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# How exemplary teachers promote scientific reasoning and higher order thinking in primary science

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# How exemplary teachers promote scientific reasoning and higher order thinking in primary science

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# USE OF THESIS

## ABSTRACT

There is an emerging interest in the development of STEM capabilities to drive Australia's future economy and workforce. As a consequence, the focus on the teaching of higher order thinking and scientific reasoning has intensified. Despite these efforts, Australia's level of achievement on international benchmarking tests has not improved.

The aim of this PhD research was to investigate how exemplary teachers develop higher order thinking and scientific reasoning in primary science. The study drew on video data from the EQUALPRIME international research project, which explored quality primary science education in different cultures (ARC Discovery Project DP110101500).

This qualitative research examined how Year 4 teachers in two contextually different schools scaffolded, supported and created opportunities for higher order thinking and scientific reasoning during the teaching of a physical science topic. Teacher beliefs, pedagogical strategies and contextual factors were viewed through the multiple theoretical lenses of social constructivism, sociocultural theory and social semiotic theory. The central data source was video which was subjected to micro-ethnographic analysis. These data were supplemented with interviews and classroom artefacts, and from these, case studies were compiled. Using a cross-case analysis and an interpretivist approach, assertions were drawn from which the research questions were answered.

The study identified that the teaching of these skills was a complex multifaceted process influenced by the combination of teacher beliefs and contextual factors. Based on safe and supportive learning cultures, the teachers employed inquiry-based approaches and a combination of language- and body-based pedagogies that built students' thinking and reasoning in parallel with conceptual development, across the unit. Outcomes of the research will contribute to new and deeper understanding of effective scaffolding, support and promotion of higher order thinking and reasoning in primary science which can inform enhancements to pre-service and in-service teacher professional learning.

## DECLARATION

I certify that this thesis does not, to the best of my knowledge and belief:

*i.* incorporate without acknowledgment any material previously submitted for a degree or diploma in any institution of higher education;

*ii.* contain any material previously published or written by another person except where due reference is made in the text of this thesis; or

*iii.* contain any defamatory material

[redacted]

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# Chapter 1: INTRODUCTION

This chapter sets the context for the study, identifies the problem to be addressed, explains the rationale and significance of the study and lists the purpose and research questions.  A brief overview of the study concludes the chapter.

## Background

Scientific literary continues to be a highly important and essential goal of primary school education (Australian Academy of Science, 2013a; Connolly, Dulhunty, Pedrazzini, et al., 2017; Goodrum, 2014).  Developing scientific literacy equips children with the 21st century skills, such as "higher-order thinking skills, deeper learning outcomes, and complex communication skills" (Stewart, 2012, p. 11) and helps them to understand real world problems, to reason about observations and evidence and to draw their own conclusions.  Scientific literacy empowers children to become scientifically literate citizens (Hackling, Goodrum, & Rennie, 2001; Inter-Academies Panel, 2009) and self-directed individuals who are able to positively contribute to a technologically advanced and competitive society (OECD, 2013).

Two significant components of scientific literacy are higher order thinking and scientific reasoning (Bao, Cai, et al., 2009; Hackling, 2014; Hackling & Sherriff, 2015; Ramseger & Freitag-Amtmann, 2011; Tytler, Murcia, Hsiung, & Ramseger, 2017; Waldrip & Prain, 2017).  They are complex cognitive skills that need to be taught and scaffolded and supported (Osborne, Erduran, & Simon, 2004).  Scientific reasoning is described as "the thinking skills involved in inquiry, experimentation, evidence gathering, inference and argumentation that are done in the service of conceptual change or scientific understanding" (C. Zimmerman, 2006, p. 1) and higher order thinking encompasses the more complex cognitive skills identified in Bloom's revised taxonomy such as analysis, evaluation and synthesis or creation of new knowledge (Krathwohl, 2002).  The development of both higher order thinking and scientific reasoning skills in primary school students progresses the goal of developing a more scientifically literate and sustainable society.

The study builds on the EQUALPRIME research project (http://www.equalprime.edu.au/) (Hackling, Ramseger, & Chen, 2017; Ramseger & Romain, 2017), a cross-national study funded by the Australian Research Council (ARC) Discovery program that explored teaching and learning practices that provide opportunities for quality reasoning and learning across cultures. The video and associated data collected from the EQUALPRIME study provided a rich resource and a reservoir of exemplary teacher practice for this study, which focuses on the development of higher order thinking and scientific reasoning.

## Problem

The development of scientific literacy, STEM education and the development of STEM capabilities are ongoing priorities for the Australian Government and industry (Australian Department of the Prime Minister and Cabinet, 2015; R. Collins, 2014; Stewart, 2012). Higher order thinking and scientific reasoning are recognised as key components of scientific literacy and form the basis for the development of STEM capabilities such as innovation and creativity, which are critical drivers of the economy and the ideas boom. Despite over a decade of resources provided to support primary science teaching (e.g. *Primary Connections*), professional development and relevant instruction at the pre- and in-service levels, national assessments (e.g. NAP-SL) demonstrate that there has been little change in terms of average achievement in scientific literacy over this time (ACARA, 2012). International research (e.g., TIMSS 2015, PISA 2015) indicates that Australia is becoming less competitive and is lagging behind our South-East Asian trade partners, particularly in the areas of higher order thinking and scientific reasoning (Kesidou, Sadeghi, & Marosszeky, 2012; Martin, Mullis, Foy, & Stanco, 2012; Thomson, De Bortoli, & Buckley, 2013; Thomson, Wernert, O'Grady, & Rodrigues, 2017). Of significant concern is that many primary teachers report that they lack confidence when teaching science and indicate that they do not understand what higher order thinking and scientific reasoning mean and what they look like in a primary school setting

(Australian Academy of Science, 2013a; Martin, Mullis, Foy, & Hooper, 2016; Schulz & Fitz Patrick, 2016; Skamp, 2012).

## Rationale

Over the last decade in Australia and internationally, there has been an escalating interest in the development of 21st century skills to drive economies (R. Collins, 2014; Husin et al., 2016; Office of the Chief Scientist, 2015b; Scott, 2015) and to prepare future workforces for "new employment opportunities emerging in a globalised and digitally disrupted society" (Hackling, 2015, p. 4). A key component of this focus has been the Australian Government's campaign to increase student involvement in Science, Technology, Engineering and Mathematics (STEM) disciplines and the development of STEM capabilities. Education systems with well trained and informed teachers are critical for STEM education, the development of STEM capabilities and higher order cognitive skills including: skills (e.g. research, problem solving and technical skills), ways of thinking (e.g. critical thinking, innovative, evidence-based thinking, creative and analytical capability), and knowledge (e.g. scientific method, STEM subject knowledge and vocabulary) (Hackling, 2015; Office of the Chief Scientist, 2014; West, 2012).

The fundamental basis for achieving STEM capabilities is in the development of scientific literacy; and, two important components of scientific literacy are higher order thinking and scientific reasoning. As teachers are a key factor in student achievement (Hattie, 2003), it is important to consider what exemplary teachers are doing to develop students' higher order cognitive skills and what can be learnt from their quality practice in order to bring about improvement and to make Australia more competitive internationally. This study focuses on how exemplary teachers of Year 4 primary science scaffold, support and create opportunities for higher order thinking and scientific reasoning.

One of the Government's initiatives to increasing STEM literacy in future generations is to "prepare teachers properly, so they can excel in the classroom . . . [and to] support them when they are there" (Office of the Chief Scientist, 2015b, p. 1).

Outcomes of the proposed research will contribute to new and deeper knowledge about effective scaffolding, support and promotion of higher order thinking and scientific reasoning in primary school science and add to the body of knowledge about effective practice that will contribute to pre-service and in-service teacher professional learning.

## Significance

This research will extend the literature on higher order thinking and scientific reasoning by adding to and broadening the understanding of how primary school teachers scaffold and support higher order thinking and scientific reasoning. New and deeper understanding gained from analysing exemplary teacher practice will inform pre-service education and professional development of practicing teachers.

This study will contribute to new understanding and knowledge with its contemporary and naturalistic focus. There have been many studies on scientific reasoning and higher order thinking over the years (e.g. Gillies, 2012; King, Goodson, & Rohani, 1998; Naylor, Keogh, & Downing, 2007; Osborne, Erduran, & Simon, 2004; Ramseger, 2012; Venville & Dawson, 2010). Much of the literature relates to upper primary and secondary students and concentrates on single facets of practice and or the trialling of interventions. Governments, education systems and contemporary curriculums are now focusing more on commencing the formal instruction and development of higher order thinking and reasoning skills in the younger primary school age groups (ACARA, 2016; Collins, 2014; Erduran, Simon, & Osborne, 2004; Prinsley & Johnston, 2015).

The naturalistic case study approach, adopted to examine how Year 4 primary science teachers scaffold and support higher order and scientific reasoning in their classes, supports the contemporary emphasis on the earlier teaching of these skills. Through studying the orchestration of all of the teacher’s practices and strategies (Hackling et al., 2013); with video being the main source of data, real life teaching, learning interactions and the learning environment are captured in real-time across modalities and across all instructional settings for the complete set of lessons making up the science topic.

Video-based classroom research is an emerging and growing field as it has the "capacity to capture the full multimodality (speech, gesture, images, symbols etc.) of classroom events" [and the potential to create] "permanent record of events that can be replayed, reviewed, analysed, reanalysed and shared" (Hackling, 2014b, p. 1). Fine grained analysis of the video data (Flewitt, 2006; Ibrahim-Didi, 2015), micro-ethnographic analysis (Erickson, 2006) and multimodal transcriptions (Hackling et al., 2013) enabled the Researcher to reveal and share the complex intricacies of teacher-learning interactions occurring during lessons. This study added to the literature on higher order thinking and scientific reasoning by generating a deeper understanding of how teachers scaffold and support higher order thinking and scientific reasoning in mid-primary science classes.

The second contribution of this study is the new knowledge that can inform pre-service teacher education and be shared through professional learning programs. We learn from teachers who do things well and great teachers have more influence than any other factor in learning (Hattie, 2003; Holroyd & Harlen, 1996; Martin et al., 2012; Prinsley & Johnston, 2015; Skamp, 2012). This PhD study identifies and highlights the practice of three teachers (one solo teacher, two teachers co-teaching their classes) who participated in the EQUALPRIME study. They were nominated by education sector officials, professional associations and peers for their exemplary science teaching practice, which was confirmed through interview and observation by the EQUALPRIME research team (Hackling et al., 2017).

Naturalistic case study research design (Baxter & Jack, 2008; Yin, 2014) and the use of video data provided a clear view of realistic science teaching environments and in-depth teaching examples of exemplary practice. This richer and deeper understanding of exemplary teacher practice can inform pre- and existing primary school teacher's professional learning. It identified aspects of good practice in naturalistic settings; revealed how different teachers in different contextual situations knitted together practices and strategies to scaffold and support higher order thinking and scientific reasoning. Findings from this research will ultimately support teachers to facilitate greater student engagement in science which has the potential to improve scientific literacy.

## Purpose

The purpose of this study was to examine how exemplary primary teachers develop higher order thinking and scientific reasoning in their students. This will be achieved by examining how Year 4 teachers in two contextually different classrooms scaffold, support and create opportunities for higher order thinking and scientific reasoning during the teaching of a physical science topic.

## Research questions

The overall research question was:

> *How does the teacher scaffold, support and create opportunities for higher order thinking and scientific reasoning?*

The following subsidiary questions provided focus for the research:

I. What beliefs do teachers hold about scaffolding and supporting higher order thinking and scientific reasoning?

II. What pedagogical practices do teachers employ and how do they scaffold, support and create opportunities for higher order thinking and scientific reasoning?

III. What contextual factors such as classroom culture and student demographics facilitate and constrain the opportunities for higher order thinking and scientific reasoning?

The teacher's pedagogical practices (Question II) for scaffolding and supporting higher order thinking and scientific reasoning is the main focus of this study. The Researcher however, acknowledges that in naturalistic studies it is important to consider the influence of teacher belief (Question I) and contextual factors such as classroom culture and student demographics (Question III) in the teachers' selection, planning, implementation and outcomes of their pedagogies. Therefore, they have been included as subsidiary questions.

Scientific reasoning, higher order thinking and scaffolding are discussed in detail in the Literature Review. For interpreting the research questions, 'scaffolding' is a type of teacher support and refers to teaching practices and strategies that provide "students support . . . and then gradually turning over responsibility to the students to operate on their own" (Collins, 2014, Providing Scaffolding, para. 1). The term 'support' in the research questions refers to any teacher practice, factor or resource; other than scaffolding, which assists with the development of higher order thinking and scientific reasoning skills. Some examples of these 'supports' are: a positive classroom environment, opportunities for higher order thinking and scientific reasoning created through authentic activities, questioning and discussion, metacognitive strategies, the provision of language and concepts of higher order thinking (Collins, 2014; Goodrum & Druhan, 2012; Hackling & Sherriff, 2015); the use of multimodal semiotic resources (Hackling, Murcia, & Ibrahim-Didi, 2013; Kress & Van Leeuwen, 2001), and different instructional settings (Hackling, Aranda, & Freitag-Amtmann, 2017).

## Overview of the thesis

Consistent with the theoretical frameworks of sociocultural, social constructivist, semiotic and distributive cognitive theories, this study took a qualitative case study and cross-case analysis approach and used interpretive methods of analysis to identify and understand how exemplary primary teachers of science scaffold and support higher order thinking and scientific reasoning in natural class settings. Video and associated data from two case studies (Case Study 1 and Case Study 2) of Year 4 teachers teaching a whole physical science topic in two contextually different school settings were independently subjected to micro-ethnographic analysis (Erickson, 2006). Each lesson across the topic was viewed repeatedly in its entirety and clips were identified where higher order thinking and scientific reasoning occurred. Aided by multimodal transcriptions and complementary data sources such as interviews and work samples, these clips were subjected to fine grained analysis. Analysis involved a repeated cycle of data reduction, data representation, analysis and data reduction until patterns and themes regarding how teachers developed higher order thinking and scientific reasoning emerged from which key findings were drawn (Miles & Huberman, 1994). Verification of the Researcher's interpretations were then validated by each case study teacher and key findings from both case studies were subjected to cross-case analysis from which assertions were drawn. Assertions were then used to formulate conclusions and to answer the research questions.

The following Chapter will present a literature review of the ideas, theories and significant literature currently published surrounding the topics involved in this research topic.

# Chapter 2: LITERATURE REVIEW

## Introduction

Boosting science, technology, engineering and mathematics (STEM) and the development of STEM capabilities have become national and state priorities (Australian Department of the Prime Minister and Cabinet, 2015; Government of Western Australia, 2019) and the goal of all involved in education (Prinsley & Johnston, 2015; Skamp, 2012). To lay the foundation for maximising Australia's STEM capability (Prinsley & Johnston, 2015) and to prepare a future workforce with STEM capabilities such as: research, problem solving and technical skills; critical, innovative, evidence-based, creative and analytical ways of thinking; and, knowledge of scientific methods, STEM subject knowledge and vocabulary (Office of the Chief Scientist, 2014), the focus on scientific literacy and the teaching of higher order thinking and scientific reasoning in primary school has intensified (Blackley & Sheffield, 2016; R. Collins, 2014; Connolly, Dulhunty, Kesidou, et al., 2017; Hackling, 2015; Richland & Simms, 2015). Supporting primary school teachers to be confident and effective in the development of scientific literacy and the teaching of higher order thinking and scientific reasoning is a major part to achieving this goal.

This review is divided into the following sections. The first section draws on literature to set the context for the study. This section discusses scientific literacy, scientific reasoning and higher order thinking in relation to the research questions; provides brief overviews of the *Australian Curriculum: Science* (https://www.australiancurriculum.edu.au/) and *Primary Connections: Linking science with literacy* (https://primaryconnections.org.au/); and, utilises national and international assessments to discuss the status of scientific literacy, higher order thinking and reasoning in Australia and where Australia sits in relation to other countries in these areas. The second section reviews the theoretical perspectives underpinning the study. Social constructivism and sociocultural theory, with some input from social semiotic theory and distributed cognition will be discussed relative to the social nature of knowledge construction and learning. The third section pertains specifically to the research questions. This section draws on the literature to discuss pedagogical practices that scaffold, support and create opportunities for higher order thinking and scientific reasoning; and, how teacher beliefs and contextual factors influence teacher practice. The chapter concludes with the presentation of the study's conceptual framework.

## Setting the context

In order to understand the constructs of higher order thinking and reasoning, it is important to first look at scientific literacy. Higher order thinking and scientific reasoning are components of scientific literacy.

### Scientific literacy

There is an international consensus that scientific literacy is a key goal of science education (Goodrum, Hackling, & Rennie, 2001; OECD, 2013; Osborne, 2007; Roberts, 2007; Skamp, 2008), as it has influenced educational reforms, science curricula and teacher pedagogical practices (De Boer, 2000). However, there is no real consensus when defining scientific literacy (Roberts, 2007). De Boer (2000) and Roberts (2007) indicate that the concept of scientific literacy has evolved from the late 1950s and continues to evolve with the advancement of science, technology (OECD, 2013) and significant world events.

In the literature, the term scientific literacy is often used with differing connotations; an endpoint attained through education (Australian Academy of Science, 2013b; Wyatt & Stolper, 2013; Wyatt & Stolpher, 2013) or a developmental process (Skamp, 2008; Thomson, Hillman, & De Bortoli, 2013; Tovey & Patty, 2013) where the level of scientific literacy is developed incrementally over time; being a journey not an all or nothing attainment. Roberts (2007) identifies two polarized curriculum visions for scientific literacy; where science matter and human affairs can be complementary. What has remained consistent over time is the importance of scientific literacy for making sense of the world, successful life choices and the health of communities and nations (De Boer, 2000; Feasey, 2008; Goodrum et al., 2001; OECD, 2013; Rennie, 2005; Skamp, 2008). The following description by Hackling, Goodrum and Rennie (2001), illustrates the facets encompassed by this term and the competencies possessed by a scientifically literate citizen:

> Be interested in and understand the world around them, engage in the discourses of and about science, be sceptical and questioning of claims made by others about scientific matters, be able to identify questions, investigate and draw evidence-based conclusions, and make informed decisions about the environment and their own health and well-being. (Hackling, Goodrum & Rennie, 2001, p. 7)

The Organisation for Economic Co-operation and Development (OECD) in preparing for the 2015 round of the Program for International Student Assessment (PISA) redefined their definition of scientific literacy with the view of improving education policies and outcomes to satisfy the requirements of a more technologically and data driven contemporary society. It states that:

> Scientific Literacy is the ability to engage with science-related issues, and with the ideas of science, as a reflective citizen.
>
> A scientifically literate person, therefore, is willing to engage in reasoned discourse about science and technology which requires the competencies to:
>
> 1. **Explain phenomena scientifically:** recognise, offer and evaluate explanations for a range of natural and technological phenomena.
> 2. **Evaluate and design scientific enquiry:** describe and appraise scientific investigations and propose ways of addressing questions scientifically.
> 3. **Interpret data and evidence scientifically:** analyse and evaluate data, claims and arguments in a variety of representations and draw appropriate scientific conclusions. (OECD, 2013, p. 7)

Similar to Hackling et al. (2001), the OECD definition for scientific literacy is defined in terms of a set of competencies a scientifically literate person would be expected to exhibit, but the context for the definition is specific for the PISA testing as opposed to a general definition for all citizens. Asserting that the purposes of science education should be broad and applied, the OECD definition “refers to both to a knowledge of science and science-based technology" (OECD, 2013, p. 3). The definition continues the inclusion of the affective domain as discussed by Bybee and McCrae (2011) but doesn't include the application of knowledge and skills to everyday decision making which is prominent in the Hackling et al. (2001) definition.

Even though the focus of this study is on the development of higher order cognitive skills, it is important to remember the significance of content and conceptual knowledge. Students need to have a level of content or conceptual knowledge to think and reason with and about. As stated by Zohar and Dori (2003) "thinking skills are embedded in rich science contents and are also addressed as explicit educational goals" (p. 153) and that students' content knowledge has a significant impact on students' ability to solve analytical problems. Bao, Cai and colleagues (2009) support this notion by suggesting that "a balanced method of education, such as incorporating more inquiry-based learning that targets both [cognitive and conceptual] goals" should be invested in by educators (p. 587).

With this in mind, scientific literacy in this study, will refer to an amalgamation of these descriptions; combining both the application of knowledge and skills to everyday decision making prominent in Hackling et al. (2001) with "knowledge of science and science-based technology" featured in the OECD definition (2013, p. 3); both of which are necessary for the development of STEM capabilities. Two components of scientific literacy incorporated in these definitions and at the core of this research are scientific reasoning and higher order thinking (Hackling, 2014; Osborne, 2007; Zohar & Dori, 2003). These two important constructs in their own right encompass a set of skills that need to be taught to students. Prior to teaching them, teachers need to have an understanding of what they are in relation to the context of their teaching.

**Scientific reasoning**

With the current focus on the development of higher order thinking and STEM skills as educational outcomes (R. Collins, 2014; West, 2012), there is an increased interest in reasoning across subjects in primary school classrooms (Tytler, 2017). There is an array of interpretations and perspectives within fields of study and within and across cultures for the term reasoning (Tytler, 2017). The definition for reasoning in its broadest sense that will be adopted in this study is based on Peirce's (1981) definition of reasoning which Tytler characterises simply as "moving thinking forward" (Tytler, 2017, p. 226). Reasoning occurs in many forms and across modalities. It maybe language-based (Hackling & Sherriff, 2015) or in the form of representations such as in the written form or drawings (Tytler, Murcia, et al., 2017), or may occur through or demonstrated by embodied experiences (Ibrahim-Didi, Ramseger, Hackling, & Sherriff, 2017). One of the key foci of this study is scientific reasoning.

Zimmerman (2005) describes scientific reasoning as "the thinking skills involved in inquiry, experimentation, evidence gathering, inference and argumentation that are done in the service of conceptual change or scientific understanding" (p. 1). The Trends in International Mathematics and Science Study (TIMSS) assesses scientific reasoning skills of Year 4 and Year 8 students through questions that identify students' ability to: analyse/solve problems, integrate/synthesise, hypothesise/predict, design/plan, draw conclusions, generalise and evaluate (Mullis et al., 2007). Another important form of reasoning relevant to this study is argumentation.

Argumentation is a formalised syllogistic language-based form of reasoning; and, unlike simple reasoning, quality argumentation is a skill that needs to be scaffolded and taught through instruction, structuring and modelling (Dawson & Carson, 2018; Hackling & Sherriff, 2015; Osborne et al., 2004). Toulmin's model of argumentation (1958) has been widely used in science education to analyse reasoning and as a framework for forming arguments (Erduran, Simon & Osborne, 2004; Naylor et al., 2007; Simon, 2008). A simple argument using Toulmin's model would consist of an observation or some form of evidence (Grounds) leading to a conclusion or, statement of hypothesis (Claim). A more complex or higher thinking level argument would include reasons or justification (Warrant) for that claim. Teachers scaffold higher order reasoning by prompting students to use warrants; by asking open questions like "Why?" or by using metacognitive prompts like "Tell me why" or by using syntactical links like "Because…" to help students to justify and provide reasons for their claims (Hackling & Sherriff, 2015). For more sophisticated complex arguments Toulmin's model outlines other elements such as backing, clarifying claims, qualifier and rebuttal that require higher levels of thought and reasoning (Jimenez-Aleixandre, Otero, Santamaria, & Mauriz, 2009).

**Higher order thinking**

In recent times higher order thinking has been characterised by terms such as critical and creative thinking and innovation; particularly during discussions relating to 21st century skills and the skills, ways of thinking and types of knowledge described as STEM capabilities required to drive the economies and to prepare future workforces (Australian Department of the Prime Minister and Cabinet, 2015; Hackling, 2015; Office of the Chief Scientist, 2015a).

Higher order thinking encompasses the more complex cognitive processes identified in the cognitive domain of Bloom's revised taxonomy such as analysis, evaluation and synthesis or creation of new knowledge (Krathwohl, 2002) (Figure 2.1).

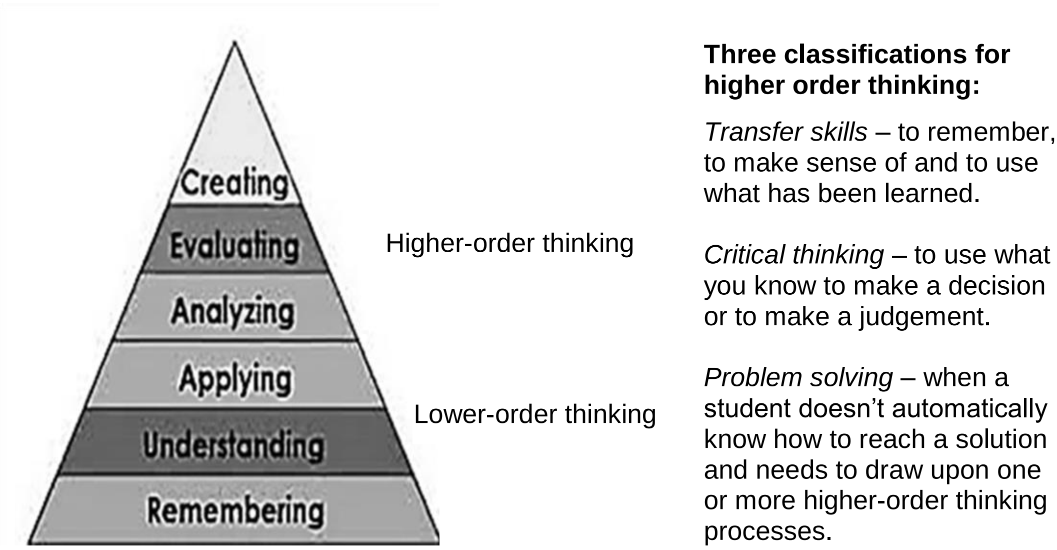



**Figure 2.1: Bloom's Revised Cognitive Domain Taxonomy (Krathwohl, 2002) and Brookhart's (2010) three classifications for higher order thinking**

For example, students engage in higher order thinking when they *analyse* or draw connections among ideas as they differentiate, organise, relate, compare, contrast, distinguish, examine, experiment, question and test; *evaluate* or justify a stand or decision as they appraise, argue, defend, judge, select, support, value, critique and weigh; and, *create* or produce new or original work as they design, assemble, construct, conjecture, develop, formulate, author and investigate (Armstrong, 2016). Brookhart (2010) classified higher order thinking into three process categories; transfer, critical thinking, and problem solving. She further clarifies these categories by giving simple examples. Transfer is to remember, to make sense of and to use what has been learned. Critical thinking involves using what you know to make a decision or to make a judgment. Problem solving is when a student wants to reach an outcome but doesn't automatically know how to reach a solution and so needs to use one or more higher-order thinking processes. In contemporary education there is a strong focus on children being creative, particularly in the area of information and communication technologies (ICT). The *Australian Curriculum: Science* was developed as an initiative to reform science education and to provide a relevant, student-centred national science curriculum focused on science literacy and science inquiry and encouraged higher order thinking and scientific reasoning.

**The Australian Curriculum: Science**

The aim of the *Australian Curriculum: Science* is to promote scientific literacy and to develop students who are interested, skilled, knowledgeable and independent future citizens, capable of investigating "the natural world and changes made to it through human activity" (Australian Curriculum, 2016, p. 4). Higher order thinking and scientific reasoning skills such as analysis, evaluation and creation of new knowledge are promoted in the *Australian Curriculum: Science*, across the three Science strands: Science Understanding; Science as a Human Endeavour; and, Science Inquiry Skills; and, the five inquiry sub-strands (Questioning and predicting, Planning and conducting, Processing and analysing data and information; and, Evaluating and communicating) of *Australian Curriculum: Science*. Critical and creative thinking (Connolly, Dulhunty, Pedrazzini, et al., 2017), being the highest category level in Bloom's revised taxonomy (Krathwohl, 2002) is listed amongst seven general capabilities of the *Australian Curriculum* (https://www.australiancurriculum.edu.au/f-10-curriculum/general-capabilities/). Praised for its constant development and keeping current with scientific and educational developments and educational reforms, the *Australian Curriculum: Science* provides "a good basis for enabling teachers to teach science effectively"

(Goodrum, 2014, p. 3). Supportive and fully aligned with the *Australian Curriculum: Science*, is the *Primary Connections: Linking science with literacy* program. It is a valuable professional development program and curriculum resource that has successfully supported and continues to support many primary teachers in their teaching of science (Skamp, 2012).

**Primary Connections**

*Primary Connections: Linking science with literacy* (*Primary Connections*) is a highly awarded professional development and curriculum resource program developed in 2003 by the Australian Academy of Science to support the implementation of national science education reforms (Goodrum et al., 2001) and to enhance primary school teachers' confidence and competence for teaching science. It is currently supported by the Australian Government Department of Education and Training through the National Innovation and Science Agenda Science Agenda measure *Inspiring all Australians in Digital Literacy and STEM.* Tens of thousands of Australian teachers have received professional development in *Primary Connections* (Australian Academy of Science, 2018) and over half of the primary schools in Australia have or are currently using *Primary Connections* resources (Peers, 2011).

Similar to the *Australian Curriculum: Science*, *Primary Connections* is a dynamic program, which is constantly under review and development. This is exemplified by the updating and development of *Primary Connections* professional learning and curriculum resources, to incorporate a focus on STEM and the development of STEM capabilities in 2018. Based on the principles of social constructivism and an argumentation pedagogy, students are encouraged "to make scientific claims and support these claims with evidence, and also to discuss and critique the evidence of others" (Peers, 2011, p. 4). *Primary Connections* curriculum resources promote cooperative hands-on inquiry learning and facilitate opportunities for higher order thinking and scientific reasoning through an inquiry and investigative approach. This is achieved through the use of the 5Es model; students representing and re-representing their understanding using a variety of different literacies; embedded authentic assessments; collaborative learning opportunities identifying linkages within the curriculum and outside of the classroom; a focus on developing evidence-based reasoning and critical thinking skills; and, by incorporating Indigenous perspectives (https://primaryconnections.org.au/about/our-teaching-and-learning-approach).

Despite the implementation of the *Australian Curriculum: Science* and education programs such as *Primary Connections*, the scientific literacy of Australian students (Thomson, De Bortoli, et al., 2013; Tovey & Patty, 2013); along with the general community (Wyatt & Stolper, 2013), continues to be of great concern to educators, industry and the government. A number of national and international assessment programs, provide an indication of the status of Australia's scientific literacy, higher order thinking and scientific reasoning.

**Status of scientific literacy, higher order thinking and scientific reasoning**

There are a number of national and international assessments utilised by Australia to indicate the status of Australia's scientific literacy, higher order thinking and scientific reasoning. Three of these assessments are: the National Assessment Program (NAP-SL), the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS).

***NAP-SL***

The National Assessment Program – Science Literacy (NAP-SL) is part of the national sample assessments developed and managed by Australian Curriculum, Assessment and Reporting Authority (ACARA). Commencing in 2003, every three years NAP-SL assesses the scientific literacy of approximately five per cent of Australia's Year 6 student population and (after 2015) Australia's Year 10 student population (Connolly, Dulhunty, Pedrazzini, et al., 2017). NAP-SL assesses science-based knowledge, understandings and skills; and, surveys students' interest in science, their engagement in science related activities and their understanding of how science is relevant in their lives (Kesidou et al., 2012). In terms of scientific literacy, higher order thinking and scientific reasoning,

> NAP–SL is testing a student's ability to apply their science knowledge to real world science concepts. This requires analysis within particular contexts and an ability to connect the inherent science with the provided

> observations and data to the given context. That is, it requires students to use their thinking skills. (Connolly, Dulhunty, Pedrazzini, et al., 2017, p. 155)

The latest available NAP-SL 2015 results signify that the scientific literacy of Australia's Year 6 population has not improved significantly from previous assessments. For example, in 2015, NAP-SL results indicated that 55.1 % of students at the national level, attained at or above the proficient standard in scientific literacy which is not statistically significantly different from 2006 (54.3 %), 2009 (51.9 %) and 2012 (51.4 %) NAP-SL results (Connolly, Dulhunty, Pedrazzini, et al., 2017). Emeritus Professor Steven Schwartz AM and Chair of the ACARA Board, commented that the NAP-SL 2015 results highlight the need for improvements in primary school science teaching and cautions "to remain creative and competitive economically and socially Australia needs more than 55.1 % at or above the proficient standard" (Schwartz in Connolly, Dulhunty, Pedrazzini, et al., 2017, p. 17).

***PISA***

The Program for International Student Assessment (PISA) directed by the Organisation for Economic Co-operation and Development (OECD), assesses a sample population of 15 year olds every three years and compares mathematics, science and reading literacies across a large sample of countries. The PISA science literacy assessment framework assesses three levels of cognitive demand.

- *Low cognitive demand:* items required students to carry out a one-step procedure, such as recalling a fact or locating a single point of information from a table or graph.
- *Medium cognitive demand:* items required students to use and apply their conceptual knowledge to describe or explain phenomena, select appropriate procedures involving two or more steps, organise or display data, interpret or use simple data sets or graphs.
- *High cognitive demand:* items required students to analyse complex information or data, synthesise or evaluate evidence or justify, reason, or develop a plan or sequence of steps to approach a problem.
  (Thomson, De Bortoli, & Underwood, 2017, p. 22)

An average score for scientific literacy is calculated using a scaling of scientific literacy items. Australia's average score in scientific literacy in 2015 was 510 points which is significantly above the OECD average of 493. What is concerning though, is

Australia's declining trend in performance in PISA assessments. For example, Australia's average scientific literacy score from 2006 to 2015 declined by 17 points, with the most substantial decline being 12 points from 2012 to 2015; the proportion of low performers increased from 13% in 2006 to 18% in 2015; the proportion of high performers declined from 15% in 2006 to 11% in 2015; and, in 2015, 61% of Australian students achieved the National Proficient Standard in scientific literacy compared to 67% in 2006 (Thomson, De Bortoli, et al., 2017).

In comparison to other countries and in terms of schooling years, Australia's average PISA 2015 scientific literacy score equates to a half a year to one-and-a-half years' behind the nine countries who performed significantly higher than Australia in PISA 2015, namely Singapore, Japan, Estonia, Chinese Taipei, Finland, Macao (China), Canada, Vietnam, and Hong Kong (China) (Connolly, Dulhunty, Pedrazzini, et al., 2017; Thomson, De Bortoli, & Underwood, 2016).

***TIMSS***

The Trends in International Mathematics and Science Study (TIMSS) assesses Year 4 and Year 8 students in Mathematics and Science every four years. It is a substantial study with 580,000 students from 57 countries participating in 2015 (Martin et al., 2016). TIMSS science assessment assesses both content and cognitive dimensions. Cognitive test items are embedded with science practice test items (e.g., asking questions based on observations, generating evidence, working with data, answering the research question, making an argument from evidence) within content dimension test items. The content dimension "specifies the subject matter to be assessed within science (e.g. life science,. . . physical science [and earth science])" (Thomson, Wernert, et al., 2017, p. 78) and the cognitive dimension "specifies the thinking processes and sets of behaviours expected of students as they engage with the science content" (Thomson, Wernert, et al., 2017, p. 78).

The cognitive domain test items provoke the use of particular cognitive skills and abilities which are classified into the following three behavioural skills domains which increase in cognitive demand as the list progresses. The three domains can be described as follows:

- Knowing – which covers the facts, procedures and concepts students need to know
- Applying – which focuses on the ability of students to apply knowledge to generate explanations and to solve practical problems
- Reasoning – which includes using evidence and science understanding to analyse, synthesise and generalise, often in unfamiliar situations and complex contexts. (Thomson, Wernert, et al., 2017, p. 79)

The science cognitive assessment dimensions (thinking processes) of knowing, applying and reasoning, assess scientific literacy and the incremental development of students' higher order thinking as they evaluate the students' ability to go "beyond the solution of routine science problems to encompass unfamiliar situations, complex contexts, and multi-step problems" (Martin et al., 2012, p. 142). As with NAP-SL 2015 and PISA 2015 results, TIMSS 2015 results suggest that Australia's overall standard in scientific literacy, higher order thinking and scientific reasoning has not improved. Despite a significant improvement in Australia's 2015 Year 4 overall cognitive score of 524 (refer to Table 2.1) from 2011's score of 516, the overall cognitive score in 2015 is below the score of 527 achieved in 2007.

**Table 2.1: Comparison of Australia's Year 4 TIMSS science cognitive domain scores for 2007, 2011 and 2015**

| **Australia** | World rank* | *Knowing* average scale score | *Applying* average scale score | *Reasoning* average scale score | Overall average cognitive score |
|---|---|---|---|---|---|
| 2007 | 13 (44) | 532 | 522 | 528 | 527 |
| 2011 | 24 (52) | 517 | 513 | 518 | 516 |
| 2015 | 25 (57) | 523 | 522 | 527 | 524 |

**The total number of participating countries or economies for that year is recorded in the brackets*

With In the eight year period (2007 – 2015), Australia's overall world ranking dropped 12 places putting it below most Asian countries, USA and Germany (Martin et al., 2012; Thomson, Wernert, et al., 2017; Thomson, Wernert, Underwood, & Nicholas, 2008) (refer to Table 2.2). With 50 points being equivalent to approximately 1.5 years of schooling (Thomson et al., 2012), Australia's 2015 Year 4 average cognitive *reasoning* score of 527 and higher order thinking ability is significantly below Chinese

Taipei (558), Korea (594) and Singapore (605), (Thomson, Wernert, et al., 2017); that is, approximately 1 - 2.5 years of schooling behind these countries.

TIMSS benchmark achievement data is also useful for comparing student achievement among and within countries (refer to Table 2.3). Australia's Year 4 2015 advanced benchmark achievement was the same as Germany but well below, Singapore, Korea, Chinese Taipei and USA, who had two to four times more of their population reaching the Advanced benchmark standard than Australia.

**Table 2.2: Australia's Year 4 TIMSS 2015 science cognitive domain score compared to other countries**

| Country | World rank* | *Knowing* average scale score | *Applying* average scale score | *Reasoning* average scale score | Overall average cognitive score |
|---|---|---|---|---|---|
| Singapore | 1 | 574 | 599 | **605** | 590 |
| Korea, Rep. of | 2 | 582 | 594 | **594** | 589 |
| Chinese Taipei | 6 | 557 | 553 | **558** | 555 |
| USA | 10 | 548 | 546 | 542 | 546 |
| Germany | 20 | 527 | 529 | 532 | 528 |
| **Australia** | **25** | **523** | **522** | **527** | **524** |

**Total number of participating countries and economies for Year 4 TIMSS Science for 2015 was 57*

**Table 2.3: Australian percentage of Year 4 students reaching the international benchmarks for TIMSS 2015 science achievement compared to other countries**

| Country | Below low benchmark | Low benchmark | Intermediate benchmark | High benchmark | Advanced benchmark |
|---|---|---|---|---|---|
| Singapore | 3 | 7 | 19 | 34 | **37** |
| Korea, Rep. of | 0 | 4 | 21 | 46 | **29** |
| Chinese Taipei | 2 | 10 | 32 | 42 | **14** |
| USA | 5 | 14 | 30 | 35 | **16** |
| Germany | 4 | 18 | 38 | 32 | **8** |
| **Australia** | **4** | **21** | **36** | **31** | **8** |

Of more concern to Australia, however, are the 21 % of Year 4 Australian students who only met the low international benchmark and the four per cent who did not even reach that (Thomson, Wernert, et al., 2017).

