the aeroplane which is © Paul Spijkers (<http://www.airliners.net/search/photo.search?id=2094033>) and is used in this research by kind permission.



Coloured pencils



Party Balloon



Plastic bag



Packet of chips

Appendix 4: Ethics approval



RESEARCH INTEGRITY Human Research Ethics Committee

Web: <http://sydney.edu.au/ethics/>
Email: ro.humanethics@sydney.edu.au

Address for all correspondence:
Level 6, Jane Foss Russell Building - G02
The University of Sydney
NSW 2006 AUSTRALIA

Ref: [SA/KFG]

13 May 2011

Dr Lina Markauskaite
Senior Lecturer, eResearch
Faculty of Education & Social Work
Education Building – A35
The University of Sydney
Email: lina.markauskaite@sydney.edu.au

Dear Dr Markauskaite

Thank you for your correspondence dated 3 May 2011 (received on 11 May 2011) addressing comments made to you by the Human Research Ethics Committee (HREC). On 13 May 2011 the Executive of the HREC considered this information and approved the protocol entitled “**Learning in and out of the classroom: The activation of productive mental resources (phase one)**”.

Details of the approval are as follows:

Protocol No.: 05-2011 / 13680
Approval Period: May 2011 to May 2012
Authorised Personnel: Dr Lina Markauskaite
Professor Peter Goodyear
Mr David Ashe
Documents Approved: Participant Information Statement – Phase One (version 2, 03/05/2011)
Participant Consent Form (version 1, 28/02/2011)
Interview Topics (version 1, 28/02/2011)

The HREC is a fully constituted Ethics Committee in accordance with the National Statement on Ethical Conduct in Research Involving Humans-March 2007 under Section 5.1.29.

The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Research Involving Humans. A report on this research must be submitted every 12 months from the date of the approval or on completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of consent for the project to proceed. Your report is due by **31 May 2012**.

Chief Investigator / Supervisor's responsibilities to ensure that:

1. All serious and unexpected adverse events should be reported to the HREC within 72 hours for clinical trials/interventional research.
2. All unforeseen events that might affect continued ethical acceptability of the project should be reported to the HREC as soon as possible.
3. Any changes to the protocol must be approved by the HREC before the research project can proceed.

Manager Human Ethics
Dr Margaret Faedo
T: +61 2 8627 8176
E: margaret.faedo@sydney.edu.au

Human Ethics Secretariat:
Ms Karen Greer T: +61 2 8627 8171 E: karen.greer@sydney.edu.au
Ms Patricia Engelmann T: +61 2 8627 8172 E: patricia.engelmann@sydney.edu.au
Ms Kala Retnam T: +61 2 8627 8173 E: kala.retnam@sydney.edu.au

ABN 15 211 513 464
CRICOS 00026A



4. All research participants are to be provided with a Participant Information Statement and Consent Form, unless otherwise agreed by the Committee. The following statement must appear on the bottom of the Participant Information Statement: *Any person with concerns or complaints about the conduct of a research study can contact the Manager, Human Ethics, University of Sydney on +61 2 8627 8176 (Telephone); + 61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).*
5. You must retain copies of all signed Consent Forms and provide these to the HREC on request.
6. It is your responsibility to provide a copy of this letter to any internal/external granting agencies if requested.
7. The HREC approval is valid for four (4) years from the Approval Period stated in this letter. Investigators are requested to submit a progress report annually.
8. A report and a copy of any published material should be provided at the completion of the Project.

Please do not hesitate to contact Research Integrity (Human Ethics) should you require further information or clarification.

Yours sincerely

Dr Stephen Assinder
Chair
Human Research Ethics Committee

cc: Professor Peter Goodyear, Associate Supervisor
peter.goodyear@sydney.edu.au

David Ashe
dash5498@uni.sydney.edu.au



**RESEARCH INTEGRITY
Human Research Ethics Committee**

Web: <http://sydney.edu.au/ethics/>
Email: ro.humanethics@sydney.edu.au

Address for all correspondence:
Level 6, Jane Foss Russell Building - G02
The University of Sydney
NSW 2006 AUSTRALIA

Ref: MF/PE

26 September 2011

Dr Lina Markauskaite
Faculty of Education and Social Work
Education Building - A35
The University of Sydney
Email: lina.markauskaite@sydney.edu.au

Dear Dr Markauskaite

Thank you for your correspondence dated 23 September 2011 addressing comments made to you by the Human Research Ethics Committee (HREC).