The TIMSS data revealed a large gap between the leading countries and where Australia is situated in regards to Science achievement and cognitive processes. A review of national and international assessments indicates that scientific literacy, higher order thinking and scientific reasoning in primary school has not improved over the last decade and Australia is becoming less competitive internationally. Dr Thomson, the Director of Educational Monitoring and Research at the Australian Council for Educational Research (ACER) comments that even though Australia has made efforts to improve scientific literacy, higher order thinking and scientific reasoning, more needs to be done. She states that,

> Australia is already making efforts to improve the quality and effectiveness of classroom teaching for improved student outcomes through work on the Australian Curriculum, national professional standards for teachers and school leaders, coordinated approaches to school improvement that focus on practices that specifically enhance the quality of teaching and learning, and a more fine-grained approach to monitoring school systems in terms of student outcomes through the National Assessment Program – but we need to do more.
> (Thomson, De Bortoli, et al., 2013, p. 2).

It will be interesting to observe the outcomes of the next rounds of national and international testing to see whether advances have indeed been made. The theoretical perspectives for the study will now be presented.

## Theoretical perspectives

It is important to understand the interacting relationships between teacher, students, resources, social and cultural settings when analysing the teaching and learning processes of contemporary science classrooms. For this reason this study will draw from the social constructivist and sociocultural theories with input from distributed cognition and social semiotic theories. All of these perspectives espouse the social nature of learning through interactions with others and/or objects and provide a useful view to investigate how a teacher supports, scaffolds and creates opportunities for higher order thinking and scientific reasoning.

**Social constructivism**

Through the lens of social constructivism knowledge is co-constructed through talk and interactions between the learner, teacher and other learners (Driver, Asoko, Leach, Mortimer, & Scott, 1994). Students drawing on prior knowledge make meaning from experiences in the classroom and conversation with others. The teacher guides learning by providing opportunities for high level discussion and by scaffolding students' ideas and language development (Tytler, 2012). Optimising opportunities for class and small group discussion is important as this is when individual conceptual positions tend to surface and are open for negotiation (Tytler, 2012). Sharing ideas and having them critiqued can be difficult for students and so it is up to the teacher to create a safe learning community where students know and are comfortable with the negotiation and co-construction process (Driver et al., 1994; Mercer & Howe, 2012; Tytler, 2012; Watters & Diezmann, 1998). Learners are expected to work with others, to negotiate meanings, to seek support when needed and share experiences with the teacher and peers. They are also encouraged to develop metacognitive strategies; to reflect, explain, justify and develop problem solving strategies (Hackling, Smith, & Murcia, 2010; Tytler, 2012; Watters & Diezmann, 1998). It is therefore a useful perspective to view how the teacher scaffolds, supports and creates opportunities for higher order thinking and scientific reasoning.

**Sociocultural theory**

Sociocultural theory runs parallel to the social constructivist theory. Both theories involve the construction of knowledge through social interactions but the sociocultural perspective gives more explicit recognition to culture, language and teacher support. Knowledge construction is guided through 'teaching and learning' rather than 'learning' or 'joint construction' as in the social constructivist perspective (Mercer & Howe, 2012; Tytler, 2012). Learning is considered to be a part of greater communities or cultures and interactions both social and cultural are not limited to the classroom. Many different sources and levels of culture, influence personal and shared knowledge construction: the school, classroom, small group and an individual's personal cultural influences together with "the culture of science with its particular forms of language, reasoning and representation" (Hackling, Murcia, & Ibrahim-Didi, 2013, p. 1).

Russian psychologist, Lev Vygotsky (1896-1934) provided much of the framework for this theory. He distinguishes between collective meaning making on the social plane of the classroom and the role of the individual in internalising the constructed understanding in a way that is meaningful to that person (Mortimer & Scott, 2003). Vygotsky highlights the importance of tools like language and culture for mediating learning (Vygotsky, 1978). We use language as a communication tool or 'mediator' to transform ideas and experiences into knowledge and understanding for ourselves and others, and as a means for negotiation and co-construction of knowledge (Mercer & Howe, 2012; Tytler, 2012). Every subject has its own specific social language (Hackling et al., 2010; Mortimer & Scott, 2003; Vygotsky, 1978). Becoming proficient in the subject specific language assists us to gain conceptual understandings through conversing with others (Lemke, 1998). Language is also an essential cultural tool, where sharing and collectively making sense of experiences transforms experience into cultural knowledge and understanding (Mercer & Howe, 2012). 'Enculturing' students in science for example (Tytler, 2012) helps students to see, know and represent the world through science; and, to develop scientific literacy (Goodrum et al., 2001; Hackling et al., 2010).

Vygotsky's other significant contribution is the Zone of Proximal Development (ZPD). He (Vygotsky, 1978) defined ZPD as, "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (p. 86). It is the notion that individuals can complete more academically demanding tasks with the support of scaffolding or tutelage by an adult or a more experienced peer (Tytler, 2012; Van de Pol, Volman, Elbers, & Beinshuizen, 2013; Wood, Bruner, & Ross, 1976) who takes on the conscious control of the learning task until the learner is able to take over the control for themselves. When the learner takes control of the new conceptual system or task, it is then they can use it as a tool. Until that point, the teacher acts as a tutor or scaffolder making it possible for the student to perform the task, that is "in Vygotsky's words, to internalise external knowledge and convert it into a tool for conscious control" (Bruner, 1985, p. 25). Scaffolding reduces the cognitive demand of the task (Tytler, 2012). Students can be challenged and assisted to access higher order concepts if they are scaffolded with tasks that are within their ZPD. Conversely if tasks are set beyond the limits of ZPD, it is unlikely even with support that they could accomplish the task (Hardman, 2008; Mortimer & Scott, 2003). Scaffolding will be discussed in greater detail later in this review.

**Social semiotic theory**

The social semiotic perspective is similar to the theories previously discussed in that meaning making is a social process. It is the study of social meaning making practices (Kress, 2010; Lemke, 1990; Saussure, 2013; Thibault, 1991; Van Leeuwen, 2004) and highlights the importance of time, culture, context and even classroom specific resources in this process (Hackling et al., 2013; Hodge & Kress, 1988; Kress, 2010). Language is an important and central semiotic resource for mediating learning (Vygotsky, 1978) but it only represents one mode amid a set of semiotic modes. Social semiotics classifies any resource that assists with meaning making as a semiotic resource and recognises that meaning making draws from a range of modes (e.g., visual, verbal, written, gestural, embodied) and that all contribute to meaning making within multimodal classroom environments (Hackling et al., 2013; Hodge & Kress, 1988; Jewitt, 2009; Kress & Van Leeuwen, 2001). With technological advancements and the availability of digital and other resources, contemporary classrooms have the potential to be multimodal learning environments (Hackling et al., 2013; Prain & Tytler, 2012), by offering a combination of semiotic resources across a number of sensory modes to support meaning making and knowledge construction.

**Distributed cognition**

Distributed cognition builds upon social constructivist and sociocultural theories with the notion that human cognition is fundamentally a cultural and social process (Hutchins, 1995; Nersessian, 2005). It emphasises the role of the learning environment; that cognition in not in the mind of the knower but is distributed between people and across materials, objects and time (Hollan, Hutchins, & Kirsh, 2000; Hutchins, 2010; Nersessian, 2006) and their interactions within that environment (Liu, Nersessian, & Stasko, 2008; Nersessian, 2009). Tools and artefacts mediate the learning process as amplifiers of cognition and transformers of difficult tasks into simpler more doable cognitive tasks (Hutchins, 1995). Distributed cognition, therefore, has clear implications for this study. Small group science learning environments provide opportunities for collaboration and co-construction of knowledge through 'hands-on' material and student-centred inquiry. Students develop and use cognitive skills to process information, reason, remember, relate and problem solve (Bennett, Lubben, Hogarth, & Campbell, 2004) through interaction with fellow students, the teacher, materials and objects.

The theoretical frameworks of social constructivist, sociocultural and social semiotic theories, together with distributed cognition, provided multiple lenses through which the researcher viewed how teachers used the social role of learning, the classroom culture, semiotic resources and multimodality in the scaffolding, supporting and creation of opportunities for higher order thinking and scientific reasoning.

The next two sections discuss literature relating specifically to the research questions. The first section discusses pedagogical practices and the second section provides a short overview of a selection of contextual factors.

## Literature relating to pedagogical practices

This section discusses literature relating to the main subsidiary research question, *What pedagogical practices do teachers employ and how do they scaffold, support and create opportunities for higher order thinking and scientific reasoning?* Pedagogical practices and teaching and learning models such as: scaffolding, inquiry teaching and learning, collaboration and small group learning; quality discourse, dialogic teaching; the 5Es and cognitive apprenticeship models; metacognition and representations will be discussed.

**Scaffolding**

Teacher scaffolding is a key focus for this research. Scaffolding assists students with learning and is considered to be at the heart of good teaching, as it provides the learner with support to complete an activity in which they currently lack competence and confidence to complete on their own (Mercer, 1995). Vygotsky (1987) very succinctly catches the essence of scaffolding by stating "what the child is able to do in collaboration today he will be able to do independently tomorrow" (p. 211). There are many interpretations, applications and contexts for scaffolding within classrooms. For example, it can refer to various kinds of support teachers provide (Mercer, 1995; Pea, 2004) to more complex applications such as Vygotsky's ZPD, which was discussed previously with sociocultural theory (Vygotsky, 1978). Bruner first introduced the concept of scaffolding in the late 1950s. His description parallels Vygotsky's in the sense that it is support given to a younger learner by an adult or more experienced learner (Wood et al., 1976). Mercer (1995) describes Bruner's (1978) view of scaffolding as a:

> . . . particular kind and quality of cognitive support which an adult can provide through dialogue, so the child can more easily make sense of a difficult task. . . . a form of 'vicarious consciousness' provided by the adult for the benefit of the child. (Mercer, 1995, p. 73)

Scaffolding is not a theory but a technique or process within a broad range of learning theories (Bruner, 1966). It has emerged out of the sociocultural theory. Within the sociocultural perspective, a peer or teacher can become actively and intimately involved in another's learning through the scaffolding process (e.g., peer tutoring and cooperative learning strategies), enabling the learner to progress further and more easily through the support of another (Bruner, 1978; Mercer, 1995). From the social constructivist perspective, the learner adds to their prior knowledge through the support of a more capable other (Raymond, 2000). Teachers as active guides, monitor learning, adjust their level of support according to the students' level of understanding and develop further opportunities to continue learning. Van de Pol, Volman and Beinshuizen (2013) argue that teacher diagnosis should occur frequently as illustrated in the four steps of their Model of Contingent Teaching (see Figure 2.2), which is based on the contingency or adaptive nature of scaffolding; that is the changing amount of support given to the learner due to the amount of support needed by the learner. Their model demonstrates the step by step cyclical nature of the scaffolding process and the importance of the teacher listening to or observing the student's response before moving to the next step in the process.

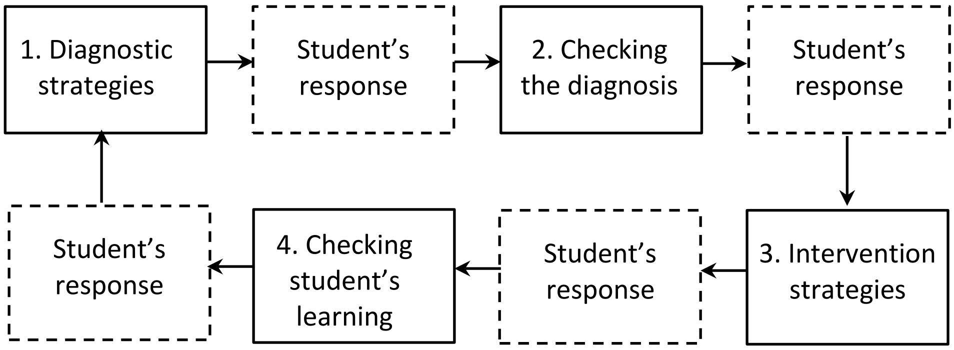



**Figure 2.2: Model of Contingent Teaching (Van de Pol, Volman, Elbers, & Beinshuizen, 2013, p. 154)**

Scaffolding provides access to meaning and learning (Bruner, 1966; Hoffmeyer, 2014) and as such is a semiotic tool. When the scaffolding has been removed and the control of the task has been handed over to the learner, these tools become independent and personal tools of the learner which can be utilised by them for further learning. There are many interpretations, applications and contexts for scaffolding within classrooms from simple teacher support (Pea, 2004; Ramseger & Freitag-Amtmann, 2011) to more complex applications such as Vygotsky's ZPD (Vygotsky, 1978). The following fundamental points of scaffolding are highlighted as being relevant for this study.

- Scaffolding involves the interaction between two people (or more when dealing with cooperative small groups) within classrooms; that is, a more knowledgeable teacher or more experienced peer, and a learner or less experienced peer who is not able to achieve the learning goal on their own (Mercer, 1995; Van de Pol et al., 2013; Wood et al., 1976).

- The scaffolder provides vicarious (external to the learner) conscious control (Bruner, 1985; Vygotsky, 1978) of the task until the learner has acquired the necessary learning or control to complete the task on their own.
- The teacher reduces the “degrees of freedom in carrying out some tasks so that the child can concentrate on the difficult skill she is in the process of acquiring" (Bruner, 1978, p. 19; Vygotsky, 1978).
- The scaffolder requires diagnostic ability to ascertain the learners’ capability and level of understanding prior to and during the learning task to judge the nature of scaffolding required and when to fade it out (for example, see Figure 2.2). Many researchers, however, have reported that teachers often do not do enough diagnosis during the scaffolding process (e.g. Pea, 2004; Van de Pol, Volman, & Beinshuizen, 2010).
- Scaffolding is removed incrementally as the learner increases her/his ability. This process is often referred to as fading where the support is faded out when the responsibility for the task is transferred to the learner (Pea, 2004).

Some examples of pedagogical strategies used in scaffolding are: instructing (for example, Bybee et al., 2006; Caine & Caine, 2014a; Jumaat & Tasir, 2014), explaining, modelling and coaching (for example, Brill, Kim, & Galloway, 2001; García-Cabrero et al., 2018; Kluth & Straut, 2003); sequencing of tasks (for example, A. Collins, Brown, & Holum, 1991), questioning (for example, Chesser, 2014; Chin & Osborne, 2010), prompting and feedback (e.g., gestural, verbal and positional); multiple multimodal representations (for example, Hackling et al., 2013; Ibrahim-Didi et al., 2017; Kress, 2010; Tytler, Murcia, et al., 2017), advanced organisers (e.g., flow charts and investigation planners), student performance feedback, clues or suggestions, worked examples, worksheets and handouts. As computers, use of the web, virtual laboratories and on-line learning are common features in contemporary classrooms technology scaffolds may also present in this study (Jumaat & Tasir, 2014).

When studying teacher pedagogical practices, it is also important to consider the instructional approaches that provide the foundations for pedagogies and strategies.

A well-considered instructional approach is a determining factor for the successful implementation and outcomes of pedagogies and strategies (Caine & Caine, 2014b). For this study instructional approach refers to a teacher's mental models regarding instruction (Caine & Caine, 2014a); their "dynamic set of context-driven decisions" (Glickman, 1991, p. 6) embracing facets of instruction such as teaching pedagogies and strategies, classroom climate and management and use of instructional settings (Caine & Caine, 2014b). Inquiry teaching and learning is an instructional approach used by many contemporary primary science teachers to scaffold and develop deeper level thinking and reasoning skills (Chen & Tytler, 2017).

**Inquiry teaching and learning**

Contemporary quality teachers of primary science in Australia and internationally, base their instructional approaches on inquiry teaching and learning (Chittleborough, Ramseger, Hsiung, Hubber, & Tytler, 2017). Adopted by many as an approach to teaching science and developing students' deeper level thinking skills, inquiry teaching and learning is ambiguously defined due to it often being linked to different theoretical perspectives which affects its framing (Chen & Tytler, 2017). Formulating a definition for it can be challenging as inquiry teaching can be placed on a continuum (Banchi & Bell, 2008) from "partial to full inquiry, . . . from guided to open inquiry, depending on the degree of responsibility allowed the learner as a result of the degree of closeness of scaffolding by the teacher" (Chen & Tytler, 2017, p. 95).

Despite the ongoing debate on the merits of different interpretations and combinations of teacher-led instruction and student discovery learning along the inquiry continuum (Clark, Kirschner, & Sweller, 2012; Furtak, Seidel, Iverson, & Briggs, 2012; Kirschner, Sweller, & Clark, 2006), there is a core element to inquiry teaching, in that it ". . . involves an emphasis on students being actively involved in reasoning and exploring ideas, with the teacher monitoring, shaping and responding to students' ideas rather than simply delivering knowledge" (Chen & Tytler, 2017, p. 95). This is supported in the Inter-Academies Panel (2010) statement that inquiry "goes beyond manipulation of materials to the key factor of engaging students in identifying relevant evidence, in critical and logical reasoning about it and reflection on its interpretation" (p. 4).

As the Researcher embraces an interpretation of inquiry that is situated in the middle of the inquiry continuum and due to the simplicity, succinctness and theoretical framing, Anderson's (2002) characteristics of inquiry will be utilised as the basic definition for inquiry in this study. Anderson (2002) describes inquiry using the following three headings: *Teacher's role*, *Student's role* and *Nature of student work* (Figure 2.3). The teacher takes the role of coach and facilitator and helps students to process information, coaches students' actions, facilitates student thinking and models the learning process. Students take the role of active participant in the exploration of ideas and are given opportunities and the responsibility to direct and process information, to interpret, explain and hypothesise, to design their own activities and to share the authority for answers. The nature of student work is student-directed learning, with students directing their own learning, tasks vary among students, students design and direct their own tasks and student work emphasises reasoning, reading and writing for meaning, solving problems, building from existing cognitive structures and explaining complex problems.

<table>
<tr><th>Teacher Role:</th><th>Student Role</th></tr>
<tr><td>As a coach and facilitator:<br>• Helps students to process information<br>• Communicates with groups<br>• Coaches students' actions<br>• Facilitates student thinking<br>• Models the learning process<br>• Flexible use of materials</td><td>As a self-directed learner:<br>• Processes information<br>• Interprets, explains, hypothesises<br>• Designs own activities<br>• Shares authority for answers</td></tr>
<tr><th colspan="2">Nature of Student Work</th></tr>
<tr><td colspan="2">Student-directed learning:<br>• Student directs own learning<br>• Tasks vary among students<br>• Students design and direct own tasks<br>• Student work emphasises reasoning, reading and writing for meaning, solving problems, building from existing cognitive structures, and explaining complex problems</td></tr>
</table>

**Figure 2.3: Anderson's (2002) characteristics of inquiry teaching and learning**

Anderson's (2002) description, however, doesn't emphasise some areas of inquiry teaching and learning that are important for this study. For example, the importance of hands-on experiences (Chittleborough et al., 2017; Peers, 2011), providing students with opportunities for talk and collaboration; and, creating a safe and supportive learning environment (Pieczura, 2009); all of which are key facets of contemporary primary science inquiry (Alexander, 2018; Gillies, 2016; Scott & Meiers, 2009). This may be due to the focus of Anderson's (2002) description being on the individual student rather than students working in collaboration (Bennett, Hogarth, Lubben, Campbell, & Robinson, 2010; Hackling, Aranda, & Freitag-Amtmann, 2017). Collaboration, whether it be in paired work, small group or whole class contexts (Hackling, Aranda, et al., 2017), is a key pedagogical practice in inquiry learning.

**Collaboration and small group learning**

Research over the last two decades has highlighted the broad spectrum of benefits of collaborative learning and in particular, the benefits of small group learning (for example, Bennett et al., 2004; Gillies, 2012; Hackling, Aranda, et al., 2017; R. T. Johnson & Johnson, 1994). Hackling, Peers and Prain (2007) for example, contend that collaborative learning "facilitates gains in achievement, higher order thinking, generation of new ideas, and in social and communication skills" (p. 14).

Small group collaborative learning is consistent with social constructivist, sociocultural, distributed cognition and social semiotic perspectives. Individual students with their prior learning and experience interact verbally, socially, physically and culturally with peers (typically three to four students) (Bennett et al., 2004) and materials, to jointly construct knowledge and understanding. Compared with the whole class setting, small group work allows students to have greater access to materials, be more cognitively and physically active in their own learning; and, gives greater opportunity for students to explore, talk, listen, think out-loud, problem solve and discuss their science ideas and understandings with peers (Bennett et al., 2004; Driver et al., 1994; Hackling, Aranda, et al., 2017; Hodgkinson & Mercer, 2008). By talking through ideas and sharing experiences (Goodrum & Druhan, 2012), students can clarify and organise their thoughts and understanding (Bennett et al., 2004; Ramseger & Freitag-Amtmann, 2011), identify incorrect conceptions (Skamp, 2008) and be scaffolded by more experienced peers (Mercer, 1995).

Whilst working in collaboration has the potential to develop critical thinking, argumentation and problem solving skills (Waldrip & Prain, 2017), it can also bring a variety of challenges for individual students. To collectively reason and to come to a group consensus requires critical engagement with other students' ideas (Mercer, Hennessy, & Warwick, 2017; Naylor, Keogh, & Downing, 2007; Richland & Simms, 2015). It also requires students to justify their positions, to accept criticism and to consider and challenge alternate perspectives. Setting guidelines for collective reasoning ensures students feel safe and supported. Exploratory talk guidelines (Littleton & Mercer, 2013; Richland & Simms, 2015; Rojas-Drummond & Zapata, 2004) such as: everybody offers their relevant information and everyone's ideas are treated as worthy of consideration, ask questions and answer questions; and, members of the group try to reach agreement at each stage before progressing (Littleton & Mercer, 2013) is one example of guidelines that provide students with a structure for collective reasoning and ensures students of all abilities feel safe and supportive to share their ideas. In addition to collaboration, encouraging quality discourse is a strategy that supports inquiry and the development of higher order thinking and scientific reasoning.

**Quality discourse**

There is a clear association between quality discourse, quality learning and quality reasoning (Alexander, 2018). Discourse is essential for talking and thinking about the world (Mortimer & Scott, 2003) and is the basis for communication and learning (Alexander, 2017), but, it is more than talk or dialogue; it is a pattern or mechanism of teacher and student talk and interaction (Kaya, 2014; Mortimer & Scott, 2003). Discourse is essential for science inquiry-based teaching and learning (Smith, 2013; Smith & Hackling, 2016). It is a tool for learning through social exchange and provides an indication of understandings and misunderstandings. Being an important component of scientific literacy, discourse enables students to explore and talk ideas into existence (Lemke, 1998), to critically evaluate science related information (Michaels & O'Connor, 2012) and allows a collaborative community of learners to co-construct meaning and conceptual understanding (Goodrum & Druhan, 2012; Louca, Zacharia, & Tzialli, 2012).

Quality classroom discourse is generally guided by the teacher and unlike general conversation, teachers mostly know its endpoint. "Classroom dialogue explicitly seeks to make attention and engagement mandatory and to chain exchanges into a meaningful sequence" (Alexander, 2017, p. 8), such as making conversation threads for language-based reasoning (Hackling & Sherriff, 2015). Research tells us that quality classroom discourse improves thinking, understanding, achievement, reasoning and argumentation (for example, Hackling, Ramseger, et al., 2017; Mercer & Howe, 2012; Scott & Meiers, 2009; Smith & Hackling, 2016). It is a vehicle for teachers to help students to work through their ideas, develop understandings and support meaning making through prompting, questioning (open and closed), modelling and scaffolding (Hackling et al., 2010; Mercer, 1995; Vygotsky, 1987). Strategies such as 'talk time' (Mercer, 2008), 'thinking time', 'wait time' (Alexander, 2018; Rowe, 1972; Smith, 2013) and 'sharing time' (Gillies, 2016) enhance the quality of discourse by allowing students to think-out-loud, to access, process, formulate and build their thoughts; and, to collaborate and to communicate their thoughts and ideas with others (Alexander, 2018; Scott & Meiers, 2009).

There have been numerous studies, which have highlighted that teachers' discourse practices impact students' thinking, reasoning and learning (for example, Alexander, 2000, 2017; Cormack, Wignell, Nichols, Bills, & Lucas, 1998; De Boer, 2000; 2003; Nystrand, Gamoran, Kachur, & Prendergast, 1997; Scott & Meiers, 2009). As a consequence, there have been many studies that have analysed, classified (for example, Mortimer and Scott's (2003) dialogic-authorative and interactive-non-interactive two dimensional categorisation of classroom discourse), postulated models and implemented professional learning interventions to understand and address this issue (for example, Alexander, 2014; Gillies, 2016; Kim & Roth, 2018; Louca et al., 2012; Smith, 2013; Smith & Hackling, 2016; Tytler, Aranda, & Freitag-Amtmann, 2017).

Alexander's substantial five-nation comparative study of classroom discourse in primary school classrooms (Alexander, 2001), highlighted that classroom talk was dominated by teachers and too little classroom talk was devoted to reasoning and dialogic teaching. Challenging interactions that encouraged students to think were scarce; questions were predominately closed, low level of cognition and were used more for evaluation rather than for promoting thinking and reasoning; teacher feedback was generic and not constructive and informative; interactions were largely teacher controlled; there was a domination of the I-R-E pattern in classroom discourse (Mehan, 1979) which limits the monitoring of learner's understandings and misunderstandings (Lemke, 1990). In response to the five nation study, Alexander (2017) developed a set of dialogic teaching strategies and techniques to promote quality discourse and to stimulate higher order thinking and reasoning.

**Dialogic teaching**

Dialogic teaching (Alexander, 2017) is an approach not a specific method of teaching and draws on a broad range of strategies and techniques (e.g., discussion, dialogue, scaffolding and rote) and promotes quality discourse by harnessing the power of talk to stimulate higher order thinking in students. In dialogic teaching there is a distinct change in the balance in power from transmissive instruction. Students are more involved in their individual learning journey with the teacher sharing in the experience also as a learner.

Dialogic teaching promotes quality discourse through:

- **interactions** which encourages students to think, and to think in different ways
- **questions** which invite much more than simple recall
- **answers** which are justified, followed up and built upon rather than merely received
- **feedback** which informs and leads thinking forward as well as encourages
- **contributions** which are extended rather than fragmented
- **exchanges** which chain together into coherent and deepening lines of enquiry
- **discussion and argumentation** which probe and challenge rather than unquestioningly accept
- **professional engagement with subject matter** which liberates classroom discourse from the safe and conventional

- **classroom organisation, climate and relationships** which make all this possible. (Alexander, 2014, para. 2)

Scott and Meiers (2009) highlighted the merits of dialogic teaching and encouraged Australian teachers: to talk less and increase student talk, to increase quality classroom discourse by allowing longer student-led interactions, to use more open questions; to allow students the time to build knowledge and to explore and practise ideas through talk with others. A change such as this requires fundamental changes in teacher pedagogy, teacher belief and classroom culture. An approach introduced by the *Primary Connections* program and used by many Australian teachers that promotes quality discourse, supports the dialogic teaching process and scaffolds higher order thinking and scientific reasoning is the 5Es instructional approach.

**5Es Model**

The 5Es instructional model which was developed by Bybee (1997) and adapted and used as part of the instructional approach in the *Primary Connections* program facilitates inquiry, scaffolds and supports scientific literacy and provides opportunities for students to practice and develop 21st century skills such as critical thinking, communication, collaboration and creativity (Chitman-Booker, 2017). Focused on inquiry teaching, the student is at the centre of their own learning journey and the teacher's role is to facilitate, orchestrate and scaffold opportunities and experiences to build understandings and to create opportunities for students to think and reason. Through five sequential phases: Engage, Explore, Explain, Elaborate and Evaluate, this constructivist approach is a framework for teachers to facilitate and build inquiry via student-centred tasks. Figure 2.4 provides a summary of the *Primary Connections* 5Es inquiry teaching and learning model with an embedded assessment focus.

Another model to consider when looking at how teachers scaffold, support and create opportunities for higher order thinking and scientific reasoning is the cognitive apprenticeship model (A. Collins, Brown, & Newman, 1989; Ghefaili, 2003). The cognitive apprenticeship model and the 5Es model are similar in that they focus on building learning through the sequencing of tasks.

| Phase | Focus | Assessment Focus |
|---|---|---|
| Engage | Engage students and elicit prior knowledge | Diagnostic assessment |
| Explore | Provide hands-on experience of the phenomenon | Formative assessment |
| Explain | Develop science explanations for experiences and representations of developing understandings | Formative assessment |
| Elaborate | Extend understandings to a new context or make connections to additional concepts though student planned investigations | Summative assessment of the Science Inquiry Skills |
| Evaluate | Re-represent understandings, reflect on learning journey and collect evidence about achievement of outcomes | Summative assessment of the Science Understanding |

**Figure 2.4: Summary of the *Primary Connections* 5Es inquiry teaching and learning model**

Both models align with Collins, Brown and Holum's (1991) three principles for effective sequencing, in that they build a conceptual model of the whole task before separating the tasks into smaller portions, gradually increase the complexity of tasks over the sequence; and, introduce a variety of situations for students' to practice their newly acquired set of skills. The cognitive apprenticeship model, however, differs from the 5Es Model in that the teacher has an active role in students' learning as a mentor, model and coach. Cognitive apprenticeship is more about the development of expertise in a skill or skills, rather than the development of content knowledge; even though, in cognitive apprenticeship, content and a variety of types of knowledge are important and drawn upon support the development of expertise.

**Cognitive apprenticeship model**

The cognitive apprenticeship model is an instructional model that involves "learning-through-guided-experience on cognitive and metacognitive, rather than physical, skills and processes" (A. Collins et al., 1989, p. 456) and "enculturate[s] students into authentic practices through activity and social interaction" (Brown, Collins, & Duguid, 1989, p. 37). Founded on constructivism and based on traditional craft apprenticeship, cognitive apprenticeship focuses on the "co-creation of learning" (Scott, 2015, p. 4), with a more experienced master or a more experienced peer passing on their expertise of problem-solving processes for handling complex tasks to a novice or less experienced learner (Ghefaili, 2003). It works on deliberately "making thinking visible" (A. Collins et al., 1991, p. 6), where emphasis "is placed upon the thinking that might precede and be part of the task, and accompany any necessary observations made after its completion" (Woolley & Jarvis, 2007, p. 75).

The cognitive apprenticeship model became increasingly prominent as a model of instruction with the rise of situated cognition (Brown et al., 1989) and has been used in in educational settings to scaffold and teach complex skills (Choi, Hong, Park, & Lee, 2013; Woolley & Jarvis, 2007), and, in more recent times has been used as a model for designing learning-centred online environments (García-Cabrero et al., 2018). Ghefaili (2003) claims that as a model, Cognitive Apprenticeship is "successful in promoting students' higher order thinking skills as well as in shaping the social interactions between teachers and students to goal-orientated problem solving" (p. 24). The cognitive apprenticeship model is composed of four main components: Methods, Sequencing, Sociology, and Content (Knowledge) (Figure 2.5). Each of the four components has a number of parts or sub-components.

For example, the methods component has a number of sub-component strategies (modelling, coaching, scaffolding and fading, articulation, reflection and exploration) that when used sequentially promote the development of expertise. Choi, Hong, Park and Lee (2013) assert that these multiple strategies when "provided to students in a coherent manner" (p. 236) are powerful tools for enhancing dynamic-decision making skills and facilitating reasoning. These processes or strategies involve students in meaningful learning, metacognition and application/transfer of knowledge. The other three components in the model highlight ways to sequence activities, how to use the social characteristics of learning and the different types of content or knowledge required for expertise.

An outcome of Articulation, a sub-component in the Methods section in the cognitive apprenticeship model is metacognition (refer to Figure 2.5). Metacognition is both an important higher order cognitive skill and a pedagogy for scaffolding, supporting and creating opportunities for higher order thinking and scientific reasoning.

| | | |
|---|---|---|
| **1. Methods - ways to promote the development of expertise** | | |
| Modelling (and Explaining) | Master performs a task so students can observe | Receptive meaningful learning |
| Coaching | Master observes and facilitates while students perform a task | |
| Scaffolding (and Fading) | Master provides supports to help students to perform a task | |
| Articulation | Master encourages students to verbalise their knowledge; thinking | Metacognition |
| Reflection | Master enables students to compare their performance with others | |
| Exploration | Master invites students to pose and solve their own problems | Application/Transfer |
| | | |
| **2. Sequencing - ways to ordering learning activities** | | |
| Increasing complexity | Meaningful tasks gradually increasing in difficulty | |
| Increasing diversity | Practice in a variety of situations to emphasize broad application | |
| Global before local | Conceptualizing the whole task before executing the parts | |
| | | |
| **3. Sociology - social characteristics of learning environments** | | |
| Situated learning | Students learn in the context of working on realistic tasks | |
| Community of practice | Communication about different ways to accomplish meaningful tasks | |
| Intrinsic motivation | Students set personal goals to seek skills and solutions | |
| Exploiting cooperation | Students work together to accomplish their goals | |
| | | |
| **4. Content - types of knowledge required for expertise** | | |
| Domain knowledge | Subject matter, specific concepts, facts, and procedures | |
| Heuristic strategies | Generally applicable techniques for accomplishing tasks | |
| Control strategies | General approaches for directing one's solutions process | |
| Learning strategies | Knowledge about how to learn new concepts, facts and procedures | |

**Figure 2.5: Overview of the cognitive apprenticeship model (adapted from Tables 2 & 3, Ghefaili, 2003, p. 11 & pp. 14-17)**

**Metacognition**

Metacognition is a crucial component of higher order thinking and needs to be taught and practiced for its development (Zohar & Barzilai, 2015). First introduced by Flavell (1979), metacognition involves four higher level cognitive processes in relation to thinking and achieving goals: awareness, planning, monitoring and evaluation (Zohar & Dori, 2003). It refers to an individual's control or regulation of mental processes in pursuit of a goal or put simply, the ability to think about thinking (Murray, 2014). Zohar and Barzilai (2015) identify metacognitive knowledge and metacognitive skills (also known as metacognitive processes and metacognitive strategies) as two components of metacognition relevant to higher order thinking in science education.

It is important for teachers to teach students to reflect upon "what thinking strategies they can accomplish, about when, why, and how to use these strategies and about the goals and requirements of tasks" (Zohar & Barzilai, 2015, p. 230). In addition, students require teacher support and guidance to develop and apply metacognitive skills such as monitoring and self-regulation, which are essential skills for higher order thinking and reasoning (Flavell, 1979; Gillies, 2016; Murray, 2014; Zohar & Barzilai, 2015). Murray (2014) asserts that it is important for individuals to be aware of "their own learning habits and capacities in order to better self-monitor, self-assess, and self-regulate their own learning" (p. 57). Zimmerman (1986) concurs with this sentiment and comments that self-regulated learners are "metacognitively, motivationally, and behaviourally active participants in their own learning process. . . . [they] plan, organise, self-instruct, self-monitor, and self-evaluate at various stages during the learning process" (p. 308). Beyond self-regulation it is also important to train students to be independent and critical thinkers.

Inquiry learning, higher order thinking and scientific reasoning are enhanced through student metacognition; by students who can think about what they think; and, by providing themselves feedback by asking the right questions, such as 'What', 'Why' and 'How' questions and 'Where to from here?' (Chesser, 2014; Hattie & Timperley, 2007). In addition to metacognition, the use of representations is another cognitive strategy used by quality contemporary science teachers for scaffolding, supporting and creating opportunities for higher order thinking and scientific reasoning.

## Representations

Representations are valuable semiotic resources for developing thinking, reasoning and learning. As a type of learning task, representations depict a concept, idea or process or part thereof; in ways and modalities that often don't mirror reality but instead offer a different experience of it. A review of the literature reveals that representations are used for many purposes: for motivating and engaging students and for communicating ideas; as a way of accommodating different student learning styles; for monitoring and assessing students' work; and, in relation to this study, for building and mediating students' meaning making and higher order thinking and reasoning (Hackling et al., 2013; Tang, Delgado, & Moje, 2014; Tytler, Haslam, Prain, & Hubber, 2009; Tytler, Murcia, et al., 2017; Tytler, Prain, Hubber, & Haslam, 2013; Waldrip & Prain, 2017; Waldrip, Prain, & Carolan, 2010).

Studies have highlighted the importance of teacher questions and prompts for scaffolding and encouraging thinking and reasoning during the interpretation of representations. Thinking and reasoning occurs during the linking and transferring of salient points of understanding between representations, when students are caused to refer back and forth to representations; during the highlighting of common features of representations and when key features of representations and their relationships to phenomenon are identified and highlighted (Hackling et al., 2013; Tang et al., 2014; Tytler et al., 2009; Tytler, Murcia, et al., 2017; Tytler, Prain, Hubber, & Haslam, 2013; Waldrip & Prain, 2017; Waldrip et al., 2010).

Representational use can range from single to multiple representations (Tang et al., 2014; Treagust, Duit, & Fischer, 2017). They can vary in modality; for example, quality teachers throughout Australia and internationally (Tytler, Murcia, et al., 2017), routinely incorporate and coordinate the use of multiple representations across modalities (for example, verbal, written, graphical and body-based or embodied) in their teaching (Ibrahim-Didi et al., 2017; Waldrip et al., 2010). They can also vary in complexity. For example, simple representations, which are teacher directed and scaffolded are mostly used to support and revise students' conceptual understanding and offer little cognitive challenge. In contrast, complex representational challenges that are student directed and require students to apply their knowledge and thinking skills to design, generate and construct their own representations or to re-represent phenomenon create the greatest cognitive challenge for students and hence opportunities for higher order thinking and scientific reasoning (Tytler, Prain, Hubber, & Waldrip, 2013).

In relation to this study it is recognised that the dominant representational mode for thinking and reasoning is verbal or via language and discourse (Hackling & Sherriff, 2015; Lemke, 1990; Smith & Hackling, 2016; Vygotsky, 1987). Another powerful and versatile representational form which has gained teachers' interest in building cognition, are body-based representations or experiences (for example, Ibrahim-Didi et al., 2017; Ionescu & Vasc, 2014; Lindgren & Johnson-Glenberg, 2013; Wellsby & Pexman, 2014). Embodied cognition theories emphasise that "human cognition is deeply rooted in the body's interaction with its physical environment" (Lindgren & Johnson-Glenberg, 2013, p. 446) and that sensorimotor experiences are important for acquiring and representing conceptual understanding (Wellsby & Pexman, 2014) and are an intrinsic part of higher level cognition (Ionescu & Vasc, 2014).

This section discussed research literature in relation to Research Question 2, pedagogical practices such as: scaffolding, inquiry teaching and learning, collaboration and small group learning, quality discourse, dialogic teaching, 5Es model, the cognitive apprenticeship model, metacognition and representations and they support teachers to scaffold, support and created opportunities for higher order thinking and scientific reasoning. The next section is a brief review of literature relating to Research Question 1 and Research Question 3, regarding the influence of contextual factors such as teacher belief, student demographics and classroom culture on the development of higher order thinking and scientific reasoning.

## Literature relating to contextual factors

Context is a broad multifaceted construct that has the potential to shape and influence the focus and delivery of education from national curriculums down to a classroom teacher's practice, both between countries and within countries

(Denscombe, 2017; Hackling, Ramseger, et al., 2017; E. Johnson, 2008). It is quite clear from research that contextual factors such as: broad social and cultural factors (Hackling, Chen, & Romain, 2017; Hackling, Ramseger, et al., 2017), school context, school philosophy (Hackling, Chen & Romain, 2017; Johnson, 2008; Ryan & Paquette, 2001), curriculum organisation (Chittleborough, Ramseger, Hsiung, Hubber, & Tytler, 2017; Tytler, Ramseger, Hubber, & Freitag-Amtmann, 2017), student demographics (Hackling, 2014; Martin, Mullis, Foy, & Stanco, 2012; Stewart, 2012), classroom culture (Alexander, 2008) and physical learning environments (Hubber & Ramseger, 2017) influence classroom culture and pedagogy, and students' thinking, reasoning and learning. Lewthwaite (2006) contends that Science teaching and learning is a "cultural-contextual process influenced by attributes of the individual, and the various levels of environment" (p. 346).

The notion of layers and interaction of contextual factors influencing teacher practice is supported by many who use Bronfenbrenner's (1989) ecological systems theory to frame the influence of contextual and social factors on teacher practice.

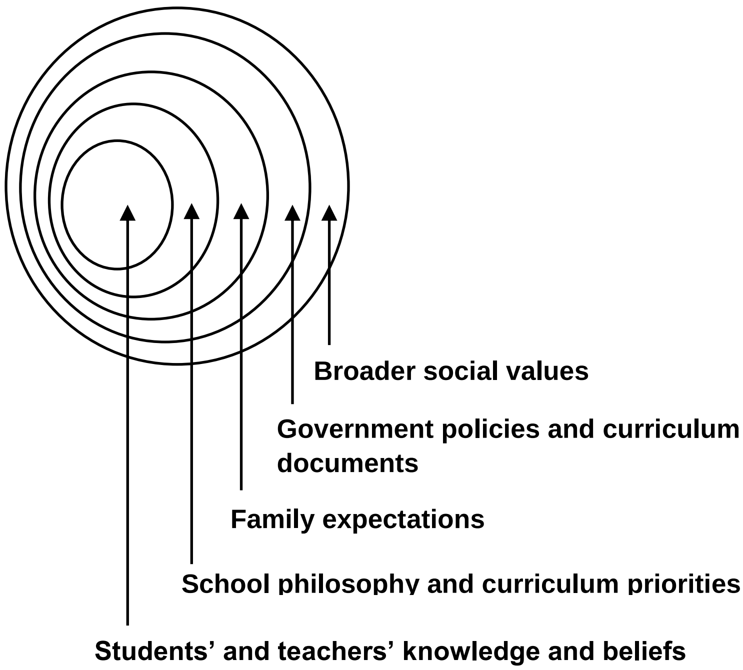



**Figure 2.6: Hackling, Chen and Romain's (2017) layers of social and cultural factors influencing classroom culture and pedagogy (Fig. 2.1, p. 20)**

Hackling, Chen and Romain (2017) for example, when analysing the social and cultural factors influencing primary science teaching across three countries assert that the interaction of contextual factors "can be understood as outcomes that emerge from interactions amongst layers of a complex system" (p. 19). This is demonstrated in their model showing layers of social and cultural factors influencing classroom culture and pedagogy (Figure 2.6 and replicated in Figure 6.2 for comparison).

The following discussion of the literature relates to subsidiary Research Questions 1 and 3 regarding contextual factors: teacher beliefs, student demographics and classroom culture. Also included, but not identified in the research questions, will be a brief discussion on teacher pedagogical content knowledge due to its importance in relation to "how" teachers scaffold, support and create opportunities for higher order thinking and scientific reasoning.

**Teacher belief and pedagogical content knowledge**

Many researchers argue that teachers are a key to student achievement and that teacher belief and pedagogical content knowledge (PCK) are driving forces behind a teacher's pedagogical practice; and, thus have an influence on the way teachers scaffold and support student learning (e.g. Fitzgerald, Dawson, & Hackling, 2012; Hattie, 2003; Holroyd & Harlen, 1996; Martin et al., 2012; Skamp, 2012; Tytler, 2012). This study is being conducted at a time when the Australian Government, the Chief Scientist and education researchers are calling for better qualified teachers of science and more effective science teaching and specifically, of STEM skills (Hackling, 2014; Office of the Chief Scientist, 2015b). Teacher science knowledge is a concern, with TIMSS 2015 data on Year 4 teachers indicating that 77 % of Australian students had teachers that majored in primary education but did not have a major qualification or specialisation in science (Thomson, Wernert, et al., 2017).

For this discussion, teacher knowledge will be confined to PCK (Shulman, 1986). Appleton (2006) describes it simply, as the blending of content knowledge with pedagogical skill into a form that enables teachers to represent ideas in ways that make them understandable to students. Rich PCK is a characteristic of highly effective teachers; it is dynamic and a teacher develops it through learning, experience and reflection (Appleton, 2006; Fitzgerald, Dawson, & Hackling, 2009; Loughran, Berry, & Mulhall, 2012). It is essential for teaching science by inquiry and for the development of science reasoning and thinking skills in students, such as problem solving and argumentation skills (Gillies, 2012). A teacher with rich science PCK would have an understanding of the science content and processes required in a topic, know how individual students learn (e.g. identifying pre- and misconceptions), have the ability to deconstruct concepts and facilitate the co-construction of knowledge; and, to use and interchange between a variety of instructional settings (e.g., pairs, small cooperative work groups, and whole class) (Hackling, Aranda, et al., 2017) and instructional techniques (e.g., questioning, scaffolding, discussion, analogies, examples, demonstrations, investigations and multimodal representations) (Alexander, 2017; Appleton, 2006; Hackling, Murcia, & Ibrahim-Didi, 2012; Shulman, 1986; Van de Pol et al., 2013). Despite the complexity and importance of PCK, Levitt (2002) claims that beliefs are a stronger determinant of teacher practice than knowledge.

Teacher beliefs as described by Pajares (1992) consist of broad general beliefs and educational beliefs. Alexander (2017) acknowledged the importance and impact of teacher beliefs on teacher practice by declaring that teachers need to examine and assess their beliefs and PCK. Similarly, Skamp (2012), when reporting on the implementation of *Primary Connections,* recommended that teachers needed "to recognise their beliefs about science, scientists, appropriate content and concepts in science for primary learners and pedagogy in science, and to encourage them to reflect on the impact of their beliefs on their teaching" (p. 224). Ertmer (2005) and Mansour (2009) argue that beliefs are contextually bound and may constrain teacher practice. There are often inconsistencies between beliefs, knowledge and practice (Kaya, 2014). For example, a teacher understands the process and benefits of small group work and the value of discussion but may not implement the approach due to pressures to get through syllabus content or concerns that too much talking leads to an out-of-control class. Other hindrances to teachers putting their beliefs into practice are contextual factors (Figure 2.6) such as: curricular requirements, pressure exerted by parents, peers or administrators, learner behaviour, time, course content, school, broader educational contexts in which teachers work such as team teaching, room (space), availability of resources, timetable, standardised testing. If these variables become hindrances the best of teacher intentions are thwarted.

**Student demographics and classroom culture**

Research Question 3 relates to student demographics and culture and whether they constrain or promote the way teachers scaffold and support quality discourse and the development of science reasoning and higher order thinking. Analysis of the 2015 TIMSS data, provides evidence that student culture and demographics do have an effect on student achievement (Thomson, Wernert, et al., 2017) and that low participation and achievement of socially disadvantaged students in science is a major challenge internationally and in Australia (Hackling, 2014; Stewart, 2012). A review of OECD studies (Stewart, 2012) revealed that there are two key indicators to high-performing education systems: quality teachers and the provision of equitable and quality education. Quality education systems address inequality through early investment and intervention, provide effective support to low-performing and disadvantaged students and eliminate barriers that hinder equity. Quality teachers also create a positive classroom culture that promotes learning for all (Stewart, 2012).

From a sociocultural perspective, it is difficult to look at how the teacher scaffolds, supports and creates opportunities for higher order thinking and scientific reasoning without looking at the effect of culture within the classroom. Argued by many (for example, Alexander, 2017; Brown et al., 1989; Chen & Tytler, 2017; Hackling, Chen, et al., 2017; Hackling et al., 2013; Hackling, Ramseger, et al., 2017; Mansour, 2009; Ramseger & Romain, 2017; Tytler, Aranda, et al., 2017), 'culture' as a construct is complex and diverse. It has the power to influence student achievement on many levels. Building a classroom culture where students are comfortable to put forth ideas without ridicule (Alexander, 2017) comes from teaching students the ground rules for speaking and listening (Barnes, 2008; Hackling et al., 2010; Rojas-Drummond & Zapata, 2004). Unlike within interpersonal relationships, conflict and argument in the science classroom can be positive and beneficial. A systematic review of 14 studies on quality small group discussions in the United Kingdom (Bennett et al., 2004) highlighted how a positive but argumentative culture within small groups assists learning. The review suggested that conflict within and between groups improved a student's understanding, use of evidence and the ability to construct more complex arguments. Alexander (2008) suggested five principles for classroom culture that would promote and sustain quality discourse.

> **Collective:** teachers and children address learning tasks together, whether as a group or as a class, rather than in isolation.
>
> **Reciprocal:** teachers and children listen to each other, share ideas and consider alternative viewpoints.
>
> **Supportive:** children articulate their ideas freely, without fear of embarrassment over 'wrong' answers; and they help each other to reach common understandings.
>
> **Cumulative:** teachers and children build on their own and each other's ideas and chain them into coherent lines of thinking and enquiry.
>
> **Purposeful:** teachers plan and facilitate dialogic teaching with particular educational goals in view. (Alexander, 2008, p. 105)

A positive classroom culture, as described by Alexander (2008), provides the springboard for dialogic teaching and the development of scientific reasoning, higher order thinking and scientific literacy.

This section briefly discussed the influence of contextual factors such as teacher beliefs, pedagogical content knowledge, student demographics and classroom culture and how they have the potential to influence how teachers scaffold, support and create opportunities for higher order thinking and scientific reasoning. The following and final section in this chapter presents the conceptual framework for the study.

## Conceptual framework

This study will be viewed through the perspectives of social constructivist and sociocultural theories, social semiotic theory and distributed cognition. The key focus will be on the ways in which teachers scaffold, support and create opportunities for higher order thinking and scientific reasoning. There are many factors that influence and frame a teacher's practice, for example: a teacher's personal philosophy, specific beliefs, theories and PCK; contextual factors including student demographics and physical learning environments; and, social and cultural factors (Hackling, Chen, et al., 2017; Hubber & Ramseger, 2017; Loughran et al., 2012). Each of these aspects is important but for the purpose of this study the teachers' pedagogical practices will be the principal focus and contextual factors such as teachers' beliefs, classroom culture and student demographics will be considered but subsidiary to the main focus.

Therefore, in this study, the teacher's pedagogical practices being underpinned by the teacher's beliefs and contextual factors such as student demographics and classroom culture will be the framework for exploring how teachers scaffold, support and create opportunities higher order thinking and scientific reasoning skills (Figure 2.7).

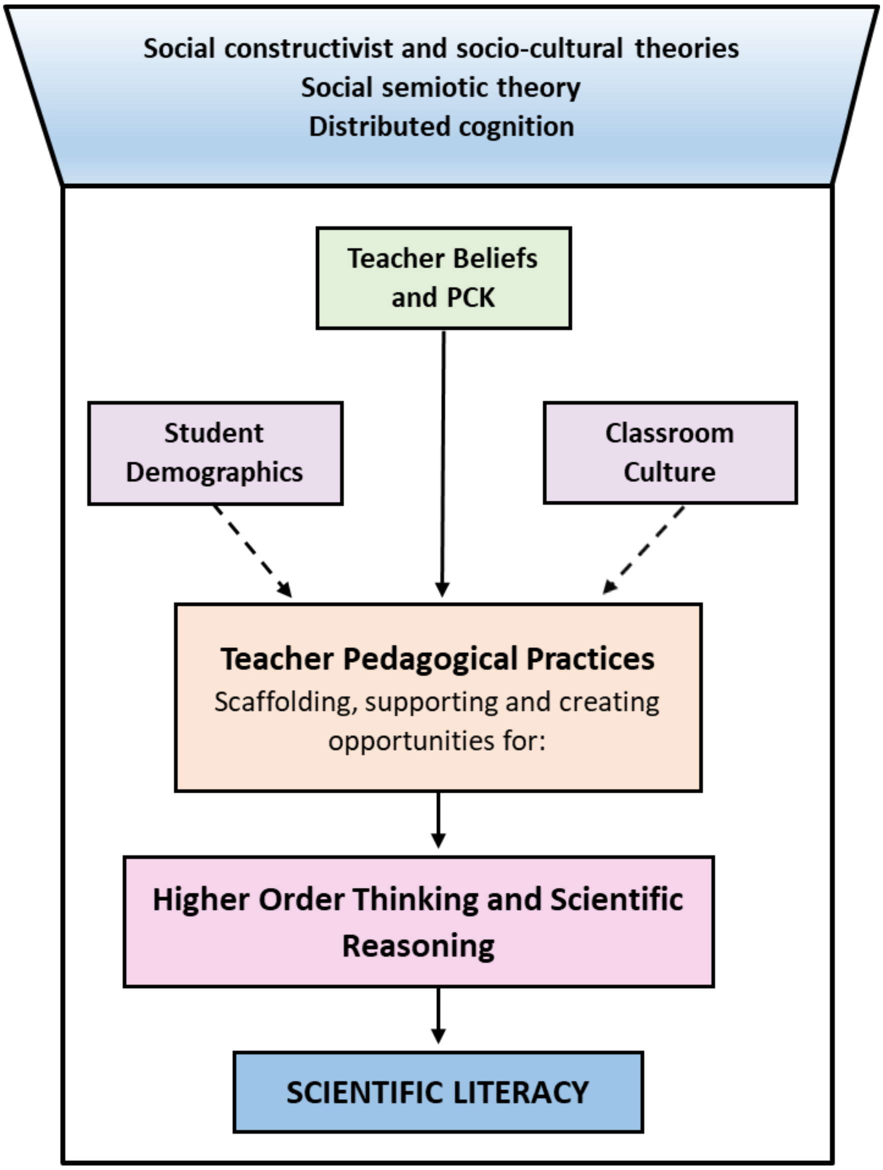



**Figure 2.7: Conceptual framework for this study**

# Chapter 3: METHODOLOGY

## Introduction

This chapter introduces the study's research approach, design, selection of participants, procedures for data collection and analysis; and, issues associated with credibility and ethics. This study is part of a larger research project funded by the Australian Research Council entitled: *Exploring quality primary education in different cultures: A cross-national study of teaching and learning in primary science classrooms* (EQUALPRIME), which focused on discursive practices that provide opportunities for quality reasoning and learning and captured video cases in Australia, Germany and Taiwan. Video and associated data from two Western Australian EQUALPRIME case studies were the principal sources of data for this study.

## Research approach

Consistent with the theoretical framework of sociocultural and social constructivist theories, this study took a qualitative case study and cross-case analysis approach and used interpretive methods of analysis, to identify and understand how exemplary primary teachers of science, create opportunities for higher order thinking and scientific reasoning during the teaching of a physical science topic in natural class settings.

### Qualitative research

A qualitative study has been adopted as a framework for this study. Qualitative research is a method of inquiry particularly valuable for working in complex educational settings as it supports the in-depth study of behaviours and the reasons behind them (Denzin & Lincoln, 2018; The National Health and Medical Research Council & the Australian Research Council Universities Australia, 2018). Eisner (2017) identified six features of qualitative studies; a typical qualitative study is field focused or naturalistic and non-manipulative; the researcher is an instrument for making sense of the situation; is

interpretive in character, delving into reasons for behaviour; uses expressive language and voice; pays attention to detail ensuring the essence of the situation is kept and not lost in transformation; and, uses multiple forms of evidence to give credibility to interpretations. Figure 3.1 maps this study's research approach alongside Eisner's' (2017) features of a qualitative study. Of the many types of qualitative research, the case study was the principal approach for this study.

**Case study research**

The case study was the approach for this study as the main research questions were "how" and "why" questions; the researcher had little or no control over classroom events; and, the focus of the study was a contemporary set of events as opposed to entirely historical phenomenon (Yin & Campbell, 2018). It employed a holistic approach and focused on a natural or real-world phenomenon taking into consideration the contextual relationships and social processes surrounding the phenomenon (Denscombe, 2017). This allowed one aspect or instance to be studied in depth providing "more chance to unravel the complexities of a given situation" (Bell, 2011, p. 36; Patton, 2015).

The study was set in the natural setting of two contextually different Year 4 school classrooms over a series of science lessons and focuses on how the teacher scaffolds, supports and creates opportunities for higher order thinking and scientific reasoning during their lessons and the influence of their beliefs and contextual factors such as classroom culture and student demographics on their pedagogies. The use of multiple data sources (such as video, interview, observations and artefacts) and theoretical perspectives ensured that the research questions were viewed through a variety of lenses allowing for different aspects to be revealed and understood (Baxter & Jack, 2008). An advantage of collecting data from many sources is that it allowed for triangulation (Yin & Campbell, 2018) and together with participant and member checking of interpretations provided rigour to the study (Denscombe, 2017).

| Eisner's six features of qualitative study | Characteristics of the study |
|---|---|
| 1. Field focused or naturalistic | • The main data source is video footage of teachers and students participating in regular science lessons in the natural setting of their classroom.<br>• Lessons are unscripted and in real-time. |
| 2. Researcher is an instrument for data interpretation | • The researcher is a credible and credentialed interpreter who is able to draw valid and trustworthy conclusions from the data. |
| 3. Interpretive in character, delving into reasons for behaviour | • Teacher and student behaviour is interpreted by the researcher who draws on prior experience and knowledge to uncover and understand how teacher belief, pedagogical practice and contextual factors such as classroom culture and student demographics influence how teachers create opportunities for higher order and scientific reasoning. |
| 4. Use of expressive language and voice | • Detailed transcriptions of utterances, gestures and other forms of embodiment used in the teaching and learning process were compiled into case studies. |
| 5. Attention to detail ensuring the essence of the situation is kept and not lost in transformation | • In-depth analysis of teacher and student interactions and relationships and the use of materials or objects used in the teaching and learning process.<br>• Use of multimodal transcriptions (Hackling et al., 2013) to represent the interactions and inter-relationships between teacher and student, student and student, and semiotic resources.<br>• Mapping within each case and between cases the types of scaffolds and supports used by each teacher, against teacher belief and contextual factors such as classroom culture and student demographics. |
| 6. Use of multiple forms of evidence | • Analysis of video, field notes, semi-structured interviews, teacher and student artefacts in the interpretation of data. |

**Figure 3.1: The research approach mapped against Eisner's (2017) six features of qualitative research**

Video in particular, was a powerful data source as it "capture[d]s the rich multimodality of classroom interactions and representations. . . . the use of language; symbolic, graphical and embodied representations; and, manipulation of objects by teachers and students" (Chittleborough et al., 2017, p. 275).

In gathering and analysing data, whether it be for separate cases or across cases, it is important to discuss the approach taken to making meaning from data; in this study an interpretivist approach was adopted.

**Interpretivist research**

In gathering and analysing the data the Researcher took an interpretivist stance. In qualitative research, questions are asked, behaviours are observed and interpretations made (Denzin & Lincoln, 2018; Yin & Campbell, 2018). Consistent with the sociocultural and social constructivist perspectives; knowledge of reality is a social construction and meaning is created through the researcher's interpretation of the data (Harrison, Birks, Franklin, & Mills, 2017; Stake, 2013). This aligns with Stake's (2013) constructivist and interpretivist approach to research, where meaning and understanding of experiences is discovered in context, reality of cases is interpreted while studying the case situationally; and, the integrated system in which each case unfolds is examined (Harrison et al., 2017, Section 3.4.3).

In support of the interpretivist approach, the Researcher brought the following prior experience and qualifications to the study: tertiary qualifications in Science and Education, 13 years' experience in Secondary Science Teaching, 14 years' experience as a tertiary educator of pre-service primary science teachers and 10 years' experience in education research, with four of those years with the EQUALPRIME project collecting and analysing video and associated data.

In summary, this research study adopted a qualitative case study approach, with the Researcher taking an interpretivist stance to gather and analysis and interpretation of the data. The research design will now be addressed.

## Research design

There were two independent case studies in this study. Classroom video and associated data of exemplary Year 4 primary school teachers, taken from the two independent and contextually different WA EQUALPRIME case studies formed the basis of the study data. A case study and cross-case analysis design was adopted (Baxter & Jack, 2008).

### Case study and cross-case analysis designs

It is important to be guided by the overall purpose of a study when considering the type of case study design (Baxter & Jack, 2008). The purpose of this study, as expressed in the overarching research question, was to examine how the teacher scaffolds, supports and creates opportunities for higher order thinking and scientific reasoning. Video and associated data taken from two independent and contextually different WA EQUALPRIME Year 4 primary school case studies were the basis of the study (Table 3.1).

**Table 3.1: Characteristics of the two (WA EQUALPRIME) case studies analysed in the study**

| Case Study | School description | Teachers | Students | School socio-economic level (ICSEA*) | Science topic |
|---|---|---|---|---|---|
| 1 | Government coeducational | 1 | 29 | Medium - Upper medium (1140) | Materials and their uses |
| 2 | Independent school for girls | 2 | 45 | Upper medium – High (1197) | Forces |

**Index of Community Socio-Educational Advantage (ICSEA). The average ICSEA value for schools in Australia is 1000*

As each case study was examined as an independent case, followed by a cross-case analysis, the collective case study design was adopted (Stake, 2013). The collective case study research design is similar to the multiple-case study design (Yin & Campbell, 2018). Both designs allow exploration within and between several case studies to understand similarities and differences within and between cases. However, they differ in focus and intention and the level of contextual relationship between selected cases. In the multiple-case study design single cases are of interest, but this interest is to do with the cases being a member of a group of cases. Similar cases are purposefully selected to either "predict similar results (direct replications) or to predict contrasting results but for anticipatable reasons (theoretical replications)" (Yin, 2014, p. 8) across cases. The case studies in the study were independent studies and weren't selected to be similar cases to predict similar or contrasting results. The collective case study design was chosen over the multiple-case study design, as it focused on in-depth learning or particularisation from individual cases and the formation of assertions from the subsequent cross-case analysis of the collection of cases (Stake, 2013).

The three subsidiary research questions regarding the teachers' beliefs, pedagogical strategies and the influence of contextual factors in relation to how they scaffolded, supported and created opportunities for higher order thinking and scientific reasoning provided focus for the study.

They were:

I. What *beliefs* do teachers have about scaffolding and supporting higher order thinking and scientific reasoning?

II. What *pedagogical practices* do teachers employ and how do they scaffold, support and create opportunities for higher order thinking and scientific reasoning?

III. What *contextual factors* such as classroom culture and student demographics facilitate and constrain opportunities for higher order thinking and scientific reasoning?

As previously argued; teacher belief, knowledge and contextual variables shape a teacher's practice. Therefore, it was anticipated when analysing the single case studies that the teachers' pedagogical practices (Research Question II) may be influenced by the teacher's beliefs and knowledge (Research Question I) and also by contextual factors (Research Question III). The differences between the cases were likely to relate to the teachers' individual beliefs (Research Question I) and contextual factors like classroom culture and school and student demographics (Research Question III). Replicated teacher pedagogical strategies across cases (Yin & Campbell, 2018) would also help answer Research Question II by highlighting pedagogical practices that were used successfully across different contexts. The differences between cases will point out the impact of teacher beliefs (Research Question I) and contextual variables (Research Question III) on the pedagogical practices used by the teacher to scaffold, support and create opportunities for higher order thinking and scientific reasoning.

In summary, a collective case study design (Stake, 2013) was used for this study. The findings from the two case studies were analysed individually prior to conducting a cross-case analysis. The key findings from individual case studies were utilised to form assertions from the cross-case analysis; and, the assertions informed the development of conclusions.

## Participants

This study was part of the larger EQUALPRIME study. Originally all three of the WA EQUALPRIME case studies were chosen for this PhD study. However, due to the richness of the data and complexities of the fine-grained data analysis the number of case studies was reduced to two to fit into the parameters of a PhD study. The two case studies chosen were chosen because of the richness and the accessibility of their data and because of their contextual differences between them.

The key participants for the study (Yin & Campbell, 2018) were three Year 4 teachers together with their classes from two of the WA EQUALPRIME case studies. One of the case studies (i.e., Case Study 2), had two teachers who co-taught science lessons, which explains the discrepancy between the number of teachers and case studies (refer to Table 3.1). In Case Study 1 (CS 1), the participants were: teacher Sandra (pseudonym) who taught a Materials and their uses unit to her Year 4 class of 29 boys and girls from a mid to upper socio-economic status public school. In Case Study 2 (CS 2), the participants were: teachers Christine and Melanie (pseudonyms) who co-taught a Forc*es* unit to their combined Year 4 classes of 45 female students at a higher end socio-economic status private school (Table 3.1).

The teachers were recognised by their peers as exemplary science practitioners, which was confirmed through an interview and observation of their teaching by EQUALPRIME research team members.

Please note that the identity of the schools, teachers and students have been kept anonymous as part of the ethical constraints of the study and whenever names were needed to be used, for example during analysis and discussion pseudonyms were used. Also, images of people or things that may identify the schools or participants have been de-identified for anonymity.

## Procedure

The following section describes the collection, analysis and verification of data for the study.

### Data collection

The majority of the data for this study was collected by the Researcher during the EQUALPRIME study (2011 - 2014) which was supplemented with additional data collections. The procedures for collecting data will be described in two phases.

Phase I took place as a part of the WA EQUALPRIME project. The Researcher was involved in Phase I collection of data as the Project Manager and Research Assistant (e.g. as camera operator, non-participant observer, interviewer and analyst) for the WA EQUALPRIME project. In this phase, ethical approval and consent was obtained at the various required levels to enable the collection of data from the teacher and class. It involved filming all lessons across a science topic from two primary schools;

and, the collection of associated data, e.g. field note observations, interviews and teacher and student artefacts from those schools.  Prior to filming cameras were operated in the case study classrooms for a period of acclimatisation to allow the teacher and students to become accustomed to the camera and operators.

Phase II involved the collection of additional data, analysis of data and the verification of the Researcher's interpretations by each case study teacher.  For Phase II, the Researcher collected additional background information from each teacher via a semi-structured interview and a video stimulated interview after analysis to validate the Researcher's interpretations of the data.

***Phase I (Pre-study): Collection of video and associated data***

The Researcher was directly involved in the following data collection processes:

- Pre-study semi structured teacher interviews conducted approximately one month prior to videoing the first lesson in each case study to determine the teachers' beliefs about and knowledge of science, science teaching and the development of science reasoning.
- Post-study teacher video stimulated interviews were conducted within a month of completing the videoing of lessons to collect additional insight into the teachers' practice.

The following processes took place for each lesson in the sequence of lessons for the three case studies.

- Lessons were videoed using two video cameras with external FM transmitter microphones. One camera followed the teacher and the other followed the interactions within a focus group of four – five students.  The Researcher was the camera operator.
- Classroom observations were conducted and field notes made by the Researcher during the videoing, e.g., recording highlights, type of student activity and instruction.

- Pre- and post-lesson interviews with the teacher and post-lesson focus group discussions with students were conducted by the Researcher.
- Classroom artefacts and field notes were collected to complement the video data for each lesson by the Researcher.
- Periodic student video stimulated interviews were conducted by or assisted by the Researcher over the period of filming the lesson sequences (average of two interviews conducted per case study).

***Phase II (During study): Collection of additional background information and verification of interpretations by case study teachers***

The Researcher conducted:

- Semi-structured interviews with the teachers using a digital audio recorder to fill in gaps regarding teacher beliefs, knowledge, pedagogical practice and any other relevant information.
- Final video stimulated teacher interviews were captured on video to check, clarify and validate the Researcher's interpretations of the data prior to the final analysis of data.

Video from the two selected WA EQUALPRIME cases studies complemented by teacher interviews and teacher and student artefacts, were then independently analysed and compiled into case studies, which was followed by a cross-case analysis. The following section outlines the methods employed for analysing the data.

**Data analysis**

The main data source for analysis in each case study was video data. Bazeley (2009) suggests that multiple data sources are important when analysing data and that "building arguments requires that conclusions are drawn from across the full range of texts available" (p. 19). For this reason, complementary data sources, for example: field note observations, interviews and teacher and student artefacts were analysed in concert with the main data source for contextualising the video data and for validating the Researcher's interpretations.

Erickson's iterative model of video micro–ethnographic analysis (2006) was used to underpin the approach for video data analysis. Steps involving data reduction, data representations and re-representations, and data analysis occurred a number of times through the analysis processes (Hackling et al., 2013) leading to fine-grained analysis of selected episodes illustrating exemplars of how the teacher scaffolded, supported and created opportunities for higher order thinking and scientific reasoning (Figure 3.2).

Each case was completely analysed before moving to the next case and prior to the cross-case analysis (Figures 3.2). Multimodal transcriptions were used to represent student and teacher utterances, interactions, and inter-relationships with semiotic resources (Hackling et al., 2013) (Figure 3. 3). The digital format of the multimodal transcript used in this study, which was developed in the EQUALPRIME study enabled the Researcher to "open digital representations of multimodal objects and processes and view them whilst reading the transcriptions of discourse and description of how gestures were being used." (Chittleborough et al., 2017, p. 276). For auditing purposes, each clip and transcript kept the time stamp assigned to it from the EQUALPRIME study.

In conjunction with multimodal transcriptions, the mapping of how teachers supported, scaffolded and created opportunities for higher order thinking and scientific reasoning against teacher beliefs and other contextual factors such as classroom culture and student demographics within individual cases and across cases, allowed patterns and themes to emerge. Bazeley (2009) argues that the analysis of qualitative data requires a deep analysis and for true interpretations, analysis needs to be enriched by refining and displaying (Miles & Huberman, 1994). In support of this argument matrices, graphs, flow charts and models were used in conjunction with multimodal transcriptions to compare, contextualise and link themes that build strong arguments that were supported by the data (refer to data representations and re-representations in Chapters 4 and 5). The following steps outline the specific steps involved in data analysis.

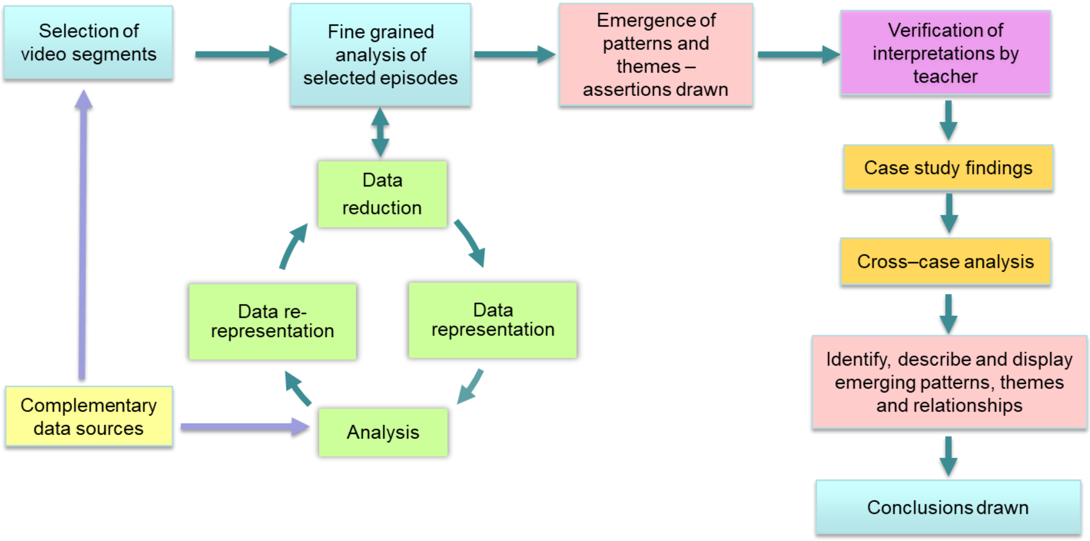



**Figure 3.2: Diagram of data analysis sequence for the study**

| TIME STAMP | SPEAKER | UTTERANCE | Embodiment Experiences | NOTES | Attachments |
|---|---|---|---|---|---|
| | | | Experienced (Exp)<br>Recalled (Rec)<br>Imagined (Imag) | L2 Sequence doc.docx | Lesson 2 CS2 transcript inqscrib11.<br>Embodiment Power Point Case Study 2.p |
| Episode 1 - Review Push & Pull (00:00:00.0 – 00:00:01:38.01)<br>*Tch M: Reviews push and pull from previous lesson by having students show her various examples of push and pull using their bodies.*<br>*N.B. Some of these embodiment experiences are recalled, imagined and/or actually experienced during this review.* | | | | | |
| Pre 00:00:00.00 (prior to this video starting - can be seen on focus group video EQ1212FG-L2-030811) | Tch M | Show me that you are pushing your hands both together. Show me your right hand pulling your left hand. Your left hand pulling your right hand. Show me pushing your imaginary hat to your head. Show me pulling your imaginary hat away from your head. | Exp<br>Imag | T modelling the gesture[1] or Embodiment action prior to students "showing" their pushes and pull examples. Ss often adding sound effects to movement. | L2-Clip 1 push pull edited.wmv |
| 00:00:02.06 | Tch M | Show me very gently pushing the shoulder of the person next to you, very gently. | Exp | Teacher Intention: 1. Review of Push and Pull- Teacher prompted embodiment of push and pull. |  |
| 00:00:06.06 | Tch M | Show me very gently pulling that person towards you. | Exp | | |
| 00:00:09.10 | Tch M | Show me pushing a big boulder and moving it. | Rec & Imag | | |

**Figure 3.3: Example of a multimodal transcript – first 9.10 minutes of Lesson 2 Case Study 2**

**Steps for data analysis**

1. Review background information on case study teachers (include teacher philosophy and beliefs), schools, classes (include classroom culture) and students in each case study using pre-study, pre-lesson, post-lesson and post-study interviews and school census information.

2. View each lesson multiple times for each case study

(Note: Conduct steps 2 – 10 for each case study before completing steps 11 – 12.)

3. Selection and clipping of video segments where the teacher was scaffolding, supporting and/or creating opportunities for higher order thinking and scientific reasoning.

4. Review clips multiple times and identify a maximum two to three rich episodes per lesson for fine grained analysis.

5. Create multimodal transcripts of selected rich episodes (Figure 3.3).

6. Conduct fine grained analysis of selected episodes using the multimodal transcripts as a basis of referral. Continue the process of data reduction and re-representation and review selected episode clips again until patterns and processes emerge and conclusions are drawn and verified (Erickson, 2006; Miles & Huberman, 1994). Use field notes, semi-structured interviews, and teacher and student artefacts in the interpretation of data.

7. Map the types of scaffolds and supports used by each teacher, against the teacher's beliefs, knowledge and contextual factors such as classroom culture and student demographics.

8. Formulate tentative key findings in regards to the research questions.

9. Verification of interpretations with case study teacher. Conduct video stimulated interview with individual case study teachers to verify the Researcher's interpretations of the data and to provide additional teacher insight into the data.

10. Compile the case study. Formalise key findings. Write up (e.g. describe, compare, contrast, relate) findings using vignettes and transcripts for each case.

11. Cross-case analysis. Using the key findings from both case studies conduct a cross-case analysis of the two case studies - by mapping, describing, comparing, contrasting and relating the supports and scaffolds used by each teacher, against the teacher's beliefs, knowledge and contextual factors such as classroom culture and student demographics. Formulate assertions.

12. Identify, describe and display (Miles & Huberman, 1994)(e.g., matrix, flow-chart, model) emerging patterns, themes and relationships (Bazeley, 2009) and write up findings and conclusions.

The following section will discuss the rigour of this research and address the credibility, transferability, dependability and confirmability of the study.

## Rigour of qualitative research

For a study to be worthwhile the researcher must demonstrate to the reader that the findings and conclusions drawn from the study are true and trustworthy (Lincoln & Guba, 1985). Studies based on acknowledged practices of good research (Denscombe, 2017), are said to have rigour. Lincoln and Guba (1985) have established the following set of evaluative criteria that provide rigour in qualitative research.

- Credibility - confidence in the 'truth' of the findings
- Transferability - showing that the findings have applicability in other contexts
- Dependability - showing that the findings are consistent and could be repeated
- Confirmability - a degree of neutrality or the extent to which the findings of a study are shaped by the respondents and not researcher bias, motivation, or interest

Drawing upon these criteria, the Researcher will identify the techniques, tools and processes employed in the study to ensure its trustworthiness and rigour.

**Credibility**

Lincoln and Guba (1985) identified that prolonged engagement, persistent observation, triangulation and member checking are some of the techniques that contribute to the credibility of a qualitative study. The Researcher, due to being the Project Manager, Research Assistant, Camera Operator and Interviewer for the WA EQUALPRIME Project, spent many hours engaged with the participants and data for the study. This prolonged engagement and "detailed scrutiny" of the data provided a basis for credible conclusions to be drawn from the data in the study (Denscombe, 2017, p. 299). The Researcher utilised micro ethnographic analysis (Erickson, 2006) to inquire into the data. Persistent observations through the fine grained analysis of selected video episodes added to the depth and credibility of the study (Lincoln & Guba, 1985). This involved the repeated sequence of: data reduction, data representation, data analysis and data re-representation; until themes and patterns emerged, from which assertions can be drawn (Erickson, 2006; Miles & Huberman, 1994).