I am pleased to inform you that with the matters now addressed your protocol entitled "**Learning in and out of the classroom: The activation of productive mental resources (phase two)**" has been approved.

Details of the approval are as follows:

Protocol No.: 14110
Approval Period: September 2011 to September 2012
Annual Report Due: 30 September 2012
Authorised Personnel: Dr Lina Markauskaite
Professor Peter Goodyear
Mr David Ashe

Documents Approved:
Letter of Invitation Version 1 16/9/2011
Information Statement for Parents Version 2 15/9/2011
Parental (or Caregiver) Consent Form Version 2 15/9/2011
Information Statement for Students Version 1 25/7/2011

The HREC is a fully constituted Ethics Committee in accordance with the National Statement on Ethical Conduct in Research Involving Humans-March 2007 under Section 5.1.29.

The approval of this project is conditional upon your continuing compliance with the National Statement on Ethical Conduct in Research Involving Humans.

A report on this research must be submitted every 12 months to the Human Research Ethics Committee from the final approval period or on completion of the project, whichever occurs first. Failure to submit reports will result in withdrawal of ethics approval for the project. Please download the Annual Report/Completion Report Form from the Human Ethics website at: http://sydney.edu.au/research_support/ethics/human/forms.

The HREC approval is valid for four (4) years from the Approval Period stated in this letter and is conditional upon submission of Annual Reports. If your project is not completed by four (4) years from the approval period, you will have to submit a Modification Form requesting an extension.

Manager Human Ethics
Dr Margaret Faedo
T: +61 2 8627 8176
E: margaret.faedo@sydney.edu.au

Human Ethics Secretariat:
Ms Patricia Engelmann T: +61 2 8627 8172 E: patricia.engelmann@sydney.edu.au
Ms Karen Greer T: +61 2 8627 8171 E: karen.greer@sydney.edu.au
Ms Kala Retnam T: +61 2 8627 8173 E: kala.retnam@sydney.edu.au

ABN 15 211 513 464
CRICOS 00026A

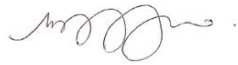
Please refer to the guideline on extension of ethics approval which is available on the website at: http://sydney.edu.au/research_support/ethics/human/extension.

Chief Investigator / Supervisor's responsibilities to ensure that:

1. All serious and unexpected adverse events should be reported to the HREC within 72 hours.
2. All unforeseen events that might affect continued ethical acceptability of the project should be reported to the HREC as soon as possible.
3. You must retain copies of all signed Consent Forms and provide these to the HREC on request.
4. It is your responsibility to provide a copy of this letter to any internal/external granting agencies if requested.
5. All research participants are to be provided with a Participant Information Statement and Consent Form, unless otherwise agreed by the Committee. The following statement must appear on the bottom of the Participant Information Statement: Any person with concerns or complaints about the conduct of a research study can contact the Manager, Human Ethics, University of Sydney on +61 2 8627 8176 (Telephone); + 61 2 8627 8177 (Facsimile) or ro.humanethics@sydney.edu.au (Email).
6. Any changes to the protocol including changes to research personnel must be approved by the HREC by submitting a Modification Form before the research project can proceed. Please refer to the website at http://sydney.edu.au/research_support/ethics/human/forms to download a copy of the Modification Form.
7. A Completion Report should be provided to the Human Research Ethics Committee at the completion of the Project.

Please do not hesitate to contact Research Integrity (Human Ethics) should you require further information or clarification.

Yours sincerely



Dr Margaret Faedo
Manager, Human Ethics
On behalf of the HREC

cc. david.ashe@sydney.edu.au