The study utilised multiple data sources or triangulation to give deeper understanding of the phenomenon being studied (Lincoln & Guba, 1985) that added to the confidence in and accuracy of the data (Denscombe, 2017). The study re-analysed data from the following WA EQUALPRIME data sources: video data (27 full science lessons), pre- and post-lesson teacher interviews, focus group post-lesson interviews, field observation notes, work samples, semi-structured pre- and post-study (video stimulated ) teacher interviews, focus group video stimulated interviews and other associated data. (The original EQUALPRIME data identification labels, including video labels and timestamps were kept to provide an audit trail.)

Additional data was collected by the Researcher to supplement the EQUALPRIME data. This included a semi-structured interview early in the analysis phase with each case study teacher, which filled in gaps regarding teacher beliefs, knowledge and pedagogical practices; and a post-analysis video stimulated interview with each case study teacher to verify the interpretations made by the Researcher. This process known as member checking together with prolonged engagement, persistent observation, triangulation and member checking are techniques that assisted to establish the credibility of the study.

**Transferability**

Detailed or thick descriptions are a way of achieving external validity by providing readers with enough information to decide if the findings are meaningful and are applicable to other contexts (Yin & Campbell, 2018). The Researcher gave rich detailed descriptions of the data through vignettes and by using multimodal transcripts. Multimodal transcripts included: time stamps indicating the position and sequence of the clip during the lesson, discourse transcripts indicating the speaker, teacher resources and the use of embodiment in the learning.

**Dependability**

Being able to replicate findings of a study demonstrates the reliability of a quantitative study. Due to the many intertwining influences in social settings, it is not realistic that findings from qualitative studies can be replicated (Denscombe, 2017). An 'audit trail', however, is one way of establishing the dependability of a qualitative study. This involves the researcher recording the steps in procedures, justifications for decisions and how conclusions were drawn from the data, from the commencement of the project and through the analysis, development and reporting of findings. An audit trail allows the reader to ascertain whether the findings, interpretations and conclusions are consistent and accurately supported by the data and could be repeated (Lincoln & Guba, 1985). For the study the Researcher provided detailed transparent descriptions and explanations of the research processes, methodological decisions (Lincoln & Guba, 1985), and an account of how conclusions were reached. These were recorded electronically in the Researcher's research journal.

**Confirmability**

Findings from qualitative studies are seldom free from the researcher's influence (Denscombe, 2017). Whilst these influences are not always undesirable, they may, if not declared affect the trustworthiness of the study (Lincoln & Guba, 1985). To establish confirmability, researchers need be open-minded and reflect upon, and sometimes put aside, positions, perspectives, beliefs, values, preconceptions and previous experiences. For the study, the Researcher informed the reader of her previous involvement with the data. Whilst the Researcher believes that this involvement and familiarity with the data will be an advantage by allowing greater depth and understanding of the data in the allotted time; preconceived judgments whether covert or overt may influence the Researcher and hence limit the potential of the study. The Researcher, despite being close to the data will need to consciously step-back and view the data with 'new eyes'. By being open about potential influences and using confirmability techniques such as triangulation and audit trail, the Researcher demonstrated that the study was being driven by the research questions and the findings and interpretations were grounded in the data (Denscombe, 2017; Lincoln & Guba, 1985) rather than researcher bias. These techniques are intended to reduce the likelihood of the researcher's objectivity being challenged (Lincoln & Guba, 1985).

In summary, the reader must be convinced that the study exhibits credibility, transferability, dependability and confirmability for it to be rigourous. In the prior discussion, the Researcher has described how these criteria were satisfied.

## Ethics

Phase 1 (pre-study) data collection of video and associated data from the WA EQUALPRIME study was conducted prior to the study and had its own ethics approval. That involved approval from Edith Cowan University Human Research Ethics Committee and the Department of Education WA . Information letters and written consent had been obtained from Principals, teachers, parents and children. For Phase 2 (during the study) data collection, the Researcher was granted further ethics approval from the relevant organisations for the new data analyses, the collection of additional background information from the case study teachers and consent to conduct a video stimulated interview with each case study teacher to verify the Researcher’s interpretations. It was specified that there was going to be no further contact required with students or parents.

## Limitations

There are some limitations to this study. For example, the small number of case studies and that all of the case study teachers were Year 4 teachers teaching in a metropolitan city school. One of the challenges of case studies is the credibility of generalisations made from findings (Denscombe, 2017), particularly with small case studies. Yin (2014) distinguishes between two types of generalisations: statistical generalisation and analytical generalisation. He argues that the former which is commonly used in experimental research cannot be applied to small sets of case studies, but analytical generalisations which “depend on using a study’s theoretical framework to establish a logic that might be applicable to other situations” (p. 18) is more suitable. Analytical generalisation follows a two-step process:

> The first step involves a conceptual claim whereby investigators show how their study’s findings have informed the relationships among a particular set of concepts, theoretical constructs, or sequence of events. The second step involves applying the same theoretical propositions to implicate other situations, outside the completed case study, where similar concepts, constructs, or sequences might be relevant. (Yin, 2014, p. 18)

Therefore, appropriate caution should be exercised in any generalisation of findings from this study.

Another limitation of this study is that PCK was excluded from the original conceptual framework (Figure 2.7) due to constraints of the doctoral study; and, as a consequence no specific data was collected about PCK, other than that which was gleaned through observing the teachers during the filming and analysis of lessons. Although PCK is an important factor to consider when looking at teacher practice (Shulman, 1986), the Researcher took Levitt’s (2002) stance that beliefs are a stronger determinant of quality practice than knowledge and chose to concentrate on teacher beliefs rather than teacher beliefs and PCK for subsidiary Research Question 1. As this study focused on the exemplary practice of case study teachers chosen for their quality science practice (Ramseger & Romain, 2017), and that rich

PCK is a characteristic of highly effective teachers (Appleton, 2006; Fitzgerald et al., 2009; Loughran et al., 2012), it was considered that all the case study teachers had well developed PCK. This was confirmed by the Researcher, an experienced primary science researcher and science teacher.

## Summary

In summary, this chapter has outlined the research approach, research design and procedures for data collection and analysis and has outlined the reasons for this methodology. The study used a qualitative case study, cross-case analysis and interpretivist approach. Video from the two WA EQUALPRIME cases formed the basis of the data complemented with observational field notes, interviews and artefacts collected from the teacher and students. Micro-ethnographic analysis took a two phase approach to data analysis and a number of checks and balances were put in place to ensure a study with a high degree of rigour. Ethical considerations have been put in place to ensure that the study meets the high standards expected. Refer to Appendix A for a summary linking the research questions with the data source and data analysis tools.

# Chapter 4: SANDRA AND HER TEACHING

## Introduction

This chapter explores Sandra's (pseudonym) teaching of a Year 4 physical science unit, Materials and their uses. The first part of the chapter examines the contextual setting of the case study, Sandra's beliefs and philosophies regarding the teaching and learning of science and an overview of the topic. This is followed by an exploration of Sandra's instructional approaches and pedagogies and strategies that scaffold, support and create opportunities for higher order thinking and scientific reasoning.

## Context

There are many contextual factors that may influence a teacher's practice. This section outlines background information relevant to Sandra's case study. It describes the school community, student group and Sandra's educational and teaching background.

### School community

Northern Plains Primary School (NPPS) (a pseudonym) is a co-educational government school located in the northern suburbs of Perth, Western Australia (WA). This case study school had a cohort of almost 500 students from Kindergarten to Year 7. The school attendance rate was 96% which is greater than the WA public school average of 92%, there were no Indigenous students enrolled and 17% of the students had a language background other than English. The School's Index of Community Socio-Educational Advantage (ICSEA) rating was 1140 which is above the average value of 1000 for schools in Australia. ICSEA is a measure of the educational and social advantage or disadvantage at the school level. It is based on a number of variables such as student family background data, socio-economic status of the area where students live, proportion of Indigenous students, location of the school (metropolitan, rural or remote) and other variables having strong association with student performance (ACARA, 2013).

NPPS is located in a high socio-economic area and offers specialist teaching programs in the area of Art, Music, Physical Education and French. The student population is stable and parents provide strong support and a high level of interest and involvement in their children's education. Spelling, Reading, Mathematics and Science were school priorities in 2013. The teaching of science takes a whole school approach and is coordinated across year levels. An enthusiastic science committee led by Sandra supports teachers with teaching science. They are provided with regular opportunities for science professional learning, have access to a well-equipped science resource room and are supported by a science education assistant who prepares resources for lessons and is available to provide assistance during science lessons.

**Student group**

Sandra's Year 4 class comprised 29 students (14 girls, 15 boys). Many of these students were also taught by Sandra in the previous year. The Year 3 NAPLAN national literacy and numeracy test results of this cohort of students indicate that they performed 35 - 59 points above the national average in reading, writing, spelling, grammar and punctuation and numeracy, and 11 – 20 points above that of similar schools, which serve students from statistically similar backgrounds.

**Key Finding 4.1**

Sandra worked in a school with an above average ICSEA rating and taught a Year 4 class she had previously taught in Year 3. These students demonstrated above average literacy and numeracy skills on NAPLAN assessments in the previous year.

**Sandra's educational and teaching background**

During the case study Sandra was in her sixth year of teaching and was the full-time teacher of a Year 4 class. Sandra completed an undergraduate degree in History and Anthropology followed by a Diploma of Education. She then taught in the country for two years before being appointed to a permanent teaching position at NPPS. In her second year at NPPS, Sandra became the Science Coordinator for the school. This coincided with the launching of the *Australian Curriculum: Science*.

Sandra's interest in teaching science was triggered by a passionate science teacher whom she collaborated with in her first school. This continued to develop in her role as the Science Coordinator at NPPS.

> [She] really got me engaged in teaching science. Then when I came here, I was given the role [of Science coordinator] and just over time my interest snowballed and I've become more excited and you know more energy towards it, [with] my professional development in science. (Teacher interview, 2014)

She has received training in the Australian science curriculum and is a *Primary Connections* professional learning facilitator. Sandra has an opportunity to access a variety of professional development opportunities in science through her science coordinator role, and she provides professional development for staff at her school and the schools within her cluster. "I consider my role, supporting teachers in science and that's whether it is with resources or whether it be with my assistance, my time and my help or guidance or whatever that may be" (Teacher pre-study interview, 2013).

Sandra is currently completing a Master's degree in school leadership. In her role as Science Coordinator Sandra set-up the school's science resource room and initiated the appointment and coordination of a science education assistant.

| **Key Finding 4.2** |
| --- |
| Sandra was not trained as a science specialist in her pre-service education. She developed an interest in science education in her first two years of teaching and increased her science knowledge through attending professional development sessions. In her role as the school's science coordinator she supports other teachers with teaching science. |

## Sandra's beliefs and philosophies

This section provides an overview of Sandra's beliefs and philosophies pertaining to both general teaching and learning and the teaching and learning of science. Sandra is very passionate about science, science education and the importance of developing her students' scientific literacy. Her philosophy of science education is based on the tenets: science is everywhere and that learning needs to be linked to everyday living; and, children being innately curious learn best through hands-on inquiry. Sandra believes higher order thinking and scientific reasoning is developed through the use of authentic activities and examples, by encouraging students to question and problem solve and through talk with others.

**Linking science to the real world**

Sandra believes that science is embedded in everything we do and as a consequence every curriculum area can be taught through science. She believes that science inquiry can be the vehicle for all learning and that by linking authentic and problem solving activities to real world situations, students will become excited, motivated and engaged in learning science. It facilitates students to "start working with the ideas and questioning the world around them and making links to what we're teaching them in theory to actual things that go on in the world" (Teacher pre-study interview, 2013). This is achieved by encouraging students to question what is happening around them. "I support kids in questioning the world around them. . . .you set up your lessons so students start making connections with what you're teaching them to the world and the phenomena in the world around them" (Teacher pre-study interview, 2013). Sandra believes that one of the most effective ways of linking science learning and everyday life is through hands-on inquiry learning.

**Hands-on inquiry learning**

An important part of Sandra's science philosophy is that students learn through practical hands-on learning and as such is a supporter of inquiry-based learning. "I think it [inquiry-based learning] is really, really important in science. . . .We should be teaching science like we do science. . . . You can't really understand science unless you have it [hands-on science]" (Teacher interview, 2014). Sandra believes that the

Australian science curriculum supports inquiry-based learning by supporting children to question and explore the world around them. Apart from opportunities to 'do' science and to learn through doing, Sandra believes that giving students the opportunity to talk in science is an important part of their learning and the development of science reasoning and higher order thinking skills.

**The importance of talk, questioning and language in science**

In Sandra's classroom talk and discussion are prominent and important features in lessons and form the predominate vehicle for learning. Sandra supports a dialogic type of teaching approach which harnesses the power of talk to stimulate higher order thinking and scientific reasoning. She believed that talking, listening, sharing ideas and working with others develops creativity and original thought both of which are higher order thinking skills.

> [Talking] encourages the students to think more creatively. They're more inclined to take in all the information and come up with interesting and original ideas . . . and particularly in science it's great because they make their connections and they're talking about things and they're expressing themselves and I think that's where good learning starts and ends. (Teacher post-study interview, 2013)

Sandra describes a productive and engaging science class as having "lots of talking, lots of questioning, lots of I guess different levels of questioning . . . getting students to like application questions" (Teacher pre-study interview, 2013). She believes that providing regular opportunities for talk and questioning between students and with the teacher allows students to verbalise and to hear each other's ideas which in turn helps students to grow and deepen their understandings. Encouraging students to question helps them "to really register their understanding and get them thinking, problem solving" (Teacher pre-study interview, 2013).

> I try to instil in them that constant questioning, that critical thinking, that you know . . . the self-reflection the metacognition, you know knowing what we need to learn but knowing why we need to learn it and caring about that, making that an important part of our day, that kind of bringing us together as a team. (Teacher post-study interview)

Sandra believes that it is important that students have a certain level of competence in general academic vocabulary and science language to talk through their ideas with others and to reason in science. Identifying each lesson's essential vocabulary is a part of her lesson planning and implementation. During lessons she introduces, promotes, models and encourages students to incorporate particular language into their talk.

Sandra believes that to establish a classroom where talk is an integral part of the learning process, it is important that the teacher and students have a clear understanding of their respective roles and responsibilities in that learning process and that there is a safe and positive learning environment.

**Key Finding 4.3**
Sandra believes that science inquiry can be the vehicle for all learning and that by linking authentic and problem solving activities to real world situations. She believes strongly in hands-on learning and that talk and discussion should feature prominently in lessons. She also believes it is important to give students the vocabulary and language to question, discuss ideas and reason in science.

**Roles and responsibilities in the learning process**

Sandra's teaching of science is underpinned by her beliefs that teachers and students need to know and understand their roles and responsibilities. She believes that the basis for teaching and learning in primary school is that children are innately inquisitive and want to explore what is around them. Sandra believes that a teacher's role is to guide, facilitate, and to focus and expand upon this intrinsic inquisitiveness. Teachers have the responsibility to make lessons interesting, relevant and age appropriate; providing opportunities for students to share their ideas, to question, to problem solve and to apply knowledge. Sandra believes it is important that students also know that they have a vital role in their own learning. With this comes certain responsibility. Students are expected to "do the right thing and to positively participate in my classes" (Teacher pre-study interview, 2013), to engage in the learning, to listen and learn from each other and to respect individual differences and opinions, to monitor their own learning and to ask for assistance when they need it. To allow students to verbalise their opinions Sandra believes is it important to create a safe and supportive learning environment.

**Collaborative learning and classroom culture**

Sandra believes in collaborative learning in science where students share their ideas and work together to find solutions. She encourages students to analyse and critique not only their own ideas but those of their peers, which often leads to "contradicting others' explanations" (Teacher pre-study interview, 2013). To support this ethos she promotes a positive classroom culture where students feel valued, respected and safe to voice personal opinions, ideas and thoughts without fear of ridicule or shame. When Sandra first meets a class group she commences the process of building a "really strong cohesive group so we all are connected and kind of try to be on the same team and be very supportive by building a culture in the classroom (Teacher pre-study interview, 2013).

**Key Finding 4.4**
Sandra believes in creating a positive supportive classroom environment that supports collaboration and deeper learning which occurs by going beyond merely sharing ideas with peers but by providing reasons, analysing and critiquing others' ideas.

**Multimodal instruction**

Sandra believes in a student-centred, hands-on, and inquiry-based science education. She accommodates and supports individual learning styles by adopting a multimodal approach to teaching. Believing that the 'chalk and talk' has a limited role, for example "for instructional purposes, [and] to clarify a concept or model" (Teacher interview, 2014) she espouses more interactive modes of instruction. Sandra considers her classroom to be a "little bit left of centre; I sometimes feel like I'm a bit more of a Montessori teacher in a mainstream context . . . there is that freedom, movement and more focus on discussion and peer tutoring" (Teacher post-study interview, 2013). Sandra believes that students must be physically and mentally involved in their own learning. Her interest in neuroscience or 'brain science' influences the strategies she employs to assist students with their consolidation of thinking, retrieval of past learning and application to new situations.

She frequently uses strategies such as chanting, song, movement, and lots of talking during lessons. Sandra describes her lessons as,

> very vibrant, particularly in science . . . [I use] a bit of role play and song and I also have brain breaks where the kids get up and we might, . . . do some brain gym or we do something that engages them and gets them back centred into the here and now and then we get back on with it. . . . My classrooms are very dynamic and vibrant and they're just full of movement and colour and energy. (Teacher pre-study teacher interview, 2013)

Sandra also believes in using technology to support student learning. This may range from electronic blogs and journals, student reports using PowerPoint presentations or movies, interactive activities on the electronic white board to computer simulation activities. Sandra's belief in the merits of multimodal instruction is complemented by her belief that different instructional settings provide different facets and levels of support in student learning and reasoning.

**Key Finding 4.5**
Sandra believes in the merits of multimodal instruction and the value of incorporating strategies such as chanting, song, movement and lots of talking to assist students with their consolidation of thinking, retrieval of past learning and application of knowledge to new situations.

**Instructional settings**

Sandra believes that is important to use a range of instructional settings during lessons.

"A lot of my science teaching is based on small group teaching and learning. . . . I use whole class and individual [teaching], but I think [small group work] would reflect my teaching" (Teacher interview, 2014). Whilst whole class, small group, pairs and individual work are all important in science, she believes that small group work is essential to support hands-on collaborative inquiry based learning. Sandra believes that each setting provides particular affordances in the development of higher order thinking and science reasoning in students. Her views are summarised in Figure 4.1.

| Instructional setting | Affordance for teachers | Affordance for students |
|---|---|---|
| Whole class activity (WCA) | WCA provides teachers with opportunities to introduce the lesson, to outline success criteria, to model activities and skills, to evaluate the overall class understandings, to address general class misconceptions and shortfalls in learning, to summarise concepts and to conclude the lesson. | WCA provides students with opportunities to receive instruction and to share ideas and learn through whole class instruction and discussions. |
| Small group activity (SGA) | SGA allows teacher the flexibility to move around the classroom to listen and to observe students at work, to evaluate student progress, to diagnose gaps and focus student learning. It provides teachers with the opportunity to provide extra support to individuals and small groups. | SGA provides students with opportunities to explore and investigate concepts practically, to build skills through hands-on activities, to discuss ideas with peers and the teacher, to consolidate their understandings and to highlight their personal misconceptions. |
| Paired activity (PA) | PA can assist the teacher in providing support to individuals through pairing them with another learner. | PA provides students with the opportunity to work with another individual, to share the opportunity for learning and to bounce their ideas off someone else. PA can afford students with an emotional safety support mechanism. |
| Individual student activity (ISA) | ISA allows the teacher to opportunity to diagnose individual progress, understandings and misconceptions, to work one on one with individuals and to assess individual conceptual development. | ISA encourages students to be responsible for their own learning, to read and comprehend by themselves and to participate in evaluation of their learning. |

**Figure 4.1: Sandra's beliefs regarding the affordances of different instructional settings**

**Key Finding 4.6**
Sandra believes that her teaching is characterised by a large proportion of small group work. However, she believes that each instructional setting is important and provides particular affordances for the development of higher order thinking and science reasoning.

## Topic and unit overview

This section provides an overview of the structure, objectives and concepts and processes Sandra incorporated into her Materials and their properties unit.

**Unit structure and objectives**

The unit comprised nine lessons. Lessons of duration between 70 - 85 minutes were taught weekly (Figure 4.2 and Appendix B).

| Lesson | 5E stage | Title | Concepts |
|---|---|---|---|
| 1 | Engage | Frank's fish and chips | Materials have properties that make them suitable for some uses and not for others. |
| 2 | Explore | Unfair class relay | What makes an investigation fair? |
| 3 | | Soak, leak or repel | Some materials are better at absorbing water than others |
| 4 | | Snap, tear or stretch | Some materials have a higher tensile strength than others. |
| 5 | | Natural vs. synthetic packaging peanuts | Products made from natural materials are more biodegradable than products made from synthetics. |
| 6 | Explain | Puzzling with plastics | Some materials if not managed can lead to pollution. |
| 7 | Elaborate | Thermal insulation | Some materials are better insulators than others. |
| 8 | | Opaque, translucent and transparent | Different materials let different amounts of light through. This makes them suitable for some uses and not for others. |
| 9 | Evaluate | Curtain design brief | Selecting materials for uses based on their properties. |

**Figure 4.2: Overview of Sandra's lessons and main concepts material**

Sandra based her lessons on the *Primary Connections* unit *Material world*, Stage 2, Natural and Processed Materials (https://www.primaryconnections.org.au/curriculum-resource/material-world); which she modified to suit her class and classroom, and utilised the *Primary Connections* inquiry and investigative approach and focus on literacy. She sequenced her lessons using the constructivist 5Es model (Engage, Explore, Explain, Elaborate and Evaluate) (Bybee et al., 2006)(Figure 4.2) and applied a themed approach to the unit. The theme was based on an authentic dilemma which was introduced at the beginning of the unit.

**Classroom dilemma**

Sandra used a dilemma that there was too much light coming into the classroom as a theme to focus her lessons about the properties of materials. After a class discussion students decided that they needed to make a classroom curtain to block the light and so Sandra posed the question, *What type of material would be best for our classroom curtain?* This question became an important vehicle for thinking and reasoning, linking learning and reviewing of concepts across lessons. It also formulated the basis for assessment in the final lesson. Students explored the properties of absorbency, tensile strength, biodegradability, thermal insulation and opacity of various materials using fair test investigations. The unit culminated in an evaluation lesson. Each student was given access to a variety of fabrics and resources and tasked to design and make a model of a curtain that would meet the specifications of a pseudo client. On their individual design boards, students were required to describe the properties of the fabric they had chosen for their client and justify, giving reasons for their fabric selection.

**Key Finding 4.7**

Sandra modified a *Primary Connections* unit on materials and utilised the 5Es constructivist approach to focus on an authentic question of significance to her class which involved investigating the properties of materials. The question, *What type of material would be best for our classroom curtain?* became an important vehicle for linking learning and reviewing of concepts across lessons, promoting thinking and formulated the basis for assessment in the final lesson.

## Sandra's instructional approach

An important aspect of Sandra's science teaching practice was her detailed planning and organisation. This section highlights and describes Sandra's instructional approach. Sandra plans and organises the classroom, unit, lessons, learning activities and instructional settings to support and scaffold higher order thinking and scientific reasoning within her Science lessons.

**Physical organisation of the classroom**

Much of Sandra's teaching was geared towards small group learning supported by whole class discussion. Over the nine lesson topic, 81% of lesson time was devoted to small group (32%) and whole class activities (49%) (Figure 4.3). To this effect Sandra organised classroom furniture to facilitate these interactions.

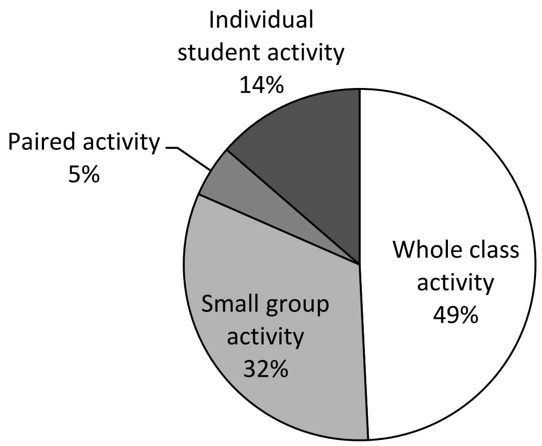



**Figure 4.3: Percentage of time students were occupied in each instructional setting across the unit**

Student tables were grouped to form small collaborative work groups where four to six students worked together, and an area in the front of the classroom was left free of furniture where students could sit on the carpet and participate in whole class discussions and activities (Figure 4.4). The groups of tables were positioned to allow each student a clear view of the front of the room where formal instruction took place, to enable Sandra easy access to support individual and group learning, and to facilitate the movement of students between groups and around the room.

Sandra's classroom setup provided a physical environment that supports collaborative learning where students are able to share and talk through ideas, despite the congested space.

**Figure 4.4: Photograph of Sandra's classroom**

**Key Finding 4.8**
Sandra set up her classroom and planned lessons to facilitate small group work and whole class activities and discussions. Students sat in groups at tables for the majority of the time and came together to sit on the carpet at the front of the room for receiving instructions and to review previous lesson's concepts.

**Sequencing of lessons**

Sandra's unit planning supported higher level thinking and reasoning by sequentially building and adding upon learning from one lesson to the next until the students had acquired the knowledge and skills required to choose a suitable material for their classroom curtain; as illustrated by the learning sequence.

| | |
|---|---|
| Lesson 1 | Set-up of the classroom curtain dilemma. |
| Lesson 2 | Reviewed fair testing procedures to enable students to test and compare materials. |
| Lessons 3 – 8 | Guided and supported students' exploration of a variety of materials in respect to their absorbency, tensile strength, biodegradability, insulation and opacity. |
| Lesson 9 | Assessed students' understanding of properties and their uses by having individual students complete a design brief for a pseudo client, where they had to choose a fabric for a curtain and give reasons and justification for their choice. |

**Learning through inquiry**

The development of higher level thinking and inquiry skills across lessons was another example of Sandra building and scaffolding thinking and learning across lessons. Having the belief that fair testing skills are necessary for critical thinking, Sandra developed and scaffolded student's understanding and the application of fair testing across the topic. During Lessons 2 – 5 she introduced formalised investigation planners to model the inquiry process and for a written representation of students thinking and learning. Across these lessons Sandra progressively faded the scaffolding by decreasing the amount of support she gave to students to complete the planners, which opened-up greater opportunities for student inquiry. This is exemplified in the review of her scaffolding of inquiry and fair testing in Lessons 2 – 5.

During Lesson 2 Sandra engaged students with fair testing and reviewed students' current understanding of the concept by having them participate in an unfair relay and a quiz regarding the importance of fair testing.

> there was a lot of learning there as the students had to think about what they knew about fair testing and then they had to look at somebody else's work and pick up whether they had a clear idea of where they were going with their investigation. (Lesson 2 Teacher post-lesson discussion)

In Lessons 3, 4 and 5 Sandra provided support and instruction on how to conduct and apply fair testing. Prior to the investigating in Lesson 4 Sandra explained that she would be doing less scaffolding of fair testing than in Lesson 3. "As I said before, last week I did the investigation, I stepped you through it. This week I've just modelled it for you so you know exactly what you need to do". As students became more familiar with the process of fair testing and were becoming more confident with the skill, the level of support was reduced. Students coped well with the fading of scaffolding from Lesson 3 to Lesson 4. Sandra was happy with the way students predicted, reasoned and obtained results with less support.

> I deliberately set it up that way I wanted them to work in teams and I wanted them to explore and I was concerned I was thinking oh I wonder how this will go but they actually did a really good job and they followed the steps, everybody filled in, because what usually can happen is that

> kids will get off task and they won't be you know following the procedure but they did it beautifully today and I'm really happy with their predictions their reasoning and their results. (Lesson 4 Teacher post-lesson discussion)

Students' development of higher order thinking skills and reasoning were also enhanced when Sandra incorporates authentic activities into her lessons.

| **Key Finding 4.9**<br>Sandra set up the topic by introducing the problem (Lesson 1) that they needed a classroom curtain. Lessons were taught through inquiry. She sequenced activities and lessons and scaffolded learning (concepts and skills), using investigation planners to guide inquiry and to be a written representation of students thinking and learning; and, by building and adding upon learning from one lesson to the next until the students had acquired the knowledge and skills required to choose and justify a suitable material for making their classroom curtain (in the final lesson). Teacher scaffolding and the use of the formalised investigation planners was decreased, and the openness of the investigations were increased, as the unit progressed. As students' understanding and skill level increased Sandra's level of support was decreased. |
|---|

**Selection of authentic learning activities**

Sandra's lessons are based on authentic activities and draw upon students' life experiences. For example, Sandra introduced the unit and gained students' interest by asking them to think about hot fish and chips; something most Year 4 students can relate to, especially when they have their individual serve wrapped in paper. Lesson 1 was introduced with the question "What is the best paper to wrap your fish and chips with, so they don't go soggy or fall through the paper?". This was followed with a more pressing problem that too much glare was coming into the classroom for the researchers to film. Sandra saw the potential of this real life situation and implemented the question, "What material would be best to make a classroom curtain?" as the vehicle for learning throughout the topic. Authentic activities such as these provide interest and relevance to learning, for thinking and discussion between students.

**Key Finding 4.10**
Sandra utilised a classroom problem relating to the topic as the vehicle for learning. Her planning, organisation and sequencing of lessons was purposeful and involved building and equipping students with the conceptual understandings and skills to find a solution to the problem.

**Lessons structured for discussion**

Viewing Sandra's lessons through social constructivist, sociocultural and distributed cognition lenses, it was observed that Sandra structured her lessons to maximise hands-on learning and whole class and small group discussion. Sandra's lessons generally followed the sequence given in Figure 4.5. Each of the five stages involves students sharing and formulating ideas through talk and discussion. This pattern is evident in the overviews of Lessons 4 and 5 (Appendix F).

| Whole Class Instruction | Small Group Activity | Whole Class Discussion | Whole Class Activity | Whole Class Discussion |
|---|---|---|---|---|
| Review, introduction to lesson and activity | Investigation | Sharing investigation findings | Review and consolidation of personal understandings | Application of new concepts and terminology |
| • Previous concepts and terminology reviewed<br>• WILF* and TIB** success criteria unpacked<br>• Explanation and modelling of small group activity | • Students are encouraged to formulate, share, discuss, justify, test and adjust ideas if necessary to come to a consensus.<br>• Teacher monitors, scaffolds, supports student/s exploration, thinking and discussion | • Small groups share their findings with the class<br>• Differing group findings are 'teased out' and summarise d by Sandra | • Teacher-led discussion, debate and Fish bowl strategies allowed students to examine, refine, and consolidate learning and to develop higher order thinking | • Review of concepts and new terminology<br>• Students' thinking is extended through applying their learning to everyday situations |

**Figure 4.5: Sandra's general sequence of instruction for learning through discussion *WILF – *What am I looking for* **TIB – *This is because***

Sandra orchestrated higher order thinking and scientific reasoning through a number of pedagogical strategies which will be discussed in more detail later in this chapter. The structure of Sandra's lessons allows her to scaffold and support quality discourse and learning by providing opportunities for students to experience, talk, explain, discuss, justify and come to a consensus with peers in the small group and whole class settings. Students were given the opportunity to experience a phenomenon during small group activities and investigations. Through shared experiences, talking and 'thinking out loud' students formulated personal ideas and shared them with others. By explaining and justifying their ideas and conclusions to others, ideas were adjusted and strengthened.

**Instructional settings and setting changes**

Sandra's teaching incorporates a range of different instructional or activity settings during lessons and across the topic. Sandra's practice of exercising instructional setting changes not only catered for individual learning preferences and paced learning but it was a strategy for building and progressing learning. Appendix C illustrates that there are more occurrences of small group and whole class activities (SGA 28%, WCA 54%) across the unit than individual and paired student activities (ISA 12%, PA 7%) and similarly Figures 4.3 and 4.5 illustrate that the majority of class time across the unit was taken up with small group or whole class activity. The frequencies of these results reflect the importance Sandra places on student discussion in the co-construction of knowledge.

Figure 4.5 illustrates Sandra's orchestration and scaffolding of the learning process. For example, small group activity was often preceded by and followed up with whole class activity. Sandra firstly drew pre-existing ideas from the class when introducing activities; students explored, discussed, formulated and came to a group consensus during small group work and lastly there was a sharing, refining of and application of ideas during whole class discussions. The correlation between the 5E phase and the number and type of instructional setting changes also demonstrates Sandra's support and scaffolding of students' understanding and development of higher order thinking across the unit.

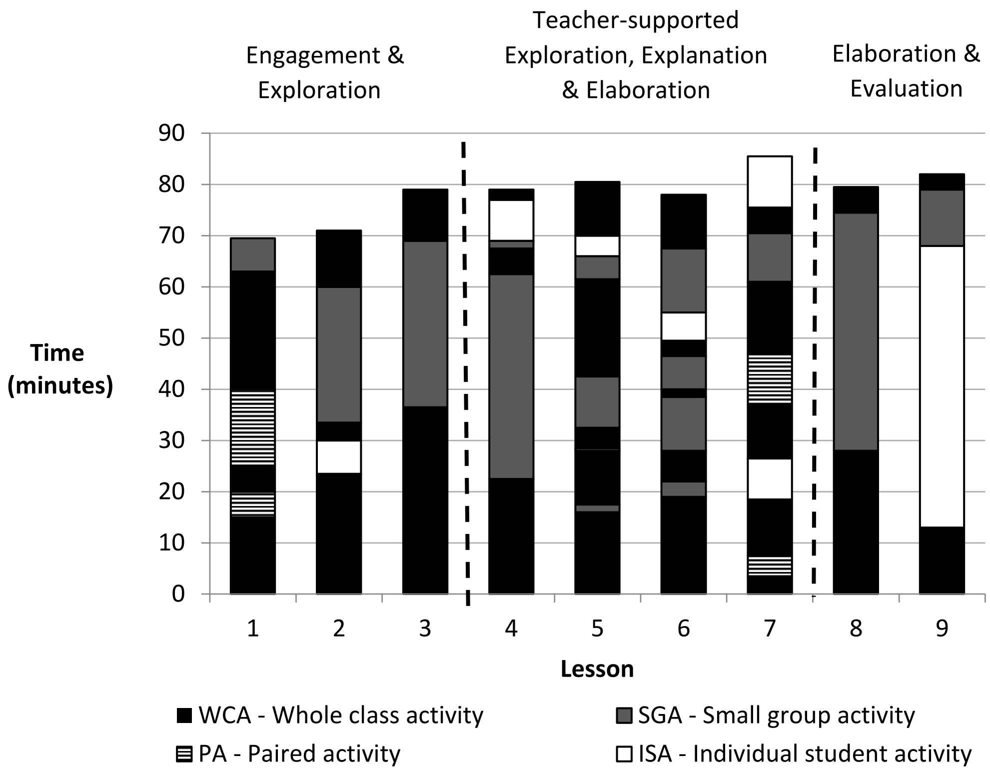



**Figure 4.6: Distribution of classroom activity time across the Materials unit**

Three broad phases are evident across Sandra's nine lessons in Figure 4.6 and Appendix C and are indicative of Sandra's scaffolding of higher order learning. These phases been marked using the dashed lines between Lessons 4 and 5 and Lessons 7 and 8 on Figure 4.6 and Appendix C. The middle phase (Teacher Supported Explore, Explain and Elaborate phase) comprising Lessons 4 - 7, differs from the other broad phases as the lessons contain an above average number of instructional setting changes which reflect greater teacher intervention and support in scaffolding learning and higher order thinking.

Taking these results and Sandra's beliefs regarding the affordances attached to each instructional setting (Figure 4.1) into consideration, it was evident that Sandra purposefully planned the changing of instructional settings within lessons and used this as a strategy to support and scaffold higher order thinking and scientific reasoning. Sandra's instructional approach was founded on a supportive and positive classroom environment and learning culture. Her detailed planning and organisation is a feature of her teaching. The combination of factors such as her preparation of the physical classroom setting, sequencing and structuring of lessons, selection of authentic lesson activities and use of different instructional settings provided a strong foundation and platform for her pedagogical practices and strategies that scaffolded and supported the development of higher order thinking and scientific reasoning within her Science lessons.

| |
|---|
| **Key Finding 4.11**<br>Sandra utilised different instructional settings to pace and progress learning, to cater for individual learning styles and as a strategy to support and scaffold higher order thinking and scientific reasoning. She orchestrated and sequenced talk opportunities for students to formulate and represent their thinking and learning verbally. |

## Sandra's pedagogies and strategies

Sandra adopted a top down approach to scaffolding and supporting individual students' development of higher order thinking and science reasoning skills. A positive and already established classroom environment and supportive science learning culture was fundamental to the success of Sandra's pedagogical practices and strategies (Figure 4.7).

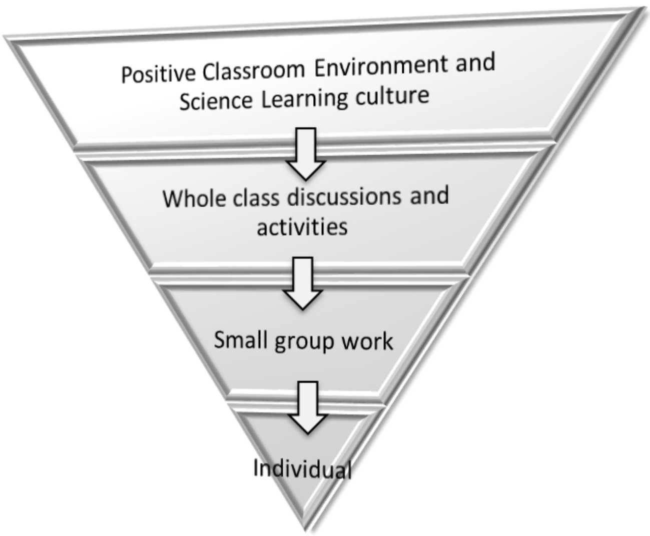



**Figure 4.7: Sandra's approach to scaffolding and supporting the development of an individual student's higher order thinking and reasoning skills**

Approximately half of Sandra's instructional class time was taken up with whole class activities and discussion and one third was taken up with small group work. This section will highlight strategies and practices Sandra implemented in the whole class and small group settings that scaffolded and supported higher order thinking and scientific reasoning.

**Whole class practices and strategies**

Sandra implemented a variety of practices and strategies in the whole class setting which supported and scaffolded higher order thinking and scientific reasoning. Key features of her practice were strategies which integrated the development of vocabulary and scientific language with concept development, the use of metacognitive strategies for scaffolding reasoning, self-regulation and argumentation; and the development of a cooperative and collaborative classroom culture that supported thinking out-loud, the critiquing of peers' ideas and the co-construction of ideas and arguments. Each of these strategies used to scaffold and support higher order thinking and scientific reasoning will be described, exemplified and discussed in this section.

**Sandra's emphasis on language development**

From a sociocultural perspective, it was obvious that Sandra placed great emphasis and time into developing the language and vocabulary students need for thinking and reasoning. The following features of her practice are discussed and exemplified in the following section.

- Development of language to support concept development
- Identification, assessment and early introduction of terminology
- Coupling, repetition, touch and embodiment (e.g. gestures) used to introduce and explain new vocabulary
- Teacher modelling of language
- Reinforcement of vocabulary and concept understanding across lessons

**Development of language to support concept development**

A distinctive feature of Sandra's practice was her emphasis on language and vocabulary development to support conceptual development. Sandra's belief that students need access to relevant science language and vocabulary to connect and build science ideas and to reason in science is reflected in her lessons. "Every [Science] lesson has incorporated some new vocabulary . . . to classify and connect the ideas and the concepts they've been working with" (L5 Pre-lesson Teacher discussion). Key terms and new terminology are introduced to students early in each lesson. Initially Sandra endeavoured to draw these terms from students' prior knowledge and experiences and then modelled their use and incorporated them into whole class and small group conversations. Analyses of Sandra's lessons indicated two types of conversation threads in her lessons: "those developing vocabulary, and others with a focus on conceptual development" (Hackling & Sherriff, 2015, p. 19). She integrated language development with conceptual development using the following five step approach.

1. Diagnosing students' current knowledge of key terms.
2. Probing, drawing-out and highlighting key vocabulary both scientific and general.
3. Introducing, developing and elaborating students' use of key terms with some initial conceptual development.
4. Focus on conceptual development with continuing vocabulary development and integration.
5. Reviewing and evaluating student understandings (Hackling & Sherriff, 2015, p. 19)

Through these five steps Sandra, first provided students with the language to talk and discuss their ideas and secondly the conceptual understanding to reason in science. Once students had achieved an initial conceptual understanding, Sandra extended students' thinking and reasoning by setting up situations where they applied their knowledge to solve problems.

Lesson 5 exemplifies Sandra's development and integration of language and conceptual understanding using the five step process (Appendix D).

**Identification, assessment and early introduction of terminology**

During lesson planning Sandra identified important science terms and general vocabulary to support the lesson's concepts. For Lesson 5 the terms *biodegradability, polymer, corn-starch, synthetic* and *natural* were selected to support the development of the learning outcome: *Products made from natural* *materials can be more biodegradable than those made from synthetic material*. (Refer to Sandra's Lesson 5 plan in Appendix E).

The introduction and assessment of students' understanding of these terms commenced from the onset of the lesson. The term *polystyrene* for example was drawn from students when Sandra distributed activity resources prior to commencing the lesson. Sandra placed a polystyrene cup on each small group's table and asked the students what material the cup was made from. In earlier lessons students had used the commercial name of *Styrofoam* but for Lesson 5 Sandra wanted the students to adopt the scientific term *polystyrene.* The following transcript demonstrates the vocabulary thread used by Sandra to draw the term *polystyrene* from students' prior knowledge. Sandra's prompting led the conversation from Styrofoam -> foam -> polystyrene. To be noted, Sandra did not conduct any conceptual development regarding polystyrene at this stage of the lesson. That occurred later in the lesson when polymers were explained.

Lesson 5
(00.01:24 – 00.03:42)

Teacher: And you also have a cup. Does anyone know what type of cup this is? Who knows what we call this material? Yes.
Student: Styrofoam
Teacher: Styrofoam, anyone got another name for it? No, no it is called a Styrofoam cup; it's also called something else.
Student: Foam cup
Teacher: Foam cup, Annabelle?
Student: Polystyrene
Teacher: Polystyrene. Put your hand up if you have heard of the word polystyrene before. Okay, very good.

To assess, diagnose and ascertain starting points for learning it is important to establish students' prior understanding. Sandra used the Sticky note fact graph strategy to determine students' understanding of *biodegradability*, the overarching theme for Lesson 5 (refer to Figure 4.8 for a description of the strategy). Students were asked to assess their personal level of understanding of the term *biodegradability*; to match it with one of a range of descriptors and to place a sticky note on the classroom noticeboard under a label indicating that descriptor. The collection of the students' sticky notes formed a graph and provided a visual representation of each student's understanding and the class' collective understanding of the term. It engaged students, introduced the theme, focused students' thinking by providing them with a starting point to which new learning could be attached, and provided Sandra with a baseline from where to commence language and conceptual development. The strategy was also used with different coloured sticky notes as a post-assessment tool. The comparison of the two graphs indicated the increase in understanding of *biodegradability* that took place over the lesson (the Sticky note fact graph was also a metacognitive tool for students and will be discussed in the next section on metacognitive strategies).

| | |
|---|---|
| Sticky note fact graph | Is a visual representation of students understanding of biodegradability. Students are asked to put a sticky note on the side wall over the letter A, B, C or D (defined descriptors) to illustrate their level of understanding of a 'fact' or word. The graph illustrates the range of understanding across the student group. When repeated with a different coloured sticky note after a period of time changes in understanding are visually obvious. |
| Interactive word sort | Students drag and drop words and phrases on the IWB into the correct columns and match the correct property and use for each material. |
| Word/concept wall | Visual reminder of words and concepts introduced during the topic and the relationships between them |
| Word cards | Visual reminder to use key terminology in discussion and written tasks |

**Figure 4.8: Assessment and language development strategies used in Lesson 5**

Sandra used a variety of visual representational strategies to support and scaffold students' understanding and incorporation of key terms during lessons. For example, in Lesson 5, Sandra used the strategies described in Figure 4.8. Word cards for example, were used as prompts to help students to use scientific terminology.

During Lesson 5 Sandra explained to students how to use the word cards to assist them with describing the two types of packaging peanuts. She stated, "If you are struggling to find words to describe them you can have a look at your word pack" (Lesson 5 transcript (00.39:04)).

**Coupling, repetition, touch and embodiment used to introduce and explain new vocabulary**

Sandra continued to introduce and explain new vocabulary as the lesson progressed and conceptual understandings were developed. This exemplified her belief that language is important to connect and build ideas and to reason in science. Sandra encourages students

> to make connections and access and apply new vocabulary as they develop their ability to talk about their thinking, articulate their beliefs and reason scientifically. . . . I ensure that the introduction of new vocabulary is always used in context and linked to prior knowledge. (Personal communication, June 2014)

Sandra employed a variety of strategies like coupling, repetition, touch and embodiment (e.g. gestures) to introduce and explain new and unfamiliar vocabulary to students. All of these strategies linked new learning to something that students were familiar with.

Sandra often used 'coupling'; a linking strategy to introduce and reinforce new vocabulary. For example, during small group work in Lesson 5 students were tasked to physically and verbally distinguish between synthetic and natural packaging peanuts. The majority of students struggled with the definition and understanding of *synthetic*. Sandra scaffolded students' understanding by verbally linking synthetic with its opposite *natural*, a term that students were familiar with. She also coupled it with *man-made*, a more familiar and easier term to comprehend. The following transcript demonstrates how Sandra coupled terms to increase students' understanding of them.

Repetition, chanting and embodiment strategies were used by Sandra, often in conjunction with coupling to reinforce students' understanding and use of science terminology.

> I often associating new words with gestures, images, equipment and objects and I then reinforce the new language continuously throughout the lesson. My aim is to assist students in creating a 'memory trace' that supports their retention, retrieval and application of the vocabulary and thus the science conceptual knowledge and understanding to which it is linked. During this process, students are guided and supported in their conceptual and language development simultaneously. (Personal communication, June 2014)

Sandra believes that associations will assist students with the recall of learning. By touching and then verbally repeating things students will make associations. Sandra often used touch because it helps students to recall especially when it is used in tandem with repeating or mirroring.

> It's important for them [students] to be tactile, to be touching . . . so they are touching, and they're associating, and they're also repeating. The mirroring [repeating back] is very important in learning and you know kids do it when they're really little and . . . that whole process doesn't need to be abandoned as they get older. (Lesson 5, Teacher post-lesson discussion)

The following Lesson 5 transcript illustrates the coupling of synthetic with man-made and natural and food-based; and, the standing up, repeating and use of gesture to reinforce the meaning of synthetic.

Lesson 5
(00.40.53 – 00.42.50)

| | | |
|---|---|---|
| Teacher: | **So one of your polymers is synthetic. What does synthetic mean?** Okay so we've said we have two polymers. One is synthetic. What does it mean? What does synthetic mean? Anybody know? Yes. | |
| Student: | It's **man-made**. | A student links *man-made* with *synthetic*. Sandra capitalises on the link and has the class repeat it several times whilst standing up. |
| Teacher: | **Man-made. Everyone say synthetic**. | |
| Students: | Synthetic. (choral response) | |
| Teacher: | Say man-made. | |
| Students: | Man-made. (choral response) | |
| Teacher: | **Stand up.** Synthetic. | |
| Students: | Synthetic. (choral response) | |
| Teacher: | Man-made. | |
| Students: | Man-made. (choral response)(One of the students **flexed his bicep whilst responding**.) | |
| Teacher: | Oooh, I like that Lennie. Let's do what Lennie (pseudonym) did. Synthetic. Man-made. | Sandra acknowledges a |

| | | |
|---|---|---|
| | | student's flexing biceps gesture with "man-made". She copies the gesture whilst coupling synthetic and man-made. |
| Student: | Man-made. (Children flex their biceps whilst saying man-made). | The class copies the gesture whilst repeating man-made. |
| Teacher: | Excellent sit down. Alright one of them is natural. Everybody say natural. | |
| Students: | Natural (choral response) | |
| Teacher: | Natural is food-based. | Sandra couples natural with food-based. |
| Students: | Natural is food-based (choral response) | |

The previously discussed language development strategies adopted by Sandra are complemented by her direct modelling and use of the specific language that she would like students to develop and use.

**Teacher modelling of language**

Sandra often taught students new vocabulary and science skills through modelling their use. Sandra modelled new and unfamiliar vocabulary during her lessons. Figure 4.9 illustrates and compares the number of times across Lesson 5 that Sandra and her students used particular words and phrases. These words were identified by Sandra in the planning stage as new vocabulary to be introduced in Lesson 5.

A noticeable difference can be observed between teacher and student use when looking at polymer and biodegradability. The heightened use by Sandra demonstrates her modelling of the words to help students become familiar with their use.

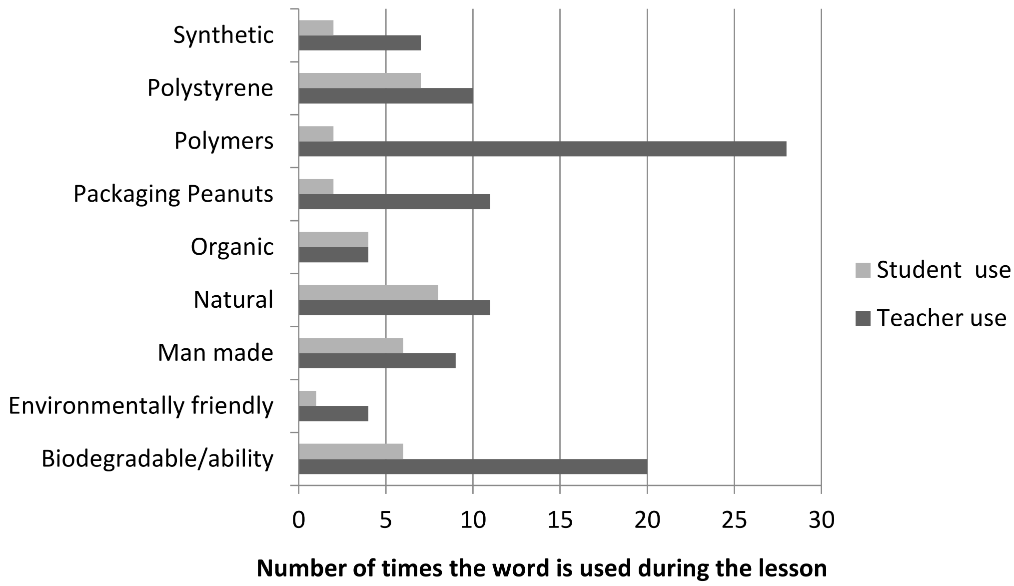



**Figure 4.9: Science words used by Sandra and her students during Lesson 5 on biodegradability**

### Reinforcement of vocabulary and concept understanding across lessons

Once Sandra introduced new concepts and vocabulary in lessons she continued to reinforce their correct application within and across lessons. Force for example, was introduced in the beginning of Lesson 4, during the explanation of tensile strength and was used by Sandra instead of *push* or *pull* throughout the lesson. Students who used the term correctly were praised or given some form of positive acknowledgement for doing so; and, when students didn't use the term in their conversations, Sandra reframed the student's response by exchanging the word *push* or *pull* with the word force. For example:

Lesson 4
(00:11:33.01)

| | | |
|---|---|---|
| Teacher: | Now all that means is that we can measure the stretchability and how strong the material is when we apply force to it. Okay, so who can think of a material that if you just applied force by say pulling it that it will just break? | Term 'force' used in tensile strength explanation. |

(00:16:47.21)

| | | |
|---|---|---|
| Teacher: | We are going to keep the peg absolutely. What else are we going to do? | Teacher reinforced student’s use of ‘force’ |
| Student: | The force that we put on it. | |
| Teacher: | The force**. OOoo**, now that is actually a really good thing to bring up because if we start giving everyone a turn, can we be sure it is the same force? | |

(00:41:27.16)

| | | |
|---|---|---|
| Teacher: | Okay, good. That's a good reason, and the cloth, you think it will stretch. Can you tell me why? | Teacher exchanges the term ‘force’ for student’s non-scientific description |
| Student: | Well, this can't tear unless you really pull it. So… | |
| Teacher: | ...if you apply a lot of force to it. | |

Sandra also reinforced and modelled vocabulary by linking the discussion to objects students were studying or manipulating over a number of lessons. For example, the yellow cloth introduced to students in Lesson 3 *Soak, leak or repel* was used again in Lessons 4 *Snap, tear or stretch* and in the revision of properties and their uses in the beginning of Lesson 5. Each time this fabric was used, Sandra elicited from the students the term ’absorbent’ or ‘absorbency’, and at the same time assessed their understanding of the concept. This is similar for the set of possible curtain fabrics introduced at the beginning of the topic and tested for their various properties across the topic. In Lesson 8, for example, when Sandra reviewed early responses on the classroom homework blog where students were putting up their suggestions for the best fabric to be used for the classroom curtain, she scaffolded one of the student’s response so that he used the newly introduced technical name ‘cotton polyester blend which is coated in acrylic’ instead of ‘curtain material’.

Lesson 8
(01.15:01)

Teacher: Let's look at Martin’s [blog]. "I think the material we need for our classroom curtain is curtain [material] because it already has all the stuff we need. It is insulation to keep the classroom cool, keep it thick so it won't tear easily and you can let the light in. DO NOT do lace because it has holes that will let light in and will not insulate the classroom.

Teacher: You said up there, ‘curtain’, because you did this . . . about a week ago didn't you, but do you know what the name of that curtain material that you were thinking of is now?

Student: Yes, polyester cotton blend coated in acrylic.

Teacher: Acrylic, Acrylic. So when I showed you the materials way at the beginning of the term, quite a few weeks ago . . . we actually didn't know which this one was called but today we do know what it is called. So when Martin is saying he thinks the ‘curtain material’, he is saying the ‘cotton polyester blend which is coated in acrylic’. Okay and using the words that we learnt today is that because it’s translucent or is it because it, or did you choose this one because it was going to keep the light out and is therefore opaque, which one?

From a social semiotic perspective, Sandra’s belief that language is an essential tool for conceptual development and reasoning was reflected in her lessons. Her early assessment, introduction, modelling, reinforcement and integration of key scientific language and vocabulary with conceptual development in each lesson, allowed students to become confident using new or unfamiliar terminology, to link concepts together, to talk about and discuss ideas and concepts with others, to co-construct and built understanding, to think more deeply and to reason as they applied their understanding to solve problems.

**Key Finding 4.12**

Language development is a significant factor in Sandra’s teaching and is evidence of her belief that access to relevant science language and vocabulary is necessary to connect and build science ideas and to reason in science.

- Sandra developed and incorporated vocabulary and scientific language with conceptual development in a five step process: selecting and diagnosing understanding of key science terms; probing, drawing out and highlighting general and key vocabulary, introducing new and unfamiliar terms with initial concept development, focusing on conceptual development with continual vocabulary development and integration, and reviewing and evaluating understandings.
- Sandra incorporated visual (e.g. Sticky note fact graph, word/concept wall, interactive word sort, word cards) and verbal representations of coupling, repetition, touch, and embodiment (e.g. gestures), teacher modelling and continual reinforcement across lessons for new science terms.

**Metacognitive strategies for scaffolding reasoning, self-regulation and argumentation**

Sandra had a sophisticated repertoire of practices and strategies for developing students' metacognitive awareness and higher order thinking and reasoning skills. She encouraged students to take responsibility for their thinking and learning and scaffolded the development of skills that enabled students to be aware of how they think, how they learn; and what they know and don't know.

Metacognition is often referred to as a self-regulatory process. Sandra taught her students to have an awareness and understanding of their own thought processes.

> I try to instil in them that constant questioning, that critical thinking, that you know . . . the self-reflection the metacognition, you know knowing what we need to learn but knowing why we need to learn it and caring about that, making that an important part of our day, that kind of bringing us together as a team. (Teacher post-study interview)

Through teaching, reinforcing and modelling a range of metacognitive strategies Sandra supported the development of higher order thinking by giving students strategies to monitor, understand and progress their learning. As previously discussed Sandra utilised formalised investigation planners. The planner acted as a metacognitive scaffold to scaffold, support and model the thinking and inquiry processes for investigations. This section will describe how Sandra incorporated metacognitive strategies like the Learning train, Sticky note fact graph, WILF and TIB statements and syntactical scaffolds like 'because' to scaffold, support and create opportunities for higher order thinking and scientific reasoning.

***Learning train as a self-regulatory strategy***

There is a little bit of fantasy and magic in Sandra's class. Learning in Sandra's class was a bit like being on a 'Polar Express' train ride. Sandra called her train the Learning train. The Learning train symbolised the learning journey that Sandra and her students were on and the destination of their journey was increased knowledge and understanding. Sandra used the Learning train analogy as a self-regulatory strategy. She encouraged students to be active participants in their learning by asking them to monitor their level of engagement and understanding and to ask for help if they found their understanding lagging. For example early in Lesson 5 Sandra reminded students to stay engaged, to monitor their understanding and to ask for help if they need it.

Lesson 5
(00.03:02)

Teacher: I need everybody to push their chairs in and sit up straight, I want you to engage. If you are on the Learning train I want to hear a "Choo choo".
Student: Choo, choo (Class chorus)
Teacher: Alright if you fall off the Learning train at any time today I would like you to raise your hand and let me know, and we'll come back and get you...

She used the Learning train analogy again in Lesson 6 but in a slightly different sense. At this part of the lesson she was preparing to extend students' thinking and reasoning. As this is not always an easy task she checked whether students were still engaged with the learning.

Lesson 6
(00.49:43)

Teacher: Okay so what I want you to do now is to put your thinking caps on... got them on? Very good. Is everyone still on the Learning train, let me hear a "Choo choo"?
Student: Choo, choo. (Class chorus)
Teacher: Excellent.
Student: My thinking cap keeps on falling off.
Teacher: Your thinking cap keeps falling off? Alright.

**Key Finding 4.13**
Sandra promoted a culture of self-regulation in her classroom highlighting to students that each student is on their own learning journey. Using the Learning train metaphor she asked students to monitor their level of engagement in the learning and to ask for help when they were disengaged or needed help with understanding.

One particular metacognitive strategy Sandra employed to promote self-regulation and higher level thinking is the Sticky note fact graph strategy.

***Sticky note fact graph strategy***

Similar to the tenets of the Learning train, the success of the Sticky note fact graph strategy is dependent upon a safe classroom learning culture. This strategy scaffolds students to self-regulate on a deeper cognitive level than the Learning train and provides students with a representation and a means to monitor and assess their thinking and understanding of particular terminology and concepts prior to and at the end of the lesson.

Sandra used the Sticky note fact graph strategy in Lesson 5 on biodegradability as a pre- and post-assessment strategy to diagnose students' understanding of the term *biodegradability*. It is a formative assessment; good for gauging "whether kids . . . have heard some vocabulary or terminology [and] whether they actually have a conceptual understanding to it or how they feel about it" (Lesson 5, Teacher post-lesson discussion). It is also a complex thinking task that prompts students to assess their own understanding of words and concepts. The success of the strategy relies on students having the metacognitive skills to think and review their understanding of a term, to identify their level of understanding using a set of descriptors; and, to reassess their understanding at a later time for any improvement in their understanding. Sandra commented that her students were familiar with this strategy having used it in the previous year when she taught the majority of them in Year 3. The strategy has value only if students are honest in their assessment and are comfortable revealing their level of understanding to their peers.

> I'm very lucky to have a class that's very honest with that kind of thing, they don't generally show bravado and say they know something when they don't, so I know that it's going to be a realistic gauge of where they're at so I wanted to know. (Lesson 5, Teacher post-lesson discussion)

The pre-assessment commenced early in Lesson 5 prior to the commencement of the hands-on small group activity. The post-assessment occurred at the end of the lesson. An overview of how Sandra implemented the sticky note pre-assessment strategy for Lesson 5 can be found in Figure 4.10.

1. Students were given a green sticky note and asked to think about their level of understanding of the word biodegradability.
2. Four larger sticky notes labelled A, B, C and D, were placed equally spaced along the length of the side noticeboard.
3. When the student's assessment of their understanding matched Sandra's verbal prompts they placed their sticky note above the appropriate letter. Sandra's prompts were as follows:
   - A - "If you know what it means, you've learnt about it, you understand it, if I asked you to describe it you could. You need to go and put it on the wall above the A."
   - B - "You think you kind of get it but you're you know, not really that sure, go and put your post-it over B."
   - C - "If you have no idea what it means but you've heard of it you know the word but you don't know its meaning go and put your post-its above C."
   - D - "Okay last one D. I've never heard of biodegradable in my life and what is biodegradability. Is it a type of bee or a shoe?"
4. The strategy was repeated at the end of the lesson using a yellow sticky note. The students and teacher were able to review and identify any changes in their understanding of the term.

**Figure 4.10: An overview of Sandra's implementation of the pre-assessment sticky note strategy in Lesson 5 on biodegradability**

Sandra's comments made during the post-lesson discussion highlight the effectiveness of this strategy.

> I knew there would be some kids who would know it [have an understanding of biodegradability] and some that wouldn't so I was actually really pleased with the [improvement]. At the beginning [pre-assessment] . . . so many kids did know but . . . a lot of kids chose D, like they didn't have any idea at all. . . . it was really nice when we re-visited it at the end [post-assessment] that just through the course of an hour and 20 minutes of doing science activities, students who had perhaps heard of it but didn't know it or perhaps had never heard of it and didn't know anything about it now consider themselves a little bit more knowledgeable because we only had 2 in the D so that was really good. (Lesson 5, Teacher post-lesson discussion)

The sticky note strategy utilised by Sandra in Lesson 5 encouraged student metacognition. By implementing this pre- and post-lesson assessment strategy, Sandra scaffolded and supported each student to identify what they knew, what they didn't know, and what they learnt about biodegradability over the lesson. The strategy afforded students ownership of their learning by encouraging them to reflect, self-evaluate and report on their personal level of understanding and was a representational stimulus for improvement as it encouraged students to identify a starting point to anchor their learning and a level of understanding to work towards during the biodegradability activity.

**Key Finding 4.14**
The Sticky note fact graph *strategy* was employed by Sandra as a pre- and post-lesson assessment and diagnostic tool and develops students' metacognitive skills. It was a visual and graphical representation of students' thinking and learning and provided a representational stimulus for students' to improve their thinking and learning across the lesson on biodegradability.

***WILF and TIB as metacognitive scaffolds***

WILF and TIB statements are another metacognitive strategy employed by Sandra to encourage and scaffold deeper thinking and to promote science reasoning. Students in Sandra's class were very familiar with WILF and TIB statements. For each lesson Sandra wrote WILF ('What I am looking for?') and TIB ('This is because…') statements on the IWB to indicate to students the instructional intentions and expectations for the lesson and to relate how the learning in the lesson is important for everyday living (Figure 4.11).

As a class group at the commencement of the lesson Sandra had the students read out the statements. Commensurate with Sandra's belief, that it is important to give students the language to reason in science and that language development is important for conceptual development; each statement was unpacked and new or unfamiliar terms (conceptual and process) were discussed to ensure that students had a basic understanding of what was required of them during the lesson.

| Lesson 1 | Lesson 4 |
| --- | --- |
| WILF (What am I looking for?)<br>• *Can you* make a prediction based on what you already know?<br>• *Can you* describe your thinking and explain the reasons for your ideas?<br><br>TIB (This is because)<br>• Science talk is fun but it *is important* that it is supported by explanations and evidence. | WILF (What am I looking for?)<br>• *Can you* make predictions about the tensile strength of materials?<br>• *Can you* plan and conduct a test of the tensile strength of materials?<br>• *Can you* record results in a table and interpret them?<br><br>TIB (This is because)<br>• Knowledge of tensile strength *is important* when you are considering materials for certain uses. |

**Figure 4.11: Examples of Lesson 1 and Lesson 4 WILF and TIB statements**

WILF statements were written as direct questions to encourage students to evaluate their current knowledge and TIB statements give a reason or rationale for the importance of the lesson’s intended learning outcomes. Sandra explained that even though she cultivates creative and individualised thinking, organisationally WILF and TIB statements assist with structuring, guiding and focusing student learning and reasoning throughout the lesson.

> I encourage original thought and creativity in their thinking, I let them know that they have freedom if they think something, if they're thinking something it’s ok as long as they provide me with an explanation and in our class it works with; we call it a TIB, so it’s just a pattern or a process they're used to . . . they know what I'm looking for, they know, we call it a WILF, they know at the beginning of the lesson, I let them know, remind them this is what I'm looking for and they already know, it’s a part of what they, they know my expectations are that if you've got an idea I want to hear it. (Teacher post-study teacher interview)

On a deeper cognitive level WILF and TIB statements are metacognitive scaffolds that foster higher level thinking and learning. When WILF statements are read out and discussed in the beginning of the lesson they function as signposts for student learning and set a level of conceptual understanding for students to work towards.

TIB statements model the higher order skill of applying knowledge to real life situations and the development of argumentation skills through the process of justifying ideas with reasoning. Sandra explained that WILF and TIB statements are a guide or a metacognitive scaffold that students can measure their learning progress against, or even use as an anchor point for their learning. They help students to monitor and regulate their learning.

> so they know what I want and what I'm looking for in their learning but it also helps them to identify when they're not really understanding what's going on like or I'm supposed to be learning this but I'm really not seeing the connection which sometimes the kids they do, they have that self, especially at this age, they're starting to have that self-awareness. (Teacher post-study teacher interview)

*What I am looking for statements*

WILF *(What I am looking for?)* statements which usually have 'can you' at the start or within the body of the question are posed as semi-rhetorical questions. Sandra does not expect overt responses to WILF questions when they are first read out. Instead they are composed with the intention of causing students to reflect upon and evaluate their current level of understanding and abilities prior to and during the lesson and to give direction to what they need to do to progress their understanding during the lesson. As each statement was read out aloud, Sandra unpacked the meaning, explained new or unfamiliar terminology and checked that students understood them. For example, Sandra checked the students' understanding of *absorbency* when unpacking WILF and TIB statements in Lesson 3. (Pseudonym names have been used for students.)

| | |
|---|---|
| Teacher: | Ok next one, what's my next thing I'm looking for? |
| Neil: | "*Can you make predictions about the absorbency of materials?*" |
| Teacher: | **Absorbency, who's heard of that word before? Absorbency of materials. What could that mean? What do you think that means, anyone want to have a go?** |
| Brian: | Um how, to see how much it absorbs, how much the material absorbs. |
| Teacher: | How much liquid the material absorbs? |
| Brian: | Yeah, maybe liquid, maybe light. |
| Teacher: | Mmm, ok. Um what's another word for absorbent or absorbency, what's a simpler word we could use? |

Anabelle: Soak.
Teacher: Soak that's right. So we're looking for materials that soak up water. Ok that's what we're looking for today.

Sandra unpacked each lesson's WILF and TIB statements in great detail which demonstrates the importance Sandra places on students understanding them. The unpacking and explaining took between three to six minutes of dense teacher led conversation. Each WILF and TIB was dealt with individually before going onto the next. Sandra used questioning to draw out the meanings from the students. Initially questions were diagnostic in purpose. Once understanding was established, Sandra's further questions clarified students' understanding before moving on with the lesson. Sandra's unpacking of Lesson 6 WILF and TIB statements, is indicative of the process she goes through in the early part of each lesson.

Lesson 6 WILF and TIB statements:

WILF (What am I looking for)

i. Can you make connections between what we are learning in Science and why knowing the properties of materials is so important?
ii. Based on what you already know, can you make predictions about what is going to happen when we 'plant' the packaging peanuts?
iii. Can you plan & conduct a fair test to explore the biodegradability of packaging peanuts?

TIB (This is because)

i. Knowledge of the properties of materials helps us to determine what products are Earth friendly.

The unpacking of Lesson 6 WILF and TIB statements follows:

Lesson 6
(00.01:25 – 00.04:40)

Teacher: We're going to start off by looking at the WILF and TIBs for today's lesson. Who would like to read our first **What I'm Looking For**, Louise?
Louise: What I Am Looking For? **"Can you make connections between what we are learning in Science and why knowing the properties of materials is so important?"**
Teacher: Ok, so I'm looking to see if you can make connections between all the learning we've done and what we're doing today. We're going to be focussing on what you're saying and what you're talking about and what

you're doing in Science today. Who would like to read the next **What I'm Looking For**, Peter?

Peter: **Based on what you already know, can you make predictions about what is going to happen when we 'plant' the packaging peanuts?**

Teacher: Who remembers our discussion about that last week after our Science session; some people had some great ideas. Who wants to share their ideas with the rest of the class? Who remembers what we're going to do about testing the packaging peanuts, yes Michael?

Michael: To see if the biodegradable degrades.

Teacher: Ok and how are we going to do that Martin?

Martin: By planting the peanut.

Teacher: If we plant the peanuts will they grow into peanuts?

Students: No.

Teacher: Are they going to grow at all?

Students: No.

Teacher: No that's why I put plant in inverted commas; we're going to put it in the soil and water it and see what happens. Okay, this brings me to the next bit which is about predictions. What's a prediction? Who can tell me what a prediction is? Harriett?

Harriett: Your idea.

Teacher: Your idea, what you think is going to happen and usually we base what we think is going to happen on what we already know. Yep. So today in your activity you need to make sure you're thinking scientifically and you'll be able to make predictions and tell me why you're thinking the way you are. And lastly **"Can you plan and conduct a fair test to explore the biodegradability of packaging peanuts?"** What's a fair test Ryan?

Ryan: Um... it's like its fair between every material.

Teacher: Between the materials, it's fair between the materials, its fair between the materials ok who wants to help Ryan? Yes Erin?

Erin: Everyone has the same like amount; everyone has the same size material...

Teacher: Ok keeping things the same, very good. Mary?

Mary: Only changing one thing.

Teacher: And only changing one thing and keeping everything else the same. Excellent, okay. Why Is This, **This is because,** why am I looking for these things?

Teacher: Aspyn?

Aspyn: **"Knowledge of the properties of materials helps us to determine what products are Earth friendly."**

Teacher: That's right. So is it important to know what products are Earth friendly?

Students: Yes.

Teacher: Why is that Charlie?

Charlie: Because we can't just leave things that only biodegrade in 200 years on the ground.

Teacher: Ok so what will happen if we leave that take a long long time before they break down? Mark?
Mark: It will pollute the Earth.
Teacher: Pollute the Earth and why do we care about polluting the Earth? Why do we even care about these things? Louise?
Louise: Because if the Earth is polluted it will be not this Earth that it is today, it won't be very clean or hygienic.
Teacher: Clean or hygienic that's right and does the pollution on the Earth only affect us as Human Beings?
Students: No.
Teacher: What else does it affect, Natalie?
Natalie: Animals.
Michael: All living things.
Teacher: All living things alright so keep that in mind while we watch our next YouTube.

*This is because statements*

TIB (This is because) statements explain or justify to students the usefulness and importance of the specific learning being targeted in the lesson. TIB statements link students' school science learning to everyday life and provide a rationale for learning the key concepts and thinking and reasoning skills in the lesson. Sandra explains why her TIB statements are important to students.

> I can tell students what I'm looking for but I want them to know why, why is it important that I teach you this, why is it important that you learn this and can you make a real world connection and I think that's really important that kids know why they're learning what they're learning and it certainly it helps them you know stay engaged. (Post-study teacher interview, 2013)

As with the WILF statements Sandra had students read these statements out loud and unpacked and discussed them, often drawing on examples to clarify her meaning. A TIB statement typically followed the pattern: a concept or skill *is important* to or when . . . or a concept or skill *helps to* . . . (refer to Figure 4.11 and previous TIB statements).

The unpacking of the TIB statement from Lesson 3 illustrates how Sandra prompted students with 'Why', 'Why not' and 'because' to ascertain their understanding of the TIB.

Teacher: And *This Is Because*...
Neil: Knowledge of the properties of materials helps people to understand how to use them effectively.
Teacher: That's right, so for example if I wanted to block out light from our window and I decided to use tissues would that be an effective use of that material?
Students: No.
Teacher: No? **Why not?**
Courtney: Um **because** tissues are very thin and they can rip easily... they can tear easily and when they get wet if you accidently spilt something on them they just rip apart.
Teacher: They just rip apart. Ok. So you're saying tissue is not a good idea for a curtain or a window or a shower curtain for that matter **because** they just go soggy ha ha... Ok, any other comments?
Neil: It will still let the light through.
Teacher: It will let the light through and the main thing we want is for it to block the light.

The application of the TIB pattern has been extended by Sandra. The TIB statements that have been discussed are teacher generated. Sandra often used the TIB acronym when requesting or drawing reasons from students. Complementing her prompts of 'Why', 'Why not' and 'because' she would often say, "What is your TIB?". The owner of the TIB in this situation was not the teacher but the student. Sandra stated to students that their TIB is important, "It's important you know this because this is important for the real world and it shows me you can reason and think" (Lesson 4).

Examples of Sandra reminding students to use their TIB are found in Lesson 7 when Sandra asked students to predict which of three materials is the best conductor and to give reasons and in Lesson 8 when students were writing a virtual sticky note to post their ideas on the classroom blog regarding which material they thought would make a good classroom curtain.

Lesson 7
(00.40:38.)
Teacher: I would like you to very quietly think about your hypothesis. Out of the three materials we have here today which one do you think is going to be the best at keeping things warm? You need to write the name of your material and what do I always require? If you have an idea what do you need to give me? Hollie?

Hollie: A 'because'.

Teacher: **A 'because'. I need an explanation, and this is because**. Ok. Go. Writing now...

Sandra read out one of the student's written responses to model the use of *this is because* to the rest of the class.

> I think the foil will keep things warm **this is because** the hot air gets trapped inside, foil is a conductor. An example you're putting a chicken in the oven and you wrap it in foil the air will stay and keep it hot. (Lesson 7 transcript)

Lesson 8
(01:05:35.05)

Teacher: I hope you are all, on your sticky note, you are all remembering your TIB. Is everyone putting in their **"This is because…"**
Jessie: Yes
Teacher: You need to make sure you tell me why you think and what you think.

The students were very comfortable and familiar with WILF and TIB statements being part of their learning process. They understood the relationship between the two types of statements and connected them to processes of reasoning. When asked to describe WILF and TIB statements a student commented, "she [the teacher] writes WILF, what I'm looking for . . . and then she writes this is because, and she writes the reason that she's looking for those things" (Focus group interview). Students therefore are reminded of their expectations to give reasons with TIB statements and more particularly Sandra's use of the word *because* is used as a syntactical scaffold to promote higher order thinking.

**Key Finding 4.15**
WILF and TIB statements indicated to students the instructional intentions and expectations for the lesson and related how the learning is important for everyday living. On a deeper cognitive level they also functioned as metacognitive scaffolds to foster higher order thinking, reasoning and learning.

- WILF (What I am looking for) function as signposts for student learning and set a level of conceptual learning for students to work towards.
- TIB (This is because…) model the higher order skill of applying knowledge to real life situations and the process of justifying ideas with reasoning.

**Key Finding 4.16**
The use of and unpacking of new or unfamiliar science terminology in WILF and TIB statements indicated the importance Sandra placed on the development of science language for conceptual learning and science reasoning.

**'Because…' as a syntactical scaffold and other prompts**

Argumentation is an important feature of thinking and reasoning. Being able to provide evidence and to justify claims with reasons is central to becoming scientifically literate and acquiring higher level thinking skills. A feature of Sandra's pedagogy is her requirement for students to supply reasons for their claims. Not only does she teach her students to think and to give reasons; she instructs, models and prompts students in the language conventions of scientific reasoning.

One of Sandra's practices was to urge students to use the word 'because' in their explanations. She did this by prompting. Similar to "This is because…" previously described, her simple one word prompt "because…" reminded students to extend their unjustified claims with reasons. It also provided students with a language link or syntactical scaffold for student's higher order thinking and scientific reasoning. The use of 'Because' supports students with verbalising an argument. It is "a conjunction, a linguistic link between phrases, and has been described as a logical connective because of this linking role in making a scientific argument" (Hackling & Sherriff, 2015, p. 21).

When Sandra prompted students with "because…" she required her students to respond back to her incorporating the word because into their response; having them firstly state their claim, then insert the word 'because' followed by their reasons for the claim. Sandra's frequent use of the 'because' prompt created an expectation that students are to use 'because' in all explanations. This is illustrated in the following student's response.

> You need to say this is **because** and then you need to make your reason because if you just say, oh this material is good for a curtain and that's all you say, **you need to actually say why** it's good for a curtain. (Focus group interview)

As there was a range of ability levels across Sandra's class, it was not surprising that the amount of prompting and scaffolding needed varied. Some students incorporated because correctly into their responses without prompting; others made their claim followed by a 'because' but didn't offer explanations until prompted by Sandra. Some used 'because' but needed assistance to use it correctly. For example during Lesson 7 a student used **because** twice in their response to Sandra about which of three materials was the best insulator. They responded with, "I think foil will keep things the warmest **because** it can keep any warm things warm . . . **because** it traps the hot air in . . . so it traps the hot air in." Even though the explanation was not scientifically sound the student used 'because' twice as a link in the formulation of her argument to explain why she chose foil as the best insulator over two other materials. Other students needed Sandra's 'because' prompting to draw reasons from them.

When students needed further prompting to provide evidence and justification for their thinking Sandra often coupled the "Because…" prompt with other phrases like "Tell me why" and "Why do you think that?". The following conversation in Lesson 5 on biodegradability illustrates this.

Lesson 5
(00.41:50 -00.42:26)

| | |
|---|---|
| Teacher: | Which one of your packaging peanuts is synthetic? Which one is man-made? |
| James: | It's the ones that are shiny. |
| Teacher: | Okay give me some... you must have written down some observations so tell me some properties. The one that's shiny... |
| James: | It's shiny, it's hard, and it's man-made. |
| Teacher: | You think it is man-made, you don't know for sure yet. Okay but you think it is **because... Tell me why you think it is man-made?** |
| James: | Um **because** it is hard and the other one looks like it is man-made too, has holes in it. |

Sandra's use of the word 'because' as a syntactical scaffold and as a prompt, supported students in their development of scientific reasoning by assisting them to formulate and verbalise their justification and reasoning behind claims. By verbalising or thinking-out-loud, students can learn from each other and refine their ideas.

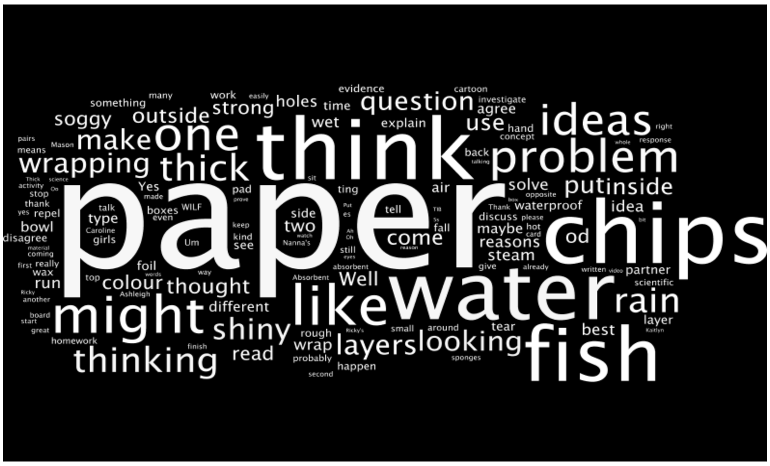
**Key Finding 4.17**
'Because' was used by Sandra as a syntactical scaffold or prompt to encourage students to justify unsupported claims and promote higher order thinking and reasoning. The frequency of its use together with other prompts such as "Tell me why" created a culture or expectation within Science lessons to always provide reasons or evidence for claims.

**Key Finding 4.18**
Sandra taught, modelled and reinforced metacognitive strategies and practices to support and scaffold students' reasoning, argumentation, metacognitive awareness and self-regulation. Strategies such as the Learning train, Sticky note fact graph, WILF and TIB statements and the use of 'because' as a syntactical scaffold or prompt assisted students to monitor, understand and progress their learning and to develop higher order thinking and reasoning skills.

**A learning culture that supports thinking out-loud, critiquing and co-construction**

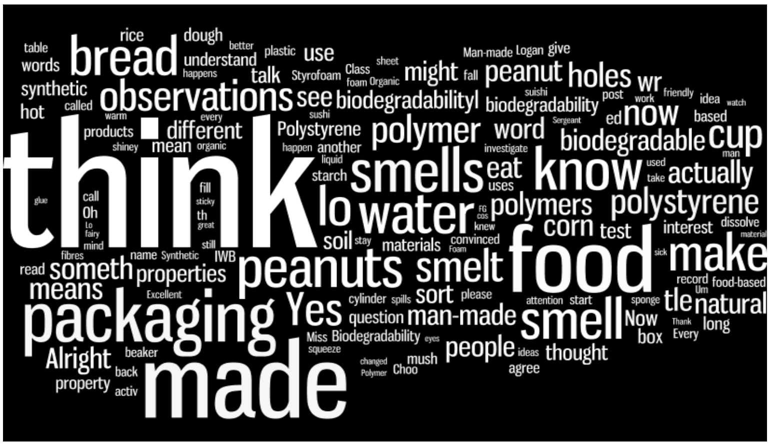
Thinking is an intimate and important part of Sandra's classroom learning culture. Sandra created a thinking environment in her class by frequently speaking about her own thinking processes and by prompting students to speak about their thinking. Thinking was often spoken about and referred to during lessons and was closely coupled with conceptual learning. For example, the words *think* and *thinking* were used 76 times during Lesson 1. To illustrate this, word cloud diagrams (Figure 4.12) generated for Lessons 1, 4 and 5 (whole class transcriptions) using the Wordle program (http://www.wordle.net/), which gives greater prominence to words that appear more frequently in the source text illustrates the large focus on thinking across lessons. It is interesting to note that the word *think* is prominent amongst content words for each of the word cloud diagrams presented and in Lesson 5 think is used more frequently than content words.

Sandra encouraged students to be aware of their thought processes. Students were required to access, verbalise and share their thinking with others as they worked together to construct knowledge and understanding. A variety of strategies and practices were employed by Sandra to scaffold and support the development of students' thinking. This section will describe how Sandra modelled and utilised




Lesson 1
Frank's Fish and Chips


Lesson 4
Snap, tear or stretch




Lesson 5
Natural versus synthetic packaging peanuts

**Figure 4.12: Word cloud diagrams for Lessons 1, 4 and 5**

thinking-out-loud, questioning, critique, and the Fish bowl and Hot seat strategies to develop higher order thinking skills.

*Teacher modelling of thinking*

From a sociocultural perspective it was evident that Sandra modelled the process of thinking-out-loud by expressing her own thinking and thought processes when speaking with students and avoided using absolute language to encourage students to think and contribute their own ideas. She frequently used the word 'think' to express her own opinion or belief and the word 'thinking' to demonstrate her processing of information and formulation of thoughts about topics or events in conversations with students. Some of Sandra's statements from Lesson 4 illustrate this.

> "I **think** I'm going to find it quite hard doing this, to snap it. It's super strong."
>
> "Okay I **think** if we are keeping our force the same, we are going to try our best to keep the same."
>
> "Now I'm **thinking because** all the pegs are the same size, so we'll put the peg the same size."
>
> "I'm **thinking** that the force is probably going to be very similar between each person so you can still let each other have a turn."

Sandra's use of "I think" and "I'm thinking" statements revealed to students that her thoughts and opinions are tentative and open to being challenged. This strategy and the safe learning environment encouraged students to think more deeply about their own ideas and to verbalise any differences in opinion or extended insights. This is different from many teachers who make statements as declarative factual statements which are not open to challenge.

By talking about her thinking Sandra also provided a model for students to follow and a thinking vocabulary when structuring and talking about their own thinking. Students copied Sandra's thinking expressions. When Sandra used questions and statements like "What are you thinking?" "Tell me your thinking?" "I like your thinking, tell me more." "Why?" "Because…?" "What convinced you?" to draw out students' thinking, students followed Sandra's example and expressed their thoughts in a similar way to Sandra using similar vocabulary. For example,

Lesson 4
(00.36:07)

Teacher: What do you **think** Lorraine? Do you **think** that it will make a difference or do you **think** it still will just tear?
Lorraine: I **think** it will tear.
Teacher: You **think** it will do the same as mine, or tear or it will completely snap?
Lorraine: I **think** it will completely snap.

### ***Thinking-out-loud***

A large part of Sandra's teaching promotes deeper thinking through thinking-out-loud which in turn supports the co-construction of arguments. For this research, thinking-out-loud refers to the verbalisation by an individual or group of people (e.g. a group *think tank*) of the thinking processes involved in the formulation of an idea or ideas. From the first lesson in the Materials topic Sandra established the expectation for thinking and reasoning with the WILF (What I am looking for) statement: "Can you **describe your thinking** and **explain the reasons** for your ideas?". Students were encouraged to verbalise or think-out loud. When students think-out-loud and share their thoughts they fine tune their personal understandings by comparing them with the ideas of others. Sandra's safe classroom environment allowed students to comfortably share their thoughts and ideas and to work out their ideas as they thought-out-loud. Sandra encouraged her students to listen and to 'measure' or critique others' ideas against their own. This will be discussed in greater detail later in this chapter.

The Fish bowl and Hot seat strategies showcase a small group of students' thinking-out–loud in front of an audience of students who have been tasked to observe and critique those students' ideas. Using the lenses of social constructivism, sociocultural theory, social semiotic theory and distributed cognition the use of these strategies for scaffolding thinking and reasoning will be explained.

### ***Fish bowl and Hot seat strategies***

Sandra frequently incorporates the Fish bowl and Hot seat strategies into lessons. These strategies could be confronting for some students but due to students' familiarity with these strategies (most of her students were in her class during the previous year) and the safe classroom environment, students were comfortable participating in them.

The Fish bowl and Hot seat are metacognitive scaffolding strategies employed by Sandra to refine and develop students' personal understandings and higher order thinking skills. Both of these strategies verbally, visually and in a sense provide an embodied representation and showcase the ideas and thought processes of a small group of expert students who are "strong in confidence and strong in ability" (Post-study Teacher interview) as they role-play and debate in front of the class, a dichotomy of ideas presented to them by Sandra. Students not involved in the role play or debate are tasked to be an audience and to listen carefully to and critique the ideas and reasoning being modelled. Sandra scaffolded and supported students to access, monitor, evaluate and adjust their own ideas and reasoning through the procedural steps of these strategies, coupled with her additional questions that focused students' attention on the salient points of the discussion or debate.

Sandra used these strategies in a variety of situations but mostly in summing-up following investigations; and, capitalised on the disagreements, agreements, consensus or lack of consensus achieved during the small group discussions. The Fish bowl role-play is a re-enactment of how students came to a consensus (or not) during small group discussions and the Hot seat strategy is a debate of two opposing views associated with the lesson topic. Figure 4.13 illustrates the student and teacher interactions of these strategies. Examples of how Sandra utilised the Fish bowl and Hot seat strategies to scaffold higher order thinking and scientific reasoning are given in the following sections.

*Fish bowl strategy*

Sandra used the Fish bowl strategy in Lesson 1 and in Lesson 5 to model a dichotomy of students' ideas and to showcase to the class the process one group of students used to come to a consensus through expressing their reasoning and argumentation.

The Fish bowl follows the following sequence. (Refer to Figure 4.13.)

1. Two pairs of students ($S_1$ & $S_2$, $S_3$ & $S_4$) are chosen to sit facing each other surrounded by the rest of the class who are the audience for the debate.
2. $S_1$ & $S_2$ is one debating team and $S_3$ & $S_4$ are the other debating team.
3. The two pairs debate and the rest of the class listen and consider whether they agree or disagree with ideas being debated.
4. One pair presents their argument with reasons.
5. The second pair critiques the argument with reasons.
6. The first pair has an opportunity to respond to the critique.
7. Steps 4 – 6 are repeated for the other pair.
8. Once the debate is completed students in the audience are allowed to make comments.
9. Audience students then separate into groups and discuss who they agree with and why giving reasons for their thoughts.

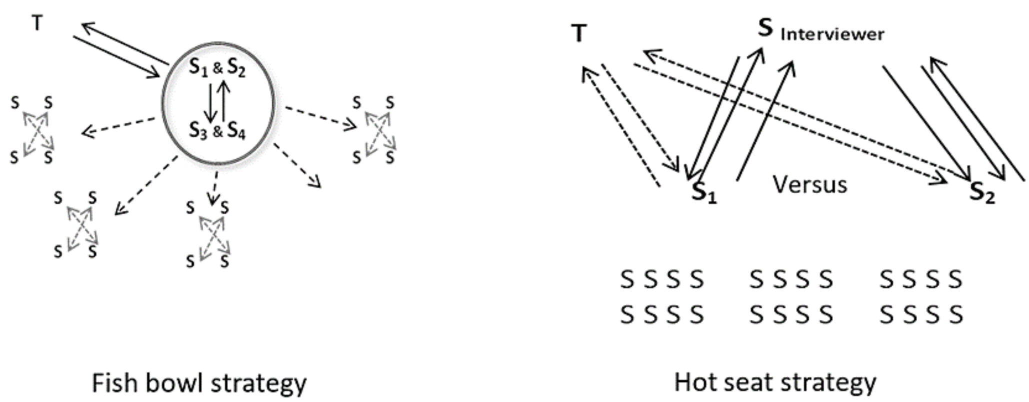



**Figure 4.13: Illustration of Fish bowl and Hot seat student and teacher interactions**

In Lesson 1, Sandra reminded students in the audience that their role is to listen and think, and to critique and evaluate their own ideas alongside those of the students in the Fish bowl. She states,

> We are all on the outside and we are looking and we are listening. Now the students in the Fish bowl are going to discuss with the other pair what

> their ideas were and their reasoning, so that's their job. Our job is to listen and **while you are listening I want you to be thinking,** *"Oh I had that idea, that's why I thought that happen and that's the way I thought we could fix it*" or maybe you think *"Oh I didn't even think of that, what a great idea"* or maybe you might be disagreeing with what they say, *"Oh I don't think that's the way to solve the problem".* Okay so **if you are on the outside you are thinking.** The only people talking are the people in the Fish bowl. I will give you some time to talk about it afterwards. (Lesson 1 transcription)

The Fish bowl models quality discussion promotes reasoning and scaffolds the process of argumentation. Sandra chooses students "who are more apt and are more inclined to stay on task; [who model] what a good discussion looks like" (Teacher post-study interview). Students in the audience "watch their peers processing ideas, providing evidence and the evidence and the justification and the reasoning behind what they're thinking" (Teacher post-study interview). As a strategy "it's a great way to trigger those kids who maybe are a little bit more reluctant to share their ideas vocally in front of peers, build confidence and consolidate learning (Teacher post–study interview). Sandra further explained how students' confidence can increase through participation in the Fish bowl.

> they can see that students that they know . . . share their opinions they're actually thinking the same things . . . and they would have said the same thing . . . so it also builds their confidence**.** Then in the lesson to follow that they might be more inclined to express their ideas. . . . It helps consolidate learning that has been done in the lesson . . . there'll be students . . . it confirms what they were thinking so they can then go away from the lesson feeling like oh you know that's what I thought. (Teacher post-study interview)

The following transcript features the Fish bowl strategy used in Lesson 5. Four students (Alan and Leo, Courtney and Natalie) were in the Fish bowl and were asked by Sandra to re-enact the sequence of thoughts and reasoning that lead them to a consensus concerning which of the two types of packaging peanuts was food based. In Sandra's class consensus was not always achieved but when it did come about, it was interesting that agreement didn't happen at the same time for each of the students. Lesson 5 is an example of this. During the activity the small group featured in the Fish bowl strategy were unable to come to agreement. There was a dichotomy of ideas. The two girls had one idea and the two boys had another idea. After some argumentation and stating of reasons to support their respective claims between the two pairs, the boys changed their mind and agreed with the girls; thus allowing the group to come to a consensus.

> At first Leo and I, we didn't agree with the girls . . . but then we smelt it like the girls did . . . and we sort of changed our minds . . . and then when we did this we changed our minds completely (Lesson 5 Focus group post-lesson discussion).

Sandra used the Fish bowl strategy in Lesson 5 to show case the thinking and reasoning process of the four focus group students and to exemplify the process of argumentation and coming to a consensus. It also reinforced and supported the notion that agreeing and disagreeing and changing one's idea is acceptable and an important part of learning.

These processes are illustrated in the following transcript.

Lesson 5
(01:08:49.23 - 01:13:56.26)

| | | |
|---|---|---|
| Teacher: | **Okay I have a few questions for you**. I'm going to throw them out to you to discuss them.<br>Your first question is: *Can you tell me a little bit about your understanding relating to the properties of the polymers we looked at today and what their uses may be?*<br>[Fish bowl students discuss the question] | Sandra used the Fish bowl strategy to review the concept of polymers. She did this by having the Fish bowl students ($S_1$, $S_2$, $S_3$, $S_4$-Refer to Figure 4.13) discuss their understanding of the properties of uses of polymers. |
| Teacher: | **Now I have a question for you and I want you all to discuss it**.<br>*If I wanted to make, or if I wanted to be more environmentally friendly, and I want to invent something that is Earth-friendly, so I'm going to invent a cup like this to have hot coffee in but I'm going to make it out of the same material our food based packaging peanuts were made of. So I'm going to make it out of corn.* | Sandra extended the students' thinking by asking the Fish bowl students to apply what they have learnt to a fictitious situation. This was initially in the form of an open question. This modelled the use of higher order thinking skills to the class. |

| | | |
|---|---|---|
| Court: | That is not a good idea. | |
| Teacher: | I'm going to put hot coffee in there and everybody is going to be happy and the Earth is going to be happy and everyone is going to think I'm great. **What do you think about that?** | Sandra scaffolded students with more direct questions to draw out student's thinking and reasoning. |
| Court: | It's not going to work. | |
| Teacher: | **What do you mean it's not going to work?** | Sandra prompted student further to give reasons for their idea. |
| Leo: | **Because** it will dissolve. | |
| Natalie: | That's what **I thought** earlier. Why didn't they just make it out of that but then it would dissolve? | A student interjects with her previous thoughts, comparing them with the previous student's thoughts. **She thinks out loud exposing how she had moved on** from that idea after working out that it would not be feasible. This demonstrated to the class the process of changing, refining and readjusting ideas when additional evidence is presented. |
| Court: | When we put cylinders into the hot water they dissolved and went into mush. So, if you made and it was hot water**, so if you made a cup out the cylinder ones, then you put hot coffee in it turn into mush.** | Student uses her past experience gained during the investigation and applies it to the fictitious situation. She states her reasons and forms a hypothesis. |
| Teacher: | It would. Can I have thumbs up **if you agree**? | Sandra asked audience to critique Fish bowl students' reasoning against their own thoughts. |
| Students: | [Class members give a thumbs up] | |
| Teacher: | Alright okay so I can't make one of these cups out of the corn starch polymer? | Sandra tested and clarified students' reasoning. |
| Student: | No. | |
| Teacher: | So it's not very useful for cups then**?** | Sandra used statement type questions to challenge and verify students' reasoning and to prompt them to justify their ideas. |

| | | |
|---|---|---|
| Leo: | You could, **but** you wouldn't put liquid in it. | Leo offered a rebuttal or exception to enable a different outcome. |
| Teacher: | Okay so Courtney and Natalie turn around and face Leo and Alan and **this is a debate** and **we are all going to judge**. So we **are all watching and we're going to be thinking. Do we agree with Leo and Alan or do we agree with Courtney and Natalie?** | Fish bowl pairs of students debated their thinking. Sandra reminded the rest of the class (who were observing the Fish bowl) that they were going to critique the pairs' thinking and reasoning and compare it with their own thoughts. |
| Teacher: | Now **in the beginning of your investigation** Alan and Leo, *can you tell Courtney and Natalie* ***what you were thinking for the investigation question?*** | Sandra started with an open question but needed to scaffold it with more direct questions to draw out students' thinking and reasoning. |
| Alan: | **We were thinking** that the polystyrene A was made out of food. | |
| Teacher: | Okay and **what made you think that?** | |
| Alan: | **Because** it smelt like that. | Student reasoning. |
| Leo: | And **because** it smelt like food and **because** me and Alan thought the food one wouldn't have as much holes, 'cos it's compressed… together more tightly**.** | Student reasoning with additional backing. |
| Court: | Yeah you thought the bumpy one was the food one. | Recall of ideas. |
| Alan: | Yeah at the start. | Indication that students thoughts changed from their original thinking. |
| Teacher: | And Natalie **can you tell the boys what convinced you the other way**? | Sandra asked the girls to give evidence and justification for their claim which was different from the boys' claim. (This modelled the argumentation process to the class.) |
| Natalie: | **What convinced me the other way was that** it smelt like food and it smelt a bit like dough and it also had a different colour. It had a bit of a yellowy colour, sort of and the other one was really white. | Natalie listed the evidence and reasons for their claim. |

| | | |
|---|---|---|
| Teacher: | So in the end boys **what did the girls say to you that convinced you?** | Sandra continued to show case the argumentation process by scaffolding the boys to explain what convinced them to change their mind. |
| Alan: | Oh well, it was actually Leo, and he said it smelt like bread. | Alan changed his claim when he listened to his partners' new claim. |
| Teacher: | Okay so initially you thought the polystyrene one smelt like food but then when it was pointed out and you had a good smell of the other one, you thought those other ones smelt more like food. | Sandra clarified and showcased the reason for Alan's change in thought. This validated to the class that it is okay change their thoughts. |
| All: | Yeah. | |
| Court: | Natalie and I just said we sniffed it and then we said, "Oh these ones smelt like food" and then Leo smelt one and he said "Oh this smells like bread" and Alan smelt one **and they changed their minds.** | An example of sharing and co-construction of ideas. Student recalled how her peer changed their minds when she shared her ideas. |
| Teacher: | **Last question for you to discuss**, *What's a product that you could make out of the corn starch?*<br><br>[Fish bowl students gave a selection of products] | Sandra concluded the Fish bowl by asking the Fish bowl students an application of knowledge question. |
| | [Sandra invites the rest of the class to respond to the question] | Sandra drew the class into the conversation |
| Teacher: | Okay any **comments from the people observing** the people in the fish-bowl?<br><br>[One student gave a suggestion for a product that could be made from corn starch.] | Sandra gave the rest of the class the opportunity to comment on any of the Fish bowl students' ideas. |

The above transcript illustrates how Sandra employed the Fish bowl strategy to review conceptual learning, to scaffold students' scientific reasoning and higher order thinking and to model to the class the application of higher order thinking skills and processes of argumentation. Another strategy similar to the Fish bowl employed by Sandra to extend and exemplify students' higher order thinking and scientific reasoning is the Hot seat, which is discussed in the following section.

Hot seat *strategy*

The Hot seat is an orchestrated debate in front of the class using selected students. Sandra used this strategy to help students formulate and justify their own ideas and to illustrate the processes involved in argumentation. Sandra used the Hot seat debate strategy in Lesson 6 to discuss the topic: S*ome materials like plastics can pollute the environment if they are not managed properly*. Lesson 6 was designed to see if the students could apply knowledge from previous lessons to real life issues concerning the environment. The following transcript illustrates how the Hot seat strategy modelled and scaffolded students' knowledge of the argumentation process. Students are well rehearsed in role play and they know this Hot seat very well. Three students participated in the debate: the interviewer and two students put into roles; one is pro-plastics (Leonie – Student 1 ($S_1$)) and the other a plastics sceptic (Courtney – Student 2 ($S_2$)). "Students had to take all the information and their prior knowledge . . . and try to convince the other person why their argument is better" (Lesson 6 Post-lesson Teacher discussion).

Lesson 6
(01:17:18.23 - 01:20:53.00)

| | | |
|---|---|---|
| Student Interviewer | Leonie **why do you think** plastics are good? | Parties given the opportunity to share their side of the argument. |
| Leonie: | Plastics are so good because…<br>[Leonie gave a number of reasons]. | |
| Student Interviewer | Courtney, **why do you think** plastics are so bad? | |
| Court: | Plastics pollute the environment…<br>[Courtney gave a number of reasons]. | |
| Student Interviewer | Leonie **what do think about what Courtney said**? | Parties are given the opportunity to comment on the other student's view. |
| Leonie: | **I think you still need plastics because**… | |
| Student Interviewer | Courtney **did Leonie persuade you to change your mind**? | |
| Court: | No, not really because… in some ways plastic is useful in some ways but **I still think it is very bad for the environment.** | |
| Teacher: | My first question to you Leonie is . . . you were saying all the useful properties plastics have, like its waterproof, it's good for carrying things; you said you could use it for a drink bottle, you can use it for all sorts of great products, it's useful in our | Sandra asks higher order application questions to test |

| | | |
|---|---|---|
| | everyday life things. **What happens when we don't want to use them anymore?** | arguments and scaffold deeper thinking. |
| Leonie: | You could always rip it apart and make it into something new and something that you will use or take it to the Salvation Army. There is the saying that one man's junk is another man's treasure. | |
| Teacher: | Hmm. I have a question for you Courtney. **What would the world look like if we didn't have any more plastic?** Like at Coral Bay, they don't use plastic bags there. | |
| Court: | It would be very strange living without plastic but the reason I don't like plastic is like some people go over the top. They don't use their plastic shopping bags again and they go home and just throw them out. | |
| Teacher: | Ok thank you very much now what I'd like you to do is we've got Lily, everybody give Lily a clap she is our pro-plastic. Ok everyone give Courtney a clap she is our plastic sceptic. | |
| Teacher: | Now I want you to do a **bottom shuffle** and I want you to sit on the side with who you agree with. Go. **(Students in the room show which argument they agree with by doing a bottom shuffle)** | Students indicate which argument they are siding with. |

Students observing the debate sat on the mat during the debate. At the end of the debate Sandra drew in the rest of the class and asked them to shuffle across on their bottom towards the candidate whose argument they agreed with. Sandra believes that observing the Hot seat debate and doing the bottom shuffle has an impact on students' reasoning especially on students who haven't developed opinions or arguments regarding the topic being debated. It models the process of argumentation and the bottom shuffle helps students to recall the reasoning presented in the debate.

> In follow up discussion I [review the debate topic]. Quite often the . . . academically stronger students . . . will give me their own reasons and the students who aren't as confident they will often base their reasoning on what our Hot seat people have said. (Lesson 6 Post-lesson Teacher discussion)

Sandra's scaffolding and use of the Fish bowl and Hot seat strategies created opportunities for students to listen to and to learn from other students' verbalising their ideas and thought processes and to assess and evaluate their own ideas. These strategies also provided a platform for students to refine their argumentation skills by observing how the selected students formulated and refined their claims with evidence, justification and reasons.

Sharing personal ideas in front of an audience of peers and having them critiqued can be a difficult task. Sandra's positive classroom environment and learning culture where critique and disagreeing with others is accepted as an essential part of the learning process, supports the successful implementation of these strategies; by providing a safe environment where verbal reasoning is encouraged and students know that they won't encounter ridicule.

Focus group students were interviewed regarding the acceptance of being critiqued and having people disagree with their ideas in Science. They indicated that disagreeing and critiquing was part of the Science learning culture and it helped them to learn.

Researcher: Do people get upset if you disagree with them?
All: No.
Court: They accept it.
Natalie: Because its science and then maybe they think that, maybe they just think about it for a moment and then they're like oh yeah that could be right maybe my idea wasn't that good.
Researcher: So is that a way to learn?
All: Yeah.

Leo said that hearing other people's ideas helped with their own reasoning. "If we agree with them we should have a reason to agree with them and if we don't agree with them we should have a reason to disagree with them". Courtney suggested listening to and critiquing other people's ideas lifted her confidence.

> It makes you more confident because you are hearing what other people think and maybe you have something different and when you hear that - you think oh no that's not what I think and you suddenly forget the feeling of being shy and scared about sharing your opinions. (Focus group Video stimulated interview 1)

Sandra scaffolded and supported higher order thinking and scientific reasoning in the whole class context by employing a variety of pedagogical practices and strategies such as the practice of integrating vocabulary and scientific language development with concept development, the development and application of metacognitive strategies for scaffolding reasoning, self-regulation and argumentation and the development of a learning culture that supports thinking out-loud and critiquing of others' opinions. The support afforded by Sandra at the whole class level provides a foundation and platform for the development of quality small group discourse.

**Key Finding 4.19**
Thinking is an intimate and important part of Sandra's classroom learning culture. She frequently spoke about thinking; shared her own thinking and thought processes, and prompted and encouraged students to do likewise. Sandra incorporated a variety of strategies and practices into her lessons (e.g. thinking-out-loud, questioning, critique, Fish bowl and Hot seat) to enable students to 'safely' and comfortably access, identify, share and extend their thoughts and thought processes as they co-constructed arguments and understanding with others.

**Key Finding 4.20**
The Fish bowl and Hot seat strategies modelled and allowed students to refine their higher order thinking and reasoning skills by providing a verbal, visual and in a sense bodily representation of students collaboratively presenting high quality arguments and coming to a consensus. The success of the Fish bowl and Hot seat strategies in Sandra's class is due to the positive and safe learning culture and environment established in the class.

**Small group practices and strategies**

During this unit of work Sandra based about one third of her instructional time on small group teaching and learning. This section describes the pedagogical strategies and practices Sandra employed to scaffold and support higher order thinking and scientific reasoning in the small group setting. The foundations for these strategies and practices were laid prior to the commencement of small group work with Sandra's classroom organisation and lesson preparation, the establishment of a positive classroom environment and learning culture and the strategies employed in other instructional settings. Each level of support is important and provides a basis for Sandra's small group strategies and practices.

During small group work Sandra's students were actively and physically engaged in their learning. They had greater opportunities for co-operative learning as they interacted with peers, had access to resources and participated in hands-on learning. The safe learning environment in Sandra's class afforded all students the opportunity to verbalise their thinking as they talked, listened, thought-out-loud, share, discussed ideas, disagreed and even argued with others in their group. The small group setting also gave Sandra greater access to monitor and assess where individuals were at in their learning and to provide relevant, timely and individualised scaffolding and support to facilitate learning.

Thinking and reasoning are major expectations in Sandra's class. More particularly, verbal reasoning and the co-construction of knowledge are Sandra's expectations of small group work. Sandra employed and integrated a repertoire of pedagogical practices and strategies within small group settings to draw out and develop students' thinking and reasoning skills. She focused on:

- fostering and sustaining student talk, discussion, thinking-out-loud and verbal reasoning;
- monitoring and assessing students' learning and identifying areas where support is needed; and,
- scaffolding, supporting and providing opportunities for development of higher order thinking and scientific reasoning skills.

Talk and discussion are important in the formulation of students' ideas and assists teachers in monitoring and assessing students' current understandings. This information guides teachers in the type of support offered to students. Sandra's small group pedagogical practices and strategies that support and scaffold quality small group discourse, higher order thinking and scientific reasoning are described below.

***Fostering and sustaining student talk and discussion***

Looking through the lenses of social constructivism, sociocultural and social semiotic theories and distributed cognition it was evident that small group work was an important context for developing students' thinking, reasoning and understanding.

During small group work, students learnt through participation in authentic hands-on activities and the sharing of ideas with others. Talk and discussion were essential in this process and provided a platform for the co-construction of knowledge. Sandra encouraged students to "talk to their team" (Lesson 4) and to work together on tasks. Talk was a vehicle for sharing, swapping and building thoughts and ideas. Sandra fostered and sustained student talk and discussion to afford students the time required for higher order thinking and reasoning and the co-construction of knowledge. This was achieved by allowing students to do the majority of the talking in small group work.

Sandra's talk time during small group work was minimal and was mainly focused on ascertaining where the students are at in their thinking and for sustaining and promoting discussion when it is waning or when students are 'stuck in first gear' with lower level thinking. When Sandra did join in with small group talk her contributions did not dominate the discussion. She often spent time at the group table observing and listening before speaking and at strategic times contributed with open questions and short responses to draw out student's thinking rather than giving judgements or instructions. Sandra's responses were mostly non-evaluative and neutral and she rarely offered her opinion or judges students' ideas but acknowledged student contributions with simple non-invasive responses like *Aah, Mmm*, *Ooh, Okay and Very interesting* and by mirroring or repeating of key phrases from students' responses. These types of responses (typified by a change in Sandra's voice tone indicating emphasis) were coupled with prompts, cues and signposts, which indicated to students that they were on the right track in their concept development and that further talk, thinking and discussion was required; or that they had jumped ahead and need to park that thought until a later time.

Using sociocultural and distributed cognition as lenses, the following transcript illustrates Sandra fostering and sustaining language through asking an open question, responding by repeating students' key phrases and the use of non-evaluative neutral language to acknowledge the student's input; whilst students work collectively on investigating the tensile strength of different materials.

(Lesson 4, 43:48 – 44:46)

| | | |
|---|---|---|
| Teacher: | **Now I'm wondering** what observations you've made when you looked at your materials through the magnifying glass.  Brian says that he can see fibres **what else did you say?** | Opening up discussion with an open question. |
| Leo: | I can't see anything because mine's... | |
| Brian: | **Incredibly tiny...** | |
| Teacher: | **Incredibly tiny**. | Mirroring student's response |
| Brian: | **But not microscopic.** | |
| Teacher: | **But not microscopic**. | Mirroring student's response |
| Leonie: | Miss Seymour I noticed that if you pull it goes thinner but if you stretch it outwards more flat. | |
| Leo: | That's because it's got elastic in it. | |
| Teacher: | **Mmm, ok.** | Acknowledgement with neutral non-evaluative response. Use of okay to continue with discussion, explanation and thinking |
| Brian: | I found... | |
| Leonie: | It doesn't have elastic in it; it's just the small fibres that are doing the stretch. | |
| Brian: | I **think** that with fibres... | Students politely disagree |
| Teacher: | Stretchy fibres ok. | Clarifies student's response but non-evaluative. Use of okay to continue discussion. |
| Brian: | With the fibres when there's colour on it it's a mix between white and the colour on the fibres. | |
| Teacher: | **Mmm, ok**. | Acknowledgement with neutral non-evaluative response |
| Brian: | Well with this pink there are some pink fibres and some white fibres in where the pink fibres are supposed to be. | |
| Teacher: | Could I have a look at that Brian? **Very interesting.** | Greater acknowledgement from teacher, non-judgmental and non-evaluative response |

A major focus of Sandra's small group strategies and practice is the fostering and sustaining of small group talk and discussion. Small group talk and discussion provides a platform for the co-construction of ideas. It also provides a window into students' thinking and thought processes, understanding and learning. This allowed her to monitor and assess where students were at in their learning and to identify areas requiring support and development.

***Monitoring and assessing learning and identification of areas requiring support***

Monitoring and assessing is an ongoing process in Sandra's class and is not confined to one particular instructional setting. Sandra utilised a range of approaches to monitor and assess students' learning across learning contexts. For example, in the whole class setting and when students were working on their own, Sandra assessed mostly through students' responses to her questions. The review of written work in journals, lesson recounts and investigation write-ups were also used to assess individual students' understanding but this was more about summative assessment and not for monitoring during the learning process.

A key feature of Sandra's practice is her ability to simultaneously monitor small groups within her class and to assess and know, on an ongoing basis where each student is at in their learning. During small group work Sandra moved from group to group assessing and monitoring student learning, first by observation so as to not interrupt the natural flow of ideas within the group and then if needed clarified her initial assessment by asking questions. She observed the dynamics of the group by observing how students were interacting with each other and with resources, and listened to student talk and discussion for similarities and differences in ideas and whether students had come to a consensus. If required, Sandra intervened for short periods during small group work and asked students questions about their work and ideas. Once Sandra has a clear indication of where students are at in their learning and if and where they need scaffolding and support, she provides scaffolding, support and opportunities to extend students' learning.

**Key Finding 4.21**
Sandra fostered and sustained student talk and discussion to afford students 'talk time', 'sharing time' and 'thinking time' for the co-construction of knowledge. Her contribution to conversations were minimal and were mainly to sustain student talk, guide the exploration of ideas and for assessment and diagnosis. Sandra's open questions, non-evaluative and neutral responses and mirroring or repeating of key phrases from students' responses are characteristic of her approach.

Sandra employs a number of small group pedagogical strategies and practices to scaffold and support higher order thinking and scientific reasoning. Sandra used open questions, prompts, the promotion of critique, change and consensus, a variety of teacher interactive roles and the promotion and the use of a dichotomy of ideas to draw out and guide students thinking and to foster justification for their ideas. These strategies and practices will be discussed in the next sections.

**Open questions and prompts**

Sandra prompts deeper thinking by encouraging students to verbalise and explain their thoughts. Her use of a range of question types, non-evaluative neutral responses (previously described) and prompts assisted with promoting and sustaining small group discourse. She used open questions and prompt statements to draw out and foster reasoning and justification. As in the whole class context, Sandra asked open questions and used prompt statements to draw out and support the development of higher order thinking and reasoning during small group work. She made specific requests for students to verbalise thinking and reasons and focused on her "dialogical interaction with students on guiding them towards making connections between their experiences and new ideas and concepts" (Personal communication, June 2014). For example, "Tell me what you are thinking." "I'm interested in what you are thinking." "What convinced you?" "What do you think?" "Tell me more about that." "Why?" "Because…?" "What is your TIB?" These questions and statements scaffolded student learning and helped make links and connections between their experiences and ideas.

**Key Finding 4.22**
Sandra’s use of neutral, open ended prompts and questions indicating her interest in students’ ideas guided students to verbalise and extend their thinking and to make connections between their experiences, new ideas and concepts.

**Critique, comparison, change and consensus**

Sandra’s pedagogical aim for small group work is for students to work together to co-construct knowledge and understanding. To achieve this she asked students working together in small groups to come to a consensus. This is dependent on student talk and discussion. Consensus is not always an easy process and doesn’t always occur especially as Sandra promoted free, individual and creative thinking. Whilst Sandra was careful not to lead students’ thoughts she did scaffold them through the consensus process via instruction, prompts and questions. Each student was required to formulate their own ideas and to have reasons or evidence to substantiate their claims.

The co-construction or consensus process commences with group members sharing and discussing, and trying to convince their peers why their ideas are correct or are the best. Sandra encouraged students to verbally critique each other’s ideas, compare them with their own ideas, disagree and to adjust and make changes to their thinking if necessary, to try to come to a group consensus.

> “I want you to talk to your group about your prediction. Someone may have a different prediction to you, so you may need to convince them of your ideas”. (Lesson 4)
>
> “You just need to see what you all think because you've got to come up with a consensus”. (Lesson 5)

It was an expectation that students evaluate their peers’ ideas and would give reasons why they agree or disagree with them. Knowing that your ideas will be critiqued by others can be difficult for those less confident but due to the positive culture and learning environment in Sandra’s class, students of all ability felt safe to ‘have a go’, to share their differences in opinion, to have their ideas debated, to accept and give criticism or even be wrong in their assessment of things. All of these processes helped students to evaluate, modify and develop their level of thinking.

Coming to a group consensus does not always occur. In Lesson 4, Andrew for example, did not agree with the rest of his group on several occasions during the unit. On one occasion the other members of his group were able to convince Andrew to change his mind.

> [Andrew] with the stretchability activity . . . was the only one in the group who didn't agree on something and it took a while for them . . . to all agree. They had to convince each other, so it's actually working for them, I think because it makes them think, "*Well how can I convince [Andrew to] the way I'm thinking*?" (Post-study Teacher interview)

On another occasion Andrew was not able to be convinced to change his view even after the students repeated the activity. Andrew was allowed to keep his view. Sandra found it interesting that Andrew was playing devil's advocate and that it "actually increased the quality of reasoning because they're [the other students in the group] having to justify explain and support their ideas" (Post-study Teacher interview).

> There was [Andrew] I noticed in a few of these focus group activities he was playing devil's advocate. . . .I think it was actually it worked very well for that group because it meant that because he on a couple of occasions was quite certain that he was right and the group was wrong that it got them talking and they had to find ways to justify when they were trying to convince him . . . they certainly had to step up their reasoning. (Post-study Teacher interview)

Whether consensus was achieved or not the process of trying to reach a consensus was in itself a successful strategy as it extended students' reasoning and argumentation skills. By asking students to convince others of the correctness of their ideas they needed to provide evidence and to justify their ideas.

**Key Finding 4.23**
In small group situations Sandra promoted the development of higher order thinking, scientific reasoning and argumentation by encouraging students to critique, compare, modify and to come to a consensus with their ideas.

**Teacher interactive roles**

Another characteristic of Sandra's teaching is her flexibility in that she takes on a variety of different interactive roles in the small group situation to ascertain students' current understanding and to progress their learning. Each role had a particular purpose and level of interaction and was based on students thinking-out-loud and verbalising their ideas and Sandra prompting students to think deeper.

For example in small groups, Sandra often took on the role of an 'onlooker' and observed students either from a distance or as a 'silent' observer sitting with the group for monitoring and assessing student learning. When eliciting student thinking and reasoning, apart from the regular teacher roles of facilitator, model and instructor; Sandra usually shunned the role of being the fount of all knowledge and often took on the role of peer learner. She avoided using absolute language and closed questions which hinder students' input and flow of ideas. Instead Sandra used open questions and prefaced her remarks with "I think" when contributing to discussions.

Sustained small group talk and discussion provides individual students with a stage and space for higher order thinking and scientific reasoning by affording them the impetus, time and opportunities to formulate personal understandings, explanations and justifications for their thinking. Sometimes, however, small group talk and discussion loses momentum and becomes less productive. During these times Sandra often assumed the role of devil's advocate and contributed an opposing or controversial view into discussions. In this role she challenged students' thinking. Sandra's input of and an alternate or opposing idea stimulated students' ideas and revitalised discussion. It caused students to defend their opinion or conclusions with evidence and to find further justification and reasons to support their ideas to convince Sandra that their ideas were right. Another consequence of this process was that students often refined their thinking causing them to re-adjust or change their ideas. Apart from playing devil's advocate Sandra often creates opportunities for disagreement and a dichotomy of views in lessons. These will be discussed further in later sections.

**Key Finding 4.24**
Sandra's teaching style is very flexible. In the small group situation she took on a range of interactive roles depending on her diagnosis of where students were at in their learning. She may play onlooker, silent observer, facilitator, peer learner, model, instructor and devil's advocate. Each role puts the students in-charge of their own learning.

### Disagreement and a dichotomy of ideas

Disagreement is a part of Sandra's established learning culture and is seen as an important part of learning and reasoning. It fosters discussion and supports higher order thinking and is a regular feature across all instructional settings in Sandra's practice and very evident during small group discussion.

> I encourage [disagreement] . . . I want a room of vibrant academic discussion. . . . My class is based on students learning and they learn from talking, they learn from each other, I do lots of co-operative learning . . . but I definitely encourage it [disagreement] and I encourage students to. (Post-study Teacher interview)

During disagreements Sandra sometimes needed to remind students of the 'ground rules' for discussion, for example "it's okay to disagree", "there are no right or wrong predictions", and "it's okay to have a different idea". Students were encouraged to disagree but were expected to be respectful of others' opinions. If they disagreed they are expected to give reasons. This promoted student reasoning and justification for ideas.

> if they really disagree with each other then they need to think of reasons you know, they need to give their TIB and by all means they are allowed to try and convince each other and they quite often do. (Post-study Teacher interview)

Not only did Sandra promote and use students' differing views to enhance discussion and student reasoning, she often created disagreement or a dichotomy of views during small group discussions. This was done quite strategically to increase discussion and to encourage students to extend their thinking. During whole class settings Sandra employed debates and formal structured strategies like the Fish bowl and Hot seat (previously described) to create or discuss a dichotomy of ideas. Her small group strategies focusing on creating a dichotomy of views were less formal and involved offering an alternate view during small group discussions or play devil's advocate by opposing students' ideas.

For example, in the following Lesson 4 transcript, Sandra introduced an idea from another group to create a dichotomy of views and to increase the complexity of the group's investigation by getting students to follow another line of investigation.

| | |
|---|---|
| Teacher: | Well, I've got an idea. Why don't you try Alice's idea because... |
| Brian: | This maybe a different brand to what we are used to. |
| Teacher: | Who remembers what Alice said? |
| Brian: | She that... |
| Teacher: | She's thought that you would have a different result if what? |
| Brian: | If we folded it or cut it. |

Although not a common practice, Sandra added her own opinion to set up a dichotomy of ideas to encourage students to justify their claims against hers. These strategies revitalised and sustained lively discussion and promoted the justification of student ideas and argumentation skills. The following Lesson 4 vignette highlights this practice and the other pedagogical strategies and practices spoken about in this section that scaffold and support higher order thinking and reasoning.

*Snap vs. Tear Vignette (Lesson 4: Tensile Strength)*

This vignette features how Sandra used disagreement and a dichotomy of views to scaffold and extend students' reasoning skills in the small group context. It showcases Sandra's interaction with focus group members Brian, Andrew, Leo, Courtney and Leonie as they tried to reach a consensus about whether newspaper 'snaps' or a 'tears' when it is stretched over a clothes peg and a force is applied to it. Each student observed a strip of newspaper through a magnifying glass, made a prediction and then placed the newspaper strip lengthwise around the long legs of a peg and opened the peg. Students observed the paper breaking and verbalised their conclusion. The students were not in a consensus. Brian said it was a snap which confirmed his prediction. Courtney and Leonie agreed with Brian but Andrew and Leo said it was a tear and provided reasons for this. Students went back and forth several times stating their particular claim. Andrew and Leo related their claim to the physical evidence.

| | | |
|---|---|---|
| Andrew: | It was a tear because it didn’t actually snap. | |
| Leo: | You can tell by the fibres. | Leo points to the ripped paper on the peg. |

Sandra was listening to the focus group disagreeing. Noticing that the group needed some help to come to a consensus she sat with the group and asked an open question to assess where the students were at.

Teacher: Okay what is happening here?

The girls responded with “It’s a snap” but didn’t provide any reasons to back their claim. Brian responded whilst holding up the peg with the broken piece of newspaper, “It's either a snap or a tear.” It was interesting that he didn’t restate his claim or give reasons to support it. Sandra took the peg and looked at the broken paper and responded with “Oooh”; a non-evaluative neutral response which demonstrated that she acknowledged what he had said. This “Oooh” also signalled to students that they needed to talk and discuss some more. They needed to try and come to a consensus. In order to do this they needed to convince the others of the correctness of their claim by providing reasons. Brian repeated his previous comment and Andrew and Leo started to build their ‘case’ but with conflicting evidence.

| | |
|---|---|
| Brian: | It's either a snap or a tear. |
| Andrew: | I reckon it tore ‘cos... |
| Leo: | It sounded like it was a snap but it looked like a tear. |

Observing that Andrew and Leo’s argument was undeveloped and required stronger backing Sandra intervened and took on the role of peer learner. She sat alongside the focus group students, looked at the broken paper on the peg and gave her opinion by stating, “I reckon that looks like a snap.” Usually Sandra does not offer her opinions when students are exploring but it was a strategic move to encourage students to think more deeply and to provide greater justification and reasons for their claims. By agreeing with Brian and the girls; Andrew and Luke needed to think more deeply and to provide greater justification and reasons to convince the others.

The disagreement caused some contention amongst the group and Sandra reminds students that Andrew was allowed to disagree. She assists Andrew to justify his stance by asking him if he had reasons why he disagreed. In the following conversation Sandra continues to respond with neutral non-evaluative prompts such as "Yes", "Ooooh", "Aah" which fostered and sustained student talk. She also reminds students that they must provide reasons for disagreeing. It is interesting that Leo provides verbal reasoning to support Andrew's claim which he backed up by showing the ripped newspaper and Andrew provides further justification which he supports with hand gestures showing the difference between a snap and a tear. Andrew gives reasons why he thought it was a tear and he extended his justification by saying why it wasn't a snap.

| | | |
|---|---|---|
| Teacher: | They are allowed to disagree. Do you have a reason why you disagree, Andrew? | |
| Andrew: | **Because**... | |
| Leo: | **Because when you snapped it out on the mat and Andrew snapped it… there were lots of fibres.** | Leo took the peg from the teacher |
| Teacher: | Yes | |
| Leo: | And since then you could tell it has **lots of fibres and when things snap there's normally not that many fibres and it's normally just a straight snap.** | |
| Teacher: | Ooooh... | |
| Andrew: | **I don't reckon it snapped because it's going up and you can't really snap something up, that's normally a tear.** | Andrew gestured the peg breaking the paper with his hands and used his hands to demonstrate a tear. |
| Teacher: | Aah... | |
| Andrew: | The **snap is where you go like that**. | Andrew demonstrated a snap with his hands. |
| Teacher: | Yeh okay… | |
| Andrew: | I reckon that was a tear 'cos it went like that and tore. | |
| Teacher: | Okay, if I have a look here, that looks like, just there it snapped and I think what you are saying is because it's got that little bit sticking up that it must be a tear. | Sandra attempted to clarify and consolidate Andrew and Luke's reasoning. |

Andrew appeared to be getting confused with what a tear was as the class had only discussed examples of snaps and tears during the introduction, not actual definitions for the two. It appears that from the following debate this was not the case. Brian then disagreed thinking that Sandra's clarification meant that she was agreeing with them. He stated that her reasoning actually supported his claim that it was a snap.

Sensing that there was not going to be any consensus Sandra was ready to leave the debate and stated, "Okay, well maybe that's something that you are just going to have to disagree on". Brian, Andrew and Leo, however, appeared to want a consensus and continued the debate. Both parties re-stated their claims and used hand movements to simulate how a snap and tear occurs in defence of their respective claims. Leonie who had not participated in the verbal debate thus far then put forward a new line of thought to bring a consensus and to support Brian's claim. She said, "I think the noise might make the difference". After a short discussion between the two parties this line of thought was not pursued.

Sandra then provided all the students with the resources to re-test the newspaper hoping that this would help with coming to a consensus. The students conducted the re-test but none of the parties changed their mind. Sandra once again reiterated that sometimes people disagree and that's okay. Even though a consensus was not gained and that reasoning was not always conceptually correct, Sandra felt that the students had developed their argumentation and higher order thinking skills through the newspaper test. She commented:

> [The] children were actually engaging and they were actually trying to convince each other of their ideas and . . . perhaps their reasoning wasn't always on the money but they were certainly thinking and you know the cogs were turning so certainly a lot of verbal reasoning. (Teacher post-study interview)

During small group work Sandra employed a repertoire of strategies and practices to scaffold and support quality small group discourse, higher order thinking and scientific reasoning. Sandra fostered and sustained small group talk and discussion and encouraged students to verbalise their thinking. This allowed her to monitor and asses where students were at in their learning and to develop those areas needing attention by providing scaffolding and support. Sandra used different teacher interactive roles, employed a variety of open questions and statements to draw out and guide students thinking; and, used a dichotomy of ideas to foster justification and reasoning during small group work.

Sandra scaffolded, supported, created and promoted opportunities for higher order thinking and scientific reasoning in stages. She first organised her classroom, established a positive environment and learning culture, planned the development of language and verbal reasoning in her lesson preparation and developed and promoted it through the implementation of a combination of pedagogical practices and strategies across the range of instructional settings. When asked to review how students' reasoning improved over the topic she commented:

> towards the end [of the topic] . . . [students] were using more sophisticated language, they were remembering their *this is because*… it was just natural, and they were making connections . . . I told them I was looking for them to make . . . connections between each lesson, because . . . sometimes the lessons crossed over but they were looking at a different concepts, but certainly there were parts of the investigating and the enquiry stages that they could make a connection with the next one the next lesson; so . . . I was very impressed when I marked their journals, some of the kids blew me away with their reasoning. (Teacher post-study interview)

**Key Finding 4.25**
Disagreement was a vibrant, acceptable and successful tool in Sandra's class. It was used for creating situations in small group discussions, where students' ideas and thoughts are challenged and extended; and, science reasoning, higher level thinking and argumentation skills are developed. Established and maintained 'ground rules' ensure that all students felt safe and supported in sharing their ideas.

**Key Finding 4.26**
In the small group setting Sandra utilised strategies (which are built upon whole class strategies and practices) to draw out and develop students' higher level thinking and science reasoning by:

- fostering and sustaining student talk, discussion, thinking-out-loud and verbal reasoning,
- representing a dichotomy of ideas to increase student exchanges
- monitoring and assessing students' learning and identifying areas where support is needed and,
- scaffolding, supporting and providing opportunities for development of quality discourse, higher order thinking and scientific reasoning skills.

## Summary

This chapter focused on Sandra and her teaching, and how she scaffolded, supported and promoted higher order thinking and scientific reasoning whilst teaching a Materials unit to her Year 4 class (KF 4.7). The chapter consisted of three sections: the contextual setting of the case study, Sandra's instructional approach, planning and organisation and Sandra's pedagogy and strategies. A brief overview of these sections and Key Findings (KF) will be given in this summary. (Appendix G provides a list of the Key Findings for Chapter 4.)

Sandra taught at a Western Australian government primary school with an above average ICSEA rating and her class of Year 4 students had above average literacy skills (KF 4.1). Although having no pre-service training in Science, Sandra was the school Science Coordinator. She was passionate about Science and took opportunities to increase her science knowledge by attending professional development sessions (KF 4.2).

Sandra's science education philosophy is based on the tenets that science is everywhere and that learning needs to be linked to everyday living. She believes in: hands-on, student-centred, science inquiry learning; where student talk and discussion are central and important in the teaching and learning process (KF 4.3); and in the importance of having a positive collaborative culture and learning environment that supports students across all abilities to share their ideas, provide reasons for their thinking and to critique others' ideas (KF 4.4). Sandra's lessons can be quite lively. She believes in using strategies such as chanting, movement and lots of talking to assist students in their consolidation of thinking, retrieval of past learning and application of knowledge to new situations (KF 4.5).

A characteristic of Sandra's science teaching practice was her detailed and purposeful planning and organisation. She set up the classroom and planned lessons for inquiry learning, to facilitate small group and whole class activities and discussions (KF 4. 8, 4.9). She utilised different instructional settings and swapped between settings to pace and progress learning, to cater for different learning styles and to support and scaffold higher order thinking and scientific reasoning (KF 4.6, 4.11). She used authentic examples and real life problems to engage and motivate students and sequenced and structured lessons to build learning during and across lessons. In her planning and implementation of lessons her initial lessons were structured to guide and scaffold student learning and reasoning and as the unit progressed and students understanding and skill level increased she proportionately reduced the amount of direct support given to students (KF 4.9, 4.10) to encourage higher order thinking and reasoning.

Talk and discussion were central to Sandra's lessons. Sandra encouraged and assisted students to formulate and evaluate their own thoughts by keeping her talking, feedback and contributions to a minimum. When she did contribute, her contributions were usually simple, non-evaluative and neutral; and were mainly prompts, cues and signposts to sustain talk, guide exploration or for instruction, diagnosis or assessment (KF 4.21). Her use of neutral, open ended prompts and questions were carefully orchestrated; indicating her interest in students' ideas but not dominating them; guiding students to verbalise and extend their thinking and to make connections between their experiences, new ideas and concepts via their own learning, discussions and experiences (KF 4.22).

Language development was very evident in Sandra's teaching practice. She developed, integrated and reinforced key vocabulary and scientific language with conceptual development from the onset of each lesson and across lessons using a variety of strategies (KF 4.12). This supported her belief that access to relevant science language and vocabulary is necessary to connect and build science ideas and to reason in science.

Small group work was a frequent feature in Sandra's teaching. In this setting Sandra put students in-charge of their own learning (KF 4.24). She fostered and sustained student talk and discussion, thinking-out-loud and verbal reasoning by monitoring and assessing students' learning and identifying areas where support was needed (KF 4.26). This was facilitated by her taking on of a variety of roles (E.g. onlooker, silent observer, facilitator, model, instructor or devil's advocate) when interacting with students in the small group setting. She encouraged students to critique, compare, disagree with, modify and to come to a consensus of ideas with their peers (KF 4.23). Disagreement was a very distinct, acceptable, positive, vibrant, and a successful part of Sandra's lessons. She used it for creating situations in small group discussions where students' ideas and thoughts were challenged and extended; and science reasoning, higher level thinking and argumentation skills were developed (KF 4.25).

Sandra utilised metacognition as a strategy to support student learning. Sandra taught, modelled, scaffolded and reinforced metacognitive awareness and self-regulation during lessons. She incorporated metacognitive strategies and practices such as Learning train, Sticky note fact graph, WILF and TIB statements, and 'because' as a syntactical scaffold into her lessons (KF 4.13, 4.14, 4.15, 4.16, 4.17, and 4.18).

Thinking was an intimate and important part of Sandra's classroom learning culture. She frequently spoke about thinking; shared her own thinking and thought processes, and prompted and encouraged students to do likewise. Sandra incorporated a variety of strategies and practices (e.g. thinking-out-loud, questioning, critique, Fish bowl and Hot seat) into her lessons that enabled students to 'safely' and comfortably access, identify, share and extend their thoughts and thought processes as they co-constructed arguments and understanding with others (KF 4.19, 4.20).

Sandra's teaching of the Materials unit was underpinned by her science education philosophy and beliefs, substantial lesson planning and classroom organisation, the establishment and of a positive and supportive classroom environment and learning culture; her use of practical student-centred hands-on inquiry-based authentic activities and a range of scaffolding strategies and practices incorporated within and across instructional settings. Together all of these factors contributed to her scaffolding, supporting and promoting opportunities for the development of higher order thinking and scientific reasoning skills within her Year 4 class.

# Chapter 5: CHRISTINE AND MELANIE's TEACHING

## Introduction

This chapter explores Christine and Melanie's (pseudonyms) co-teaching of a Year 4 physical science unit, Forces at Providence Girls College (PGC) (a pseudonym). The first part of the chapter examines the contextual setting of the case study, Christine and Melanie's beliefs and philosophies regarding the teaching and learning of science and an overview of the topic. This is followed by an overview of Christine and Melanie's instructional approaches and a detailed exploration of their pedagogies and strategies that scaffold, support and create opportunities for higher order thinking and reasoning.

## Context

This section outlines background information relevant to this case study. It provides the details of how Christine and Melanie co-taught, the College community, student group, physical organisation of the classroom and Christine and Melanie's education and teaching backgrounds.

### Teaching and planning together

For this research and for six months prior to this study, Christine and Melanie amalgamated their Year 4 classes for Science lessons and planned and taught the Forces unit together.

> We decided to combine our classes and co-teach for Science lessons as we recognised that we had a similar passion for the subject and felt that having all of the students working together would be a benefit to them with that strong collaborative approach. (Christine, Electronic communication, September 2017)

They were both present during each Science lesson and rotated roles as lead or support teacher with the commencement of each new activity. This resulted in

Christine and Melanie each having several turns as lead teacher and support teacher several times during each lesson.

**Christine's educational and teaching background**

During the case study, Christine was in her sixth year of teaching and was the full-time teacher of one of the two Year 4 classes at PGC. Christine completed a Bachelor of Education (Primary) degree with a minor in Science. After graduation she taught in a metropolitan government primary school for two years until she attained a teaching position at PGC, where she has taught for the last four years. Christine has a strong interest in Science and has been the Junior School Science Coordinator since being at PGC. In this role, her responsibilities included:

- Organising whole school incursions with a Science based focus.
- Planning activities for Science Week for all year levels in the Junior School.
- Sourcing equipment and resources for use within the College.
- Managing a substantial science budget.
- Providing science leadership in the College by keeping up to date through professional development regarding good science teaching and passing this onto colleagues (Personal communication).

Christine had the opportunity to access a variety of professional development opportunities in science through her science coordinator role. She received ongoing training in *Primary Connections* and was trained in the *Australian Curriculum: Science*. PGC was chosen as a trial school before the launch of the *Australian Curriculum: Science*. As a school representative, Christine annotated activity and assessment samples and met with representatives of ACARA to discuss the College's feedback and implementation of the new curriculum.

Christine's interest in Science also extended into the local community. As an extra-curricular project, Christine managed the College's ongoing caretaking of a park adjacent to the College campus where students recreated "the understory so that the grass trees can develop naturally rather than having an artificial burn back every year and to help to promote and encourage the natural flora and fauna that's native to this area" (Christine, Pre-study interview).

**Melanie's educational and teaching background**

During the case study, Melanie was in her seventh year of teaching and was the full-time teacher of the other Year 4 class at PGC. Melanie also completed a Bachelor of Education (Primary) degree and received an award for graduating with the highest marks in her graduating year. After graduation she taught at a private school for girls for four years before her appointment at PGC, where she has taught for the last three years. Melanie has not been involved in any initiatives in science education at PGC as it hasn't been her area of interest, but working with Christine has helped her to think about becoming more involved.

**Key Finding 5.1**
Christine and Melanie co-taught their combined Year 4 Science classes. They were not trained as specialist Science teachers. Christine's interest in science led to her completing a minor in Science for her undergraduate degree. She took on the role of Junior School Science Coordinator and managed the teaching of the curriculum across year levels, supported teachers with professional development and resourced and coordinated whole school science activities and community projects. Melanie enjoyed teaching Science and looked forward to becoming more involved in College science initiatives.

**School community**

Providence Girls College is a prestigious private (non-government) kindergarten to Year 12 day and boarding school for girls located in metropolitan Perth, Western Australia. Students pay relatively high tuition fees to attend the College and come from metropolitan, remote and rural Western Australia communities. The PGC school community promotes Christian values and prides itself in the provision of a broad up-to-date education that prepares students to live successful lives.

At the time of the study the College had approximately 1,100 students and had a school index of Community Socio-Educational Advantage (ICSEA) of 1197 which was above the average value of 1000 for schools in Australia. The College attendance rate was 95% which was greater than the WA public school average of 92% for that year; 1% of the student population were Indigenous and 13% of students had a language background other than English. There was low staff turnover and hence the staff was relatively stable. The College was well resourced and had a science budget (which was administered by Christine as the Science Coordinator), to resource the teaching of science in the Junior School (equivalent to primary school). “We are well resourced – if you need it you can get it. We have a substantial science budget, Year 6 lab set up with scientific equipment and a senior school for resources and teacher expertise” (Christine, Pre-study interview). There were many extra-curricular activities fostered in the College which often took students out of class and reduced the class time available for teaching of the curriculum. “There are time constraints in the school . . . so we just tend to pull out what we think is most relevant to the outcomes that we’re addressing (Christine, Pre-study interview).

Junior School students participate in general curricular subjects, language and music and can choose from a range of co-curricular activities (e.g., art, speech, drama, debating and dance) offered before and after class times. There is a strong focus on technology across most subject areas and a high level of parent interest and involvement in both their child’s education and in the College community. A large percentage of the students’ parents have expertise which is drawn upon to enhance the curriculum and to improve the administration and specific financial pursuits of the school.

The teaching of science takes a whole school approach and is coordinated across year levels. Christine takes the role of Junior School Science Coordinator. This involves coordinating resources, providing professional development for the staff and organising science projects outside of the College (Junior School Annual Report, 2013).

**Student group**

Christine and Melanie’s combined class comprised 45 female Year 4 students. Even though there was a range of abilities from the “very weak students to the very capable students in the classroom” (Christine, Pre-study interview), the majority of students performed above average in most subject areas. In the previous year’s National Assessment Program – Literacy and Numeracy testing (NAPLAN), Christine and Melanie’s students performed 4 - 48 points above the national average in reading, writing, grammar and punctuation, spelling and numeracy; and, slightly below the average (except for spelling which was significantly lower than the average) of similar schools who serve students from statistically similar backgrounds.

Overall, students displayed a high level of computer literacy and were confident and proficient in speaking in front of others. During science discussions, debates and presentations the majority of students demonstrated advanced general and science knowledge and vocabularies for their age, and an awareness of contemporary science issues.

**Key Finding 5.2**
Christine and Melanie co-taught their Year 4 classes for Science in a private junior boarding school for girls with an above average ICSEA rating. Their students demonstrated above average literacy skills on NAPLAN assessments; developed computer literacy, confidence in speaking in front of others, advanced general and science knowledge and vocabularies for their age; and, an awareness of contemporary science issues.

**Classroom culture and learning environment**

Congruent with sociocultural theory, prior to teaching this unit, Christine and Melanie had already established a safe and positive learning environment in their individual and combined classes. Due to established 'ground rules' students felt comfortable sharing and talking about their ideas in front of peers without fear of being ridiculed and knew of the expectation that they were required to think, think-out-loud, ask questions, reason, justify, share and discuss ideas and seek for answers to questions and solutions to problems during lessons.

**Key Finding 5.3**
Established 'ground rules' in both case studies provided a safe and supportive classroom culture that promoted thinking, thinking-out-loud, asking questions, reasoning and justification was already established in Christine and Melanie's combined class. Talking, sharing, discussing and working collaboratively provided an environment where students could build conceptual understanding and develop thinking and reasoning skills.

**Physical organisation of the classroom**

The physical set-up of Christine and Melanie's classroom provided a work environment that supported learning in the social context and facilitated students' verbal, physical and spatial interaction between others and resources. When Christine and Melanie's classes were combined for Science lessons they used an open communal space adjoining their classrooms which was the central hub of the four classroom block. As there were insufficient tables and chairs available there, Christine and Melanie had students sit on the carpeted floor in the centre of the area in front of the interactive whiteboard (IWB) (Figure 5.1).

The furniture that was in the communal space (two large work tables and eight stools and eight coloured modular small group tables arranged into two groups), were used occasionally during some Science activities but in the majority of times it was moved to the side of the room during lessons. The large open teaching space was useful for whole, small group and partner work and discussion and allowed students to move around the classroom and to become physically involved in their learning.

**Figure 5.1: Christine and Melanie's classroom setup in the communal area of their block**

**Key Finding 5.4**
The physical organisation of the classroom environment facilitated physical and intellectual interactions between students. By being in close proximity with peers and resources, students were able to talk, share, question, discuss, test and refine ideas together.

## Christine and Melanie's beliefs and philosophies

Christine and Melanie were interviewed prior to the videoing of this case study. An overview of their shared beliefs and philosophies pertaining to the teaching and learning of science follows.

**Scientific literacy and linking Science to the real world**

Christine and Melanie believed that the principal purpose of primary science education was to develop students' scientific literacy. In teaching Science, they aimed to inform students about the world and to promote thinking, awareness and understanding of the things that were around them. They also believed in promoting science to girls and to inspire students to become productive citizens and independent thinking lifelong learners who can make a difference in society.

> if they're going to be lifelong learners then they're going to have to be able to learn themselves rather than relying on someone else to tell them and I'd hate for our kids to go through life, even at this young age just accepting what people tell them is true, it's not, I think they need to be able to think for themselves and form their own opinions. (Melanie, Post-study interview)

They share the philosophy that science needs to be real. "If it's what scientists would do in the real world, that's what we want them to do" (Christine, Pre-study interview). By incorporating authentic examples, activities and problems in lessons, the subject of Science is linked with real life science. They believe that when students see the relevance and value of science, it enhances their interest, curiosity, innovation and creativity in scientific matters.

**Scientific reasoning and thinking**

Christine and Melanie believe that a key component of scientific literacy is the development of science reasoning skills. They state that "everything stems from reasoning" and that reasoning is the "culmination of thinking" (Christine and Melanie, Pre-study interviews). Christine and Melanie believe that reasoning based questions "encourage [students'] ability and confidence . . . [to] question and wonder . . . [and to be] inspired" (Christine, Pre-study interview).

**Hands-on student centred inquiry learning**

Consistent with social constructivist, sociocultural, social semiotic theories and distributed cognition, Christine and Melanie believe in hands-on student centred inquiry where students learn by doing and experimenting. "[If] we lead them too much . . . then we'll be taking away some aspects of the learning" (Melanie, Pre-study interview). They describe a good science lesson as one that engages students in lots of activity, discovery learning, open ended tasks, exploration and experimentation. Both Christine and Melanie believe that the *Primary Connections* 5Es (Engage, Explore, Explain, Elaborate and Evaluate) approach (Hackling et al., 2007) is a useful tool for developing students' science inquiry skills and incorporate this approach within lessons and across science units. Additional to a student-centred inquiry based approach, Christine and Melanie believe that students learn together in a social context.

**Cooperative and collaborative learning across instructional settings**

Christine and Melanie favoured facilitation rather than direct instruction and believed in a constructivist sociocultural approach to teaching and learning science that focuses on building students' understanding on their prior knowledge and in cooperative learning where understanding is created jointly by sharing, testing and refining ideas. They believe that this can be achieved across all classroom settings: in partnerships, small groups and during whole class activities and discussions. "Whole class collaborative activities are good for larger tasks, small group work for exploring and investigating and partner work are good for think-pair-share activities" (Christine, Pre-study interview). All involve collaboration and cooperation. Christine and Melanie believe that a fundamental aspect of collaborative and cooperative learning is lots of talk, questioning and discussions.

**Importance of talk, questioning and discussion**

Christine and Melanie believe that talk, questioning and discussion are essential for assessing students' prior knowledge and for communicating and formulating individual and collaborative ideas. "They [the students] need to talk and to discuss" (Melanie, Pre-study interview). Talking and discussion bring concepts "into existence" (Melanie, Pre-study interview). "Two heads are better than one. Being able to talk to somebody else will always help bring out more information . . . [they can] teach and learn at the same time." (Christine, Lesson 1 post-lesson discussion).

They also believe that talk and conversations are instrumental in the development of conceptual understanding, higher order thinking and scientific reasoning. "Talking consolidates everything . . . the concepts" (Melanie, Pre-lesson interview). "[It is] where a lot of the reasoning and thinking comes [from]. When [students are] engaged in a conversation . . . talking about the concepts or the idea . . . the ideas evolve from that thinking" (Christine, Pre-study interview). Talking not only provides communication; it also allows students to think-out-loud, to back up ideas, to justify their observations and to say "Well, this is why I think this. . . . [It] makes connections between ideas and cements it for kids" (Melanie, Pre-lesson interview).

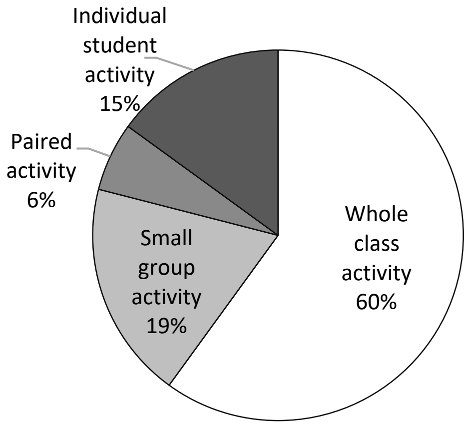



**Figure 5.2: Percentage of time students spent in each instructional setting across the unit**

Figure 5.2 demonstrates the percentage of time across the unit used in different instructional settings; namely, whole class activities and discussion (WCA), small group activities (SGA), paired activities (PA) and individual student activities (ISA). Their belief in collaborative and cooperative learning and the importance of talk and discussion for thinking and learning is demonstrated by 85% of class time over the unit devoted to WCA, SGA or PA with students working with others.

Christine and Melanie believe that questioning and discussion are essential tools for guiding, prompting, supporting and scaffolding the construction of ideas and for encouraging reasoning in science. They believe that the use of relevant questions; initiated both by the teacher and the students, enables students to link and build upon prior knowledge and to build understanding and reasoning. Teacher questions and individual and collaborative questioning, challenges ideas and makes students think and justify their reasoning. "The girls know that my favourite word is <u>because</u>… . I try to get them to use it. In our chats and discussions I believe in asking lots of questions, for example: "What did you find there?", "How did you think that?" "Well why, why would that be so, is that right?"" (Melanie, Pre-study interview).

> **Key Finding 5.5**
> Christine and Melanie believe that the development of scientific literacy is the major purpose of primary science education and that the development of students' reasoning and thinking are essential to this. They believe in hands-on student centred activity-based inquiry learning using authentic examples and find the *Primary Connections* 5Es model a useful instructional approach.

> **Key Finding 5.6**
> Christine and Melanie favoured facilitation rather than direct instruction and believed in a constructivist sociocultural approach to teaching and learning science; that learning is built upon prior knowledge and that individual learning takes place in a social context across all instructional settings, allowing students to jointly create understanding through sharing testing and refining ideas. Talk, questioning, discussion and verbalising reasons (using 'because') are important verbal forms of communication in the teaching and learning Science. Lessons were structured for collaboration and discussion. The majority of class time was spent in whole class activity and 85% of lesson time across the topic was spent in instructional settings which enabled students to talk, discuss and work collaboratively.

**Multiple modes and representations**

Christine and Melanie believe that though the verbal is an important and central mode of instruction, it is only one mode amongst multiple modes of communication. In order to fully engage a classroom of students, spanning a range of abilities and learning styles, it is important to incorporate and expose students to multiple modalities and representations of concepts. For example; providing students with "tactile, hands-on . . . visual . . . moving around . . . and kinaesthetic [experiences], the computer visual" (Christine, Pre-study interview), helps students with varying abilities and learning styles and exposes students to different ways of looking at things.

> [By] looking at all kind of the different intelligences . . . and being able to reach all the kids . . . not everyone's going to learn from the video, not everyone's going to learn best from talking to someone else, not everyone's going to learn best from doing the experiments so we've just got to get it into them whatever way we can really so the more ways that we do it the better. (Melanie, Pre-study interview)

One modality that is used extensively in Christine and Melanie's combined teaching approach is the use of the body for teaching and learning.

**Embodiment**

Christine and Melanie use embodiment as a learning strategy across all of their subject areas. They believe in kinaesthetic learning and that physical body experiences are very important in teaching and learning and that the body can act as a conduit for information and a catalyst for developing understanding. Their aim, for each lesson is to, "[physically] put students into the [their] learning" (Christine, Pre-study interview). They believe that by building learning on an embodied experience, students can access and connect to new and particularly abstract science concepts; and if students first physically experience a concept, it makes it easier for them to understand and to transfer their understanding to other modalities and representations such as verbal, written text and drawings and to apply their learning to new situations.

**Key Finding 5.7**

Christine and Melanie believe that the verbal mode is an important and central mode of instruction but that Science is best taught through multiple modes and representations. They believe strongly in kinaesthetic learning and that students need to be physically involved in their learning especially when dealing with abstract concepts. They frequently use embodiment in teaching Science and all of their other subjects.

**Literacy focus**

In accordance with sociocultural theory Christine and Melanie believe in adopting a strong literacy focus across all subject areas. In Science, they believe that the development of science language and vocabulary is important for conceptual development and reasoning. Christine and Melanie use a themed approach to teach the curriculum; students are often exposed to the current science topic's words in other subject areas. In English for example, reading texts are selected that incorporate science language and to complement the science topic being studied; and, English vocabulary exercises focus on new and unfamiliar science words which are added to the Science Word Wall for discussion during Science lessons.

> [S]o they're getting exposed to them [science words] and having to use them over and over again . . . it's just really effective in building those words into their vocab and getting them to use them comfortably because they know what they mean and they've worked with them for a long time. (Christine, Pre-study interview)

They believe it is important to include at least one written (includes drawing) or verbal literacy task in each science lesson. KWL and T charts, note taking, drawing a labelled diagram as an explanation, designing and drawing a storyboard to illustrate their understanding, writing up an investigation using correct method and scientific language, discussion of science vocabulary and adding new science words to the classroom Word Wall and are literacy tasks that can be used to organise, support and consolidate students' learning.

**Information communication technologies (ICT)**

Christine and Melanie believe that as technology is becoming an essential part of everyday life and that today's children "live in a visual world and are becoming more techno savvy" (Christine, Pre-study interview) it is important to incorporate ICT into Science lessons.

They believe it enriches and consolidates learning and "provides another way to look at things" (Melanie, Post-study interview). It is useful for demonstrating concepts, procedures and skills; that due to cost, time or practicability are difficult to model in classrooms. By using technology, students are able "to see things actually happening that aren't able to be constructed or reconstructed at school" (Melanie, Post-study interview). For example, what "they [students] can learn in a 10 minute *Clickview* [video] would take us a 2 hour session period to do" (Christine, Pre-study interview).

Christine and Melanie believe that movies and videos are particularly helpful for engagement and supporting and reinforcing conceptual and language development. "Kids engage with movies and concepts [in movies] are tightly developed" (Christine, Pre-study interview) and movies provide and reinforce "the scientific language for reasoning" (Melanie, Post-study interview).

**Key Finding 5.8**
Christine and Melanie believe in a literacy focus in Science lessons and that each lesson needs to contain some form of literacy task. Vocabulary development supports communication of ideas and is a focus in their lessons. ICT is useful for introducing, reviewing and showcasing ideas and activities that are not available in the classroom.

## Topic and unit overview

The following section presents an overview of the unit objectives, main concepts and unit structure in Christine and Melanie's Force*s* unit. It is also demonstrates how Christine and Melanie utilised the 5Es inquiry teaching approach across the unit.

### Unit objectives

The Year 4 Physical Sciences Program written by Christine and Melanie was based on the following objectives:

- investigating the effect of forces on the behaviour of an object through actions such as throwing, dropping, bouncing and rolling,
- comparing the effect of friction between different surfaces, such as tyres and shoes on a range of surfaces,
- investigating the forces of attraction and repulsion between magnets,
- observing qualitatively how speed is affected by the size of a force, and
- Year 4 *Science Inquiry Skills* (questioning and predicting, planning and conducting, processing and analysing data and information, evaluating and communicating) outlined in the National Science Curriculum (Kesidou et al., 2012).

**Unit Structure**

The Forces unit consisted of eight lessons and covered the conceptual themes: push and pull forces, gravity, friction, and magnetism. Following an exploration of each theme students were given the opportunity to investigate the effect of different sized forces on momentum, how mass affects the speed of an object and how interacting forces work together. Overviews of these lessons are found in Figure 5.1 (refer also to Appendix B: Tables B.1 and B.2 for a more detailed program). Lesson ideas and activities were drawn from *Primary Connections* unit *Smooth moves*, Stage 2, Energy and Change (https://www.primaryconnections.org.au/curriculum-resource/smooth-moves), *ClickView* (https://www.clickview.com.au/), *Scootle* (https://www.scootle.edu.au/), *Science Out of the Box* (www.teachersuperstore.com.au/product/.../science-out-of-the-box-energy-and-forces/) and Scitech (www.scitech.org.au).

**5Es approach and lesson overview**

Christine and Melanie adopted the *Primary Connections* inquiry and investigative approach and focus on literacy in this unit, and were guided by the constructivist 5Es teaching and learning model (Figure 5.3). Lessons were taught weekly with each lesson being 60 – 75 minutes in duration. During Lesson 1 (Engage) students completed the first stage of a three staged diagnostic assessment task called the Big picture question (students re-visited this task again in Lesson 5 and in the final lesson, Lesson 8) and watched, discussed and took notes from two videos on forces.

| Lesson | 5Es stage | Title | Concepts |
|---|---|---|---|
| 1 | Engage | Why do things move? | Push and pull forces, balanced and unbalanced forces, friction, gravity and mass, magnetism. |
| 2 | Explore & Explain | Push, pull and momentum | Push and pull forces cause objects to change in motion. Forces can be different sizes. Different amounts of force are required to stop hard and soft pushes due to momentum. |
| 3 | | Gravity | Gravity is a pull down attractive force that acts between any two objects. We are kept on the Earth by its gravity. Objects with greater mass have greater gravitational attraction. The moon has less gravity than the Earth. Gravity and air resistance can affect the falling rate of objects. |
| 4 | | Friction | Friction causes heat and slows things down. The greater the mass of an object the greater the friction. Surface types can affect the amount of friction. |
| 5 | | Magnetism | Magnetism is a force which can cause movement. Like poles of magnets repel and unlike poles attract. |
| 6 | Elaborate | How does mass affect the speed of an object? | Mass, friction, gravity, air resistance affects the momentum and speed a toy car travels down a ramp. |
| 7 | | How does the size of a parachute affect its fall? | Gravity and air resistance act on parachutes. The larger a parachute the longer it takes to fall. |
| 8 | Evaluate | Assessment: Why do things move? | Many forces can act together to make things move. Knowledge of different forces can be applied in the designing, making and plays games. |

**Figure 5.3: Overview of Christine and Melanie's lessons and main concepts**

**Key Finding 5.9**
Christine and Melanie based their Forces unit on the trial version of the *Australian Curriculum: Science*. They drew ideas from the *Primary Connections: Smooth moves* unit and other sources, modifying them to suit their students and classroom environment. Christine and Melanie were guided by the *Primary Connections* 5Es constructivist teaching and learning model when planning and teaching.

A summary of the structure of the unit and signature pedagogies has been included in Figure 5.4 to provide further context for the discussion of this Case Study.

**Lessons**

| | 1 Introduction Push and pull | 2 Push & Momentum | 3 Gravity | 4 Friction | 5 Magnetism | 6 Effect of mass on speed | 7 Parachutes | 8 Assessment |
|---|---|---|---|---|---|---|---|---|
| **Big picture question** | First thinking: Recording ideas on: Why do things move? | | | | Second thinking: updating Big picture question thinking on A3 sheet. | | | Third thinking: updating Big picture question thinking on A3 sheet. |
| **Activities** | Viewed and discussed real life applications of forces shown in the two movies. | Running down a hill class activity. Rolling and stopping a can small group activity. | Pushing a balloon small group activity. | Tug-of-war- class activity. | Moving toy cars with magnets activity. | Rolling a toy car down a ramp small group investigation. | Students made parachutes and dropped them from a balcony. | Students designed, made and played a fun game that incorporated the use of 3 forces. |
| **Embodiment** | Used body to show push and pulls. | Used body to show push and pull. Ran down a hill to feel stopping forces. | Used body to keep a balloon from falling. | Rubbed hands together to experience friction. Closed eyes to imagine the friction when riding a bike. | Used clenched fists to show repulsion and attraction. | Used hands and bodies to simulate pushing a shopping trolley. | Used body to demonstrate the speed that different sized parachutes fall and fingers to represent gravity and air resistance. | Used hand gestures to show push and pull, friction, air resistance on a balloon and magnetic forces. |
| **Literacy** | Note taking, recording in science journal, Word Wall. | Story boarding, used arrows to show direction of force, updated Word Wall. | Used arrows in a diagram to represent effect of gravity, note taking on videos, updated Word Wall. | Note taking. Drew diagrams to show the friction on a moving block. | Note taking, assisted to complete investigation planner, drew diagrams of attraction and repelling. | Drew diagrams with arrows to review attraction and repulsion of magnets. Completed investigation planner without little teacher assistance. | Drew diagram showing the direction of and types of forces on parachutes. | Students drew a diagram showing the forces involved in their game. |
| **ICT** | Viewed movie to introduce Forces. | | Viewed two short comic clips on Isaac Newton to movies to conclude the lesson. | Watched and interacted with movie. Complete online friction activities on PCs. Online class quiz. | Viewed a movie on magnetism. | | Whole class interactive game on parachutes. | |
| **Think-Pair-Share partner and whole class discussion** | Think-Pair-Share during WC* discussion. | Think-Pair-Share during WC discussion. | Think-pair-share during SG** and WC discussion. | Think-Pair-Share during WC discussion. | Think-Pair-Share during WC discussion. | Think-Pair-Share during WC discussion. | Think-Pair-Share during WC discussion. | Think-Pair-Share during SG and WC discussion. |

**Figure 5.4: Overview of pedagogies and strategies in the sequence of lessons in the Forces unit **Whole class **Small group***

## Christine and Melanie's instructional approach

Christine and Melanie's broad instructional approach underpinned how they created opportunities for developing students' higher order thinking and reasoning. This section demonstrates how a learning culture of inquiry, thinking, questioning and reasoning; their building of conceptual themes and increased cognitive demand of activities as the unit progressed, their use of instructional settings and setting changes, co-teaching approach, and sequencing of activities within lessons worked together to facilitate the development of students' higher order thinking and reasoning during the Force*s* topic.

**A culture of thinking, questioning, sharing and reasoning**

Christine and Melanie created a learning culture where students felt safe sharing their ideas with the rest of the class. Christine and Melanie modelled, reinforced and sustained this culture by sharing their own thinking, questions and reasoning in both their general and science talk and by frequently requesting and providing encouragement for students to think, to ask questions, to justify their ideas with reasons, and to work together to build understanding and to find solutions to problems. The expectation for thinking and reasoning was established in the unit from Lesson 1.

***Teacher modelling***

Following the lines of sociocultural theory, the thinking and reasoning culture was promoted by Christine and Melanie's modelling of these skills in their teaching. It was the norm for them to justify their thoughts or requests across general, instructional and science talk by using the word "because" to explain why they thought or did something. This even occurred with the giving of basic instructions. For example, in Lesson 2 in the beginning of the lesson students were put into groups before going outside for the running down a hill and stopping activity. Melanie provided students with a reason for organising students into groups,

> We are going to be organising you into some groups first **because** could you imagine if we have 48 of you running up the grassed here all at the same time, it would be a disaster wouldn't it? (Lesson 2 transcript)

When instructing students how to participate in activities they also provided reasons. For example, again in Lesson 2, Christine gave students reasons how she wanted them to walk and why they had to stop at the bottom of the hill. The word "because" has been highlighted.

> The brick paving has become lava and you are running from a dinosaur and so you've got to stop as quickly as you ran. Ooh. Then what you are going to do, you are going to walk to the top of the hill again and then you are going to walk down the hill and then **because** this time a pussy cat is chasing you and then you stop still **because** there is lava there still. Do you understand? (Lesson 2 transcript)

***Formal commencement of thinking in Lesson 1***

Christine and Melanie consciously considered students' thinking and learning journey in their unit and lesson planning. The aim for Lesson 1 for example, was to establish a thinking and questioning tone for the unit and set students off on a journey to find out about the different types of forces that make things move. By scaffolding and supporting students to access their prior knowledge and ideas on Forc*e*s, Christine and Melanie provided students with a personal starting point for their thinking and learning during Lesson 1. Students were encouraged to individually recall and review their prior knowledge and thinking on 'why do things move', and then to share and discuss their ideas with others. They were also encouraged to formulate and ask questions regarding what they didn't know and what they wanted to know more about. Christine utilised the following steps to scaffold students' thinking throughout the topic:

1. Recall and review prior knowledge and thinking.
2. Share and discuss ideas with others.
3. Formulate and ask questions about what they didn't know or what they wanted to know more about.

***Emphasis on the processes of thinking and questioning***

Christine and Melanie emphasised the importance of thinking and questioning to students by speaking about these processes often and by their regular requests, prompts and orchestration of activities that engaged students in these processes. The frequent use of words associated with thinking and questioning and sharing of ideas during lessons can be illustrated with the aid of word cloud diagrams using the Wordle program (http://www.wordle.net/); which give greater prominence to words that appear more frequently in a text. Word cloud diagrams have been generated for Lessons 1 and 3 using whole class discourse (substantive talk) to illustrate this.

The word cloud diagram generated for Lesson 1 (Figure 5.5) displays the words *question* and *questions* as amongst the more frequently spoken words during Lesson 1. The word cloud diagram for Lesson 3 on gravity (Figure 5.6) demonstrates Christine and Melanie's focus on thinking, with *think* being the most frequently used word after gravity and *balloon* during substantive talk in the lesson. Analysis of the Lesson 1 transcript of whole class talk additionally supports the notion that questioning is important.

Christine and Melanie used the words *question* or *questions* 27 times during the first 24 minutes of the lesson. This corresponds to the time period when Christine and Melanie introduced and explained the Big picture question task; and students were formulating and sharing their questions arising from the question "Why do things move?' with partners and the class. As the Big picture question task was an introductory diagnostic task, it is not surprising but interesting also to note, that the Lesson 1 Word Cloud diagram (Figure 5.5), depicted words associated with students sharing their thinking, ideas, words and questions; for example: *partner*, *think*, *thinking*, *ideas*, *word/s*, *information* and *points*, more prominently than words related to content words like force, *push*, and *pull*. This highlighted the importance that Christine and Melanie placed on the establishment in Lesson 1, of a learning culture that focused on the learning processes of thinking, questioning and sharing.


**Figure 5.5: Lesson 1 word cloud diagram illustrating Christine and Melanie's focus on questioning and thinking**


**Figure 5.6: Lesson 3 word cloud diagram illustrating Christine and Melanie's focus on thinking**

**Key Finding 5.10**
Christine and Melanie established and sustained a thinking, questioning and reasoning classroom culture. They modelled this culture with their general and science talk (use of 'because') and introduced the thinking and questioning emphasis in Lessons 1. Students were expected to think and question during lessons and to justify claims with reasons.

**Building conceptual themes**

In this Case Study conceptual understanding provided a contextual platform for students' thinking and reasoning. It gave students something to think and reason about. Looking through the lense of social constructivism it was evident that Christine and Melanie purposefully planned and sequenced lessons across the topic and learning sequences within lessons to build conceptual understanding and development of thinking and reasoning skills. Lessons were sequenced and structured to cumulatively expand students' knowledge of each of the main conceptual themes across the lesson sequence. All of the main conceptual themes were introduced in the first lesson and then built upon and expanded as the unit progressed.

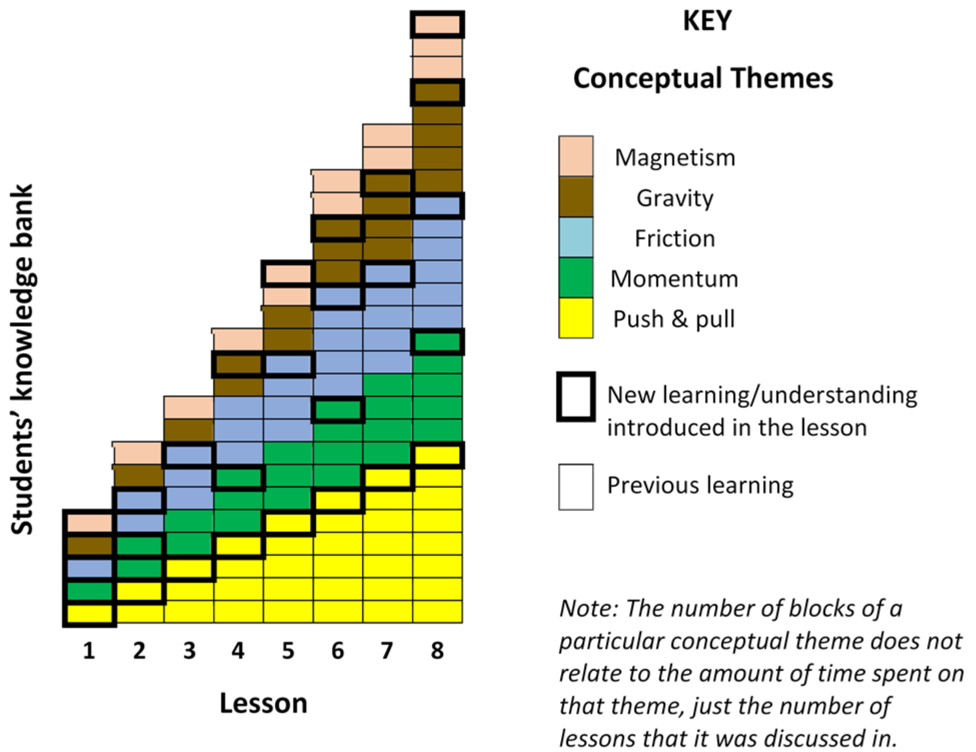



**Figure 5.7: The cumulative building of conceptual themes across the unit**

Figure 5.7 is a graphical representation of how the five conceptual themes were cumulatively built across the eight lesson topic and illustrates Christine and Melanie's constructivist approach to building upon students' previous learning. Each conceptual theme is colour coded, columns represent lessons and the number of each of the different coloured blocks in a column represents students' prior and new learning on each of the main conceptual themes.

**Key Finding 5.11**
Lessons were sequenced and structured to cumulatively build conceptual understanding. Push and pull forces were used as the foundational concepts for all of the Force concepts being taught during the unit.

***Increased cognitive demand as the unit progressed***

With a broadening and deepening of conceptual understanding as the unit progressed, Christine and Melanie's expectation for thinking and reasoning also increased. Christine and Melanie provided scaffolding and support to students until they had sufficient contextual knowledge and skills to think and reason on Force*s* on their own. As students' conceptual ability and thinking increased the amount of scaffolding and support offered to students incrementally decreased and the level of challenge and expectation for scientific reasoning and higher order thinking increased. This is illustrated in Figure 5.8.

Lessons 1 - 4 were highly scaffolded and teacher directed and focussed. Lessons 5 - 7 were more open, student centred and allowed for more exploration; and, required students to apply their new knowledge, to think critically and to solve problems. Lesson 8 the final lesson of the unit, was designed as a culmination of students' thinking and learning. It was a completely open, non-teacher supported task, except that students were given a collection of materials to work with. It required students to draw upon their newly acquired conceptual knowledge and to utilise critical thinking, problem solving, and innovative, design, communication skills to complete the assessment task.

**Instructional settings**

Christine and Melanie combined the use of whole class, small group, paired and individual student instructional settings to scaffold, support and create opportunities for higher order thinking and reasoning during the teaching of the Forces topic. Whole class settings and activities (WCA) were used to introduce activities, review essential concepts; as a forum for students to share, discuss and report their and their partner's ideas and answers to concept building and thought provoking focus questions, and, for Christine and Melanie to summarise students' explanations.

Small group settings and activities (SGA) were used for students to explore, share and discuss ideas. Paired instructional settings and activities (PA) were used for students to share, discuss, compare and clarify their thoughts, questions and answers with a partner during think-pair-share sessions. Individual student settings and activities (ISA) were used for students to consolidate and record their understandings through representational and re-representational tasks.

Figure 5.8 illustrates the use of timing and duration of instructional settings during each lesson across the unit. The number of instructional setting changes have also been tabulated in this figure.

| Lesson | Lesson overview | Level of teacher support and guidance | Expectation level for thinking and reasoning | Progression of conceptual understanding, thinking and reasoning |
|---|---|---|---|---|
| 1 | Preview of forces involved in the topic. | Low | Low | Recall of prior knowledge and building knowledge |
| 2 | Foundational lesson on *push* and *pull* and momentum. | Medium | Low –Medium (E.g. Structured rolling can of tomatoes activity.) | ↓ |
| 3-5 | Introduction, exploration and explanation of gravity, friction and magnetism in terms of *push* and *pull*. | Medium | Low - Medium | Transfer and application of knowledge to new situations |
| 6 & 7 | Investigation and the explanation of two questions concerning the effects of a number of forces. | Medium-Low | Medium | ↓ |
| 8 | Review and application of Forces assessment task | Low | High (E.g. Designing, making and demonstrating a game using three forces.) | Critically think and problem solve |

**Figure 5.8: The level of teacher support decreased and the expectations for higher order thinking and scientific reasoning increased incrementally as lessons progressed across the topic**

**Key Finding 5.12**
As conceptual understanding increased, the expectation for thinking and reasoning increased and scaffolding decreased. Lessons 1 – 5 focused on building conceptual understanding, in Lessons 6 and 7 students applied understanding to solve problems and in Lesson 8 students used their knowledge and innovation and creativity skills to make a game on Forces.

***Instructional setting changes***

Further analysis of the use of instructional settings also revealed a relationship between the number of instructional setting changes and the amount of scaffolding and support given to students. As expected, setting changes occurred typically when activities changed. They also occurred during tasks and activities; and, increased in frequency especially during cognitively and or conceptually challenging tasks.

| Total number of instructional setting changes per lesson | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
| **9** | **17** | **15** | **21** | **21** | **24** | **13** | **6** |

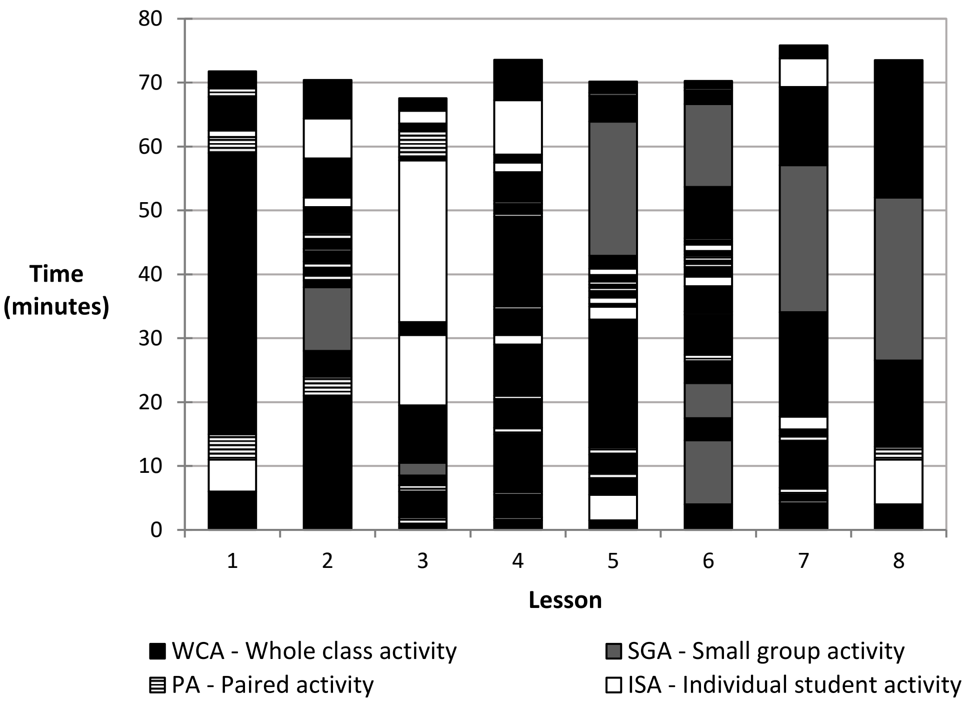



**Figure 5.9: Instructional settings used each lesson over the Forces unit**

For example, Figure 5.9 reveals that the number of instructional setting changes was greater during Explain and Elaboration Lessons 4, 5 and 6 with 21, 21 and 24 instructional setting changes respectively (average = 22), than in Engage and Exploration Lessons 1, 2 and 3 with 9, 17 and 15 instructional setting changes (average = 14) and Evaluation Lessons 7 and 8 with 13 and 6 instructional setting changes (average = 6). This is because Christine and Melanie orchestrated setting changes as part of their scaffolding and supporting process (Figures 5.9, 5.10 and 5.11).

Christine and Melanie provided more scaffolding and support to students during Lessons 4, 5 and 6 as they were cognitively and conceptually more challenging than the previous lessons and they wanted to ensure that students were scaffolded and supported in the inquiry and investigation processes, so that they had a level of confidence and skills to independently formulate and conduct their own open investigations for the tasks in Lessons 7 and 8.

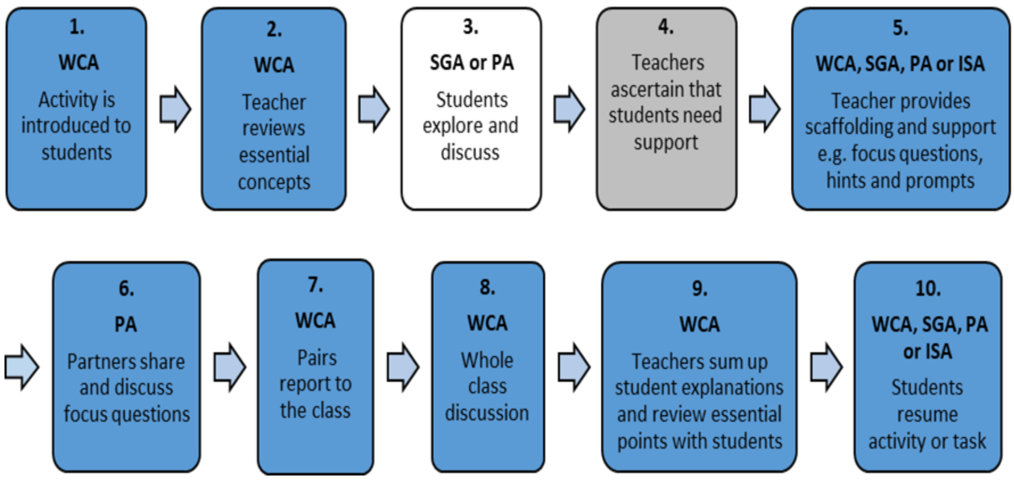



**Figure 5.10: Instructional setting and setting change steps used by Christine and Melanie when scaffolding, supporting and creating thinking and reasoning during activities and tasks**

Figure 5.10 illustrates Christine and Melanie's process and use of instructional setting and setting changes to scaffold, support and create opportunities for higher order thinking and reasoning during the unit. This process was sometimes repeated multiple times within an activity depending on the level of scaffolding and support required and the students' understanding.

**Key Finding 5.13**
Christine and Melanie used instructional settings and setting changes as a strategy to scaffold and support students' thinking, reasoning and learning within lessons. Christine and Melanie used a sequence of steps using different instructional settings, sometimes multiple times within an activity to scaffold students through activities and tasks. The whole class setting was used in between the other instructional settings for instructions, whole class discussions and for coming to a consensus.

**Co-teaching approach**

Christine and Melanie's co-teaching approach; of alternating the role of lead teacher when activities changed within lessons, saw a blending of two individual teaching styles. What was interesting is that they used instructional settings and setting changes to scaffold, support and create opportunities for higher order thinking and reasoning, but used them differently (Figure 5.11).

When Melanie was lead teacher, she changed instructional settings regularly, often stopping the class when students were working on small group or partner tasks to guide, structure, pace, scaffold and support thinking and learning. During these interventions, which were strictly timed between 0.5 to 2 minutes, Melanie focused, teased-out, highlighted, built and reinforced students' thinking, reasoning and understanding. She used focus questions to stimulate quick partner and whole class discussion and at times had students quickly record their thoughts, reasons and understandings in their science journals.

The circled sections in Figure 5.11 highlight occasions when Melanie integrated these short interventions multiple times during partner, small group and whole class tasks. Figure 5.11 provides a magnified view of Lessons 2, 3, 5 and 7 from Figure 5.9. The dotted lines and dashed lines on the right hand side of the lesson columns indicates who was lead teacher at particular times during lessons.

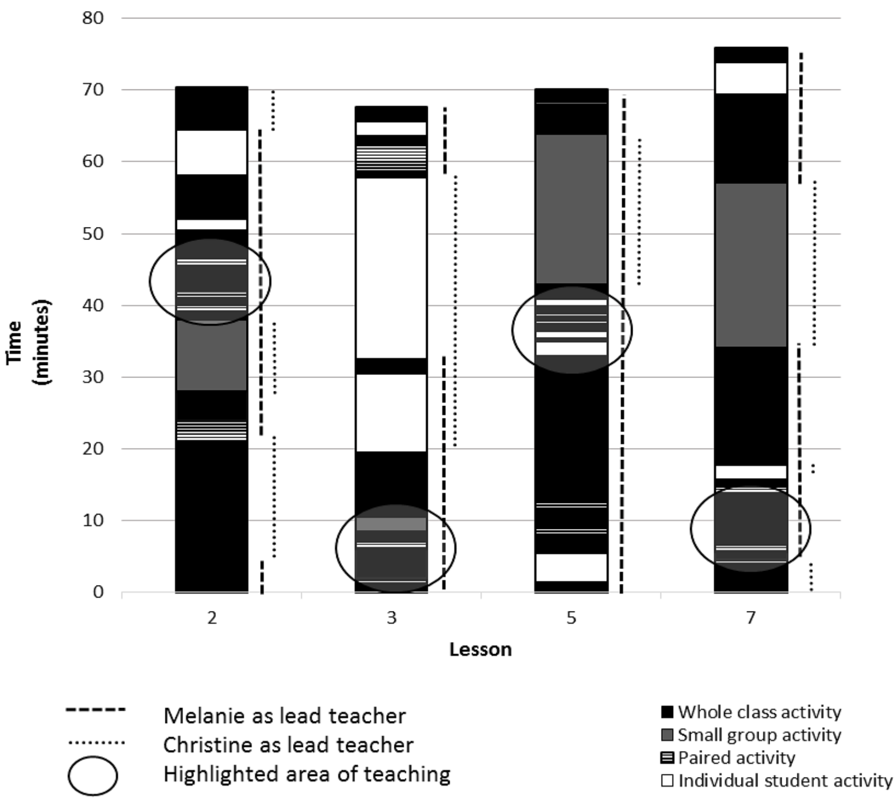



**Figure 5.11: Four lessons highlighting the Christine and Melanie's different use of instructional settings and setting changes**

When Christine took the lead for activities there were fewer instructional setting changes (refer to Figure 5.11). With less teacher intrusions, Christine gave students longer amounts of time to explore, discuss, and think and to test ideas without interrupting their thought processes. Through these sustained periods of work, Christine and Melanie moved between groups of students monitoring and informally assessing where they were at in their learning. One-on-one discussions and discussions with small groups created opportunities for Christine and Melanie to scaffold and support students during these times. The type of questions used to do this will be described later in the Chapter.

**Key finding 5.14**
Christine and Melanie co-taught their combined class and took turns being lead teacher. The support teacher moved around the class and between groups monitoring and informally assessing where students were at and gave students in need, support and guidance. Christine and Melanie use of instructional settings and changing of instructional settings within lessons created opportunities for higher order thinking and reasoning. The number of setting changes correlated with the amount of support and scaffolding afforded to students.

**Sequencing of activities within lessons**

Christine and Melanie also used the sequencing of activities within lessons in their instructional approach to scaffold, support and create opportunities for the development of the conceptual story and students' thinking and reasoning skills. Activity learning sequences which were particularly evident in the Explore/Explain Lessons (Lessons 2 – 5), consisted of a number of linked multimodal activities and representational and re-representational challenges. An example of an activity lesson sequence is found in Lesson 2. Christine gave a brief overview of the activity learning sequence in her pre-lesson interview.

> We are going to head outside and we're going to get the girls to run down the hill and make themselves stop and then walk down the hill and make themselves stop . . . then we're going to talk about how they made themselves stop and how they felt . . . and then they're going to be experimenting with pushing tin cans [of tomatoes] . . . looking at how to stop the tin cans from rolling once they've been pushed. . . . After that we're going to do a story board showing the different [sized] pushes that they applied to the tin cans, and then we're going to finish up with a discussion about momentum. (Christine, Lesson 2, Pre-lesson interview)

A more detailed view of the Lesson 2 activity learning sequence (Figure 5.12) illustrates how: a number of linked activities built the conceptual story of momentum and developed students' thinking and reasoning across the lesson;

| EPISODE, PURPOSE OF ACTIVITY & MODALITY | BRIEF DESCRIPTION OF EACH ACTIVITY | BUILDING OF CONCEPTUAL STORY |
|---|---|---|
| 1. **Review** of push and pull *(embodied)*. | Showing push and pull examples (real, recalled, imagined) with their bodies. | 1. All forces are either pushes or pulls. |
| 2. **Introduction** of concept through felt experiences *(embodied).* | Running and stopping and walking and stopping down a hill. | 2. Forces can be felt and can vary in size. |
| 3. **Translation of felt experiences into words** *(verbal)* and reasons for them *(thinking)*. Creation of a class rule. | Debrief of running and walking activity. "*What did you feel and why did you feel? Give reasons*."(IWB slide). Think-pair-share and whole class discussion leading to a class consensus. | 3. The greater the force the harder it is to stop. |
| 4. Building, and consolidating through an **additional representation**. Transfer and relating thinking from the running and walking activity to the rolling cans activity *(hands on, thinking, verbal and visual)*. | Exploring with rolling cans of tomatoes. How does the size of a push applied to a can affect the size of the force you need to apply to stop the can rolling? Whole class discussion guided by questions on the IWB. Teacher reviews push and pull forces by asking students to show various push and pull examples with their bodies. | 4. The greater the force, the greater force needed to stop it. |
| 5. **Re-representation** of the concept in a story board *(written and diagrammatic)*. Consolidation of understanding *(thinking, creativity and innovation).* | Individuals create a story board (i.e., diagrams, text and arrows) showing what they learnt from the rolling can of tomato investigation. Teachers modelled a story board and scaffolded students with highlighting salient points to include. Teachers scaffolded students' use of arrows for indicating size and direction of force on the IWB. | |
| 6. **Review, summary, linking of activities and concepts,** and consolidation of learning *(verbal, thinking, embodied, written, diagrammatic and visual)*. | Teachers reviewed activities. Teacher led discussion and questioning (facilitated by notes on the IWB) drew out and highlighted salient points from each activity. Multimodal student responses were encouraged (i.e., gesture, action, verbal, diagram on the white board). | All of the above. |
| 7. **Labelling and defining** 'momentum' *(verbal, thinking and embodied)*. | Identifying, labelling and formally defining momentum during whole class discussion. Students act out real life scenarios, e.g., braking suddenly when riding or driving fast and slowly. | 5. If an object is moving it is said to have momentum.<br>6. The more momentum an object has the harder it is to stop. |
| 8. **Linking new concepts** and terms with **previously highlighted concepts and terms**. *(Verbal, visual, thinking)*. | Updating the classroom Word Wall and making relationships between new and previously learnt concepts. | |

**Figure 5.12: The conceptual story of momentum built through the multiple, multimodal activity learning sequence in Lesson 2**

activities varied in modality, teacher guided talk and discussion linked activities and highlighted salient points required to be transferred to the next activity; and how representational activities became more conceptually and cognitively demanding as the activity sequence progressed.

This activity sequence also illustrates Christine and Melanie's focus on literacy, with the adding of scientific words to the classroom Word wall and the labelling of momentum once students' understanding of the concept was built and the linking of new concepts with previously learnt concepts. In Figure 5.12, the purpose and type of activity in the activity sequence is typed in bold, the modality of the activity is typed in italics and the short description of the activity is underlined. The word thinking has been typed in italics and underlined when opportunities were created to extend students' thinking.

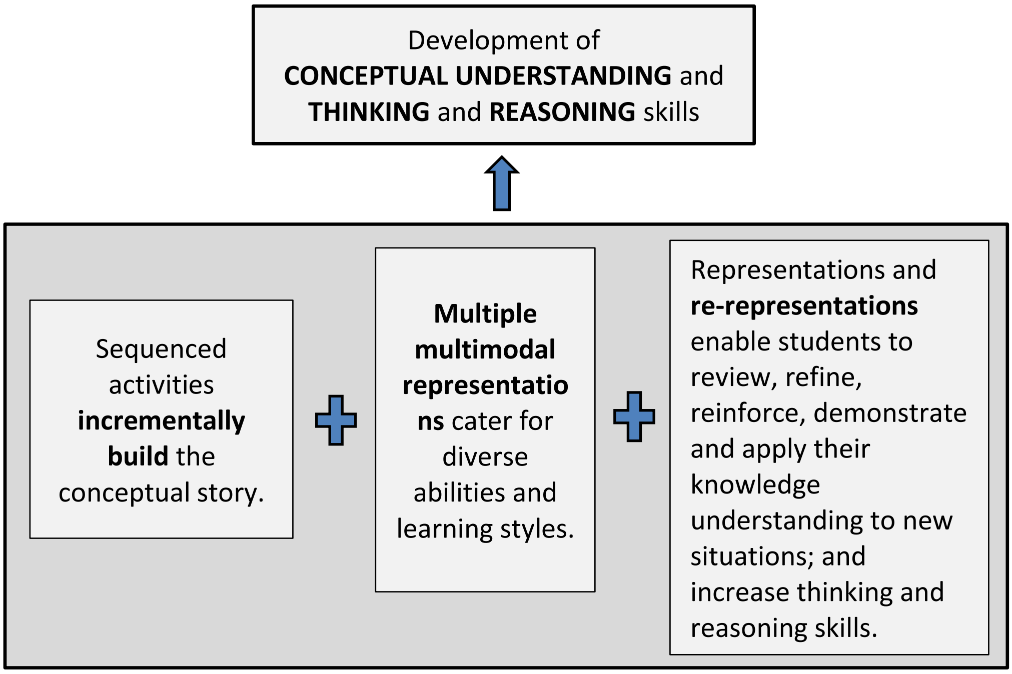



**Figure 5.13: Construction of learning activity sequences to build conceptual understanding, thinking and reasoning**

Figure 5.13 illustrates how activity learning sequences were put together to incrementally build the conceptual story through the use of multiple multimodal representations and re- representations. Each activity built and reinforced facets of the conceptual story, multimodal activities catered for the diversity in student ability and learning styles, and representational activities and re-representational challenges stimulated students' thinking and reasoning as they applied and extended their understanding to new situations.

**Key Finding 5.15**
Multiple multimodal learning activities and representations incrementally built the conceptual story and developed students' thinking and reasoning skills as the sequence progressed. The use of multiple multimodal representations catered for diverse abilities and learning styles. Different representations and re-representations enabled students to review, refine, reinforce, demonstrate, apply understandings to new situations and increase thinking and reasoning skills.

In summary, Christine and Melanie's broad instructional approach provided a basis for the development of students' higher order thinking and scientific reasoning. The combination and establishment of a thinking, questioning and reasoning culture, the building of conceptual themes across lessons, increasing cognitive demand within and across lessons, use of instructional settings and setting changes, co-teaching approach and sequencing of multiple multimodal activities within lessons underpinned, scaffolded, supported and created opportunities higher order thinking and learning. The following section describes a selection of specific pedagogies and strategies that Christine and Melanie employed during the Forces topic that worked together to further scaffold, support and create opportunities for higher order thinking and scientific reasoning.

## Christine and Melanie's pedagogies and strategies

In this section, a selection of Christine and Melanie's key pedagogies and strategies that scaffolded, supported and created opportunities for higher order thinking and scientific reasoning will be highlighted and discussed. The following pedagogies and strategies, which are complementary; and, focus on the development and use of metacognition will be discussed: the Big picture question strategy; partner work and talk, which includes discussion on the Think-pair-share and See-saw strategies, signposting and reporting back; investigation planners; verbal scaffolds; embodiment and representational and re-representational challenges.

Please note, that a themed approach was chosen over a chronological approach for this discussion, due to Christine and Melanie's simultaneous and repeated use of multiple pedagogies and strategies across the topic. Whilst accurate chronology was desired, it was not always possible.

**Big picture question as a metacognitive scaffold**

Consistent with social constructivist theory, the Big picture question task was the central metacognitive scaffolding tool used during the Forc*es* topic. It provided students with a framework for accessing their prior thinking and a process to monitor and develop their personal thinking, reasoning and learning. Throughout the Big picture question task and across the unit, Christine and Melanie encouraged students to take control of their own thinking and learning and gave them metacognitive hints and tools to help them understand the way that they learn.

The Big picture question task was a three phased task which involved students recording their thoughts and ideas on "Why do things move?" on the same piece of A3 paper, three times across the unit. It was introduced in Lesson 1 (first thinking), revisited in Lessons 5 (second thinking) and again in Lesson 8 (third thinking). During topic planning, Christine and Melanie thought carefully about what question they would ask for the Big picture question. They originally thought to use the question, "<u>How</u> do things move?" but found that limiting. Illustrative of Christine and Melanie's focus on thinking, they wanted students to investigate and think deeply about forces that make things move. They decided to change "How" to "<u>Why</u> do things move?", because it promoted deeper thought. The following transcript illustrates Christine and Melanie's careful selection of the wording for the Big picture question.

| | |
|---|---|
| Christine: | We were worried that if you just say *how do things move* that they would just say [for example] "with wheels". |
| Melanie: | Yeah, or you push it or you pull it and that's it . . . with a slope. |
| Christine: | So we really wanted [them] **to investigate** that and **get them really thinking.** |

***Requirement for deep thinking***

The Big picture question initiated student questioning, thinking and searching for answers. In Lesson 1, Melanie described to students the Big picture question as a ‘crunchy eye brow’ question (a person in deep thought, crunches up their eyebrows). The following conversation from Lesson 1 demonstrates the reinforcement of the notion that each student needed to think deeply for themselves. (Note: In transcripts, Teacher M has been used for Melanie, Teacher C has been used for Christine and pseudonyms have been used for the students.)

<table>
<tr><td>Teacher M:</td><td colspan="2">What do you think a crunchy eyebrow question is?</td></tr>
<tr><td>Sally:</td><td colspan="2">A question that makes you think so your eyebrows go crunchy.</td></tr>
<tr><td>Teacher M:</td><td colspan="2">Why do things move? Is this a yes/no question?</td></tr>
<tr><td>Samuel:</td><td>No</td><td rowspan="6">Teacher compares the Big picture question to other types of questions and answers and ascertains that students understand that some effort and thinking will be required to answer the Big picture question.</td></tr>
<tr><td>Teacher M:</td><td>Is there one answer for this question?</td></tr>
<tr><td>Madison:</td><td>No</td></tr>
<tr><td>Teacher M:</td><td>Is there an easy simple answer to this question?</td></tr>
<tr><td>Veronica:</td><td>No</td></tr>
</table>

Students were informed that after Lesson 1, they would revisit (on the same A3 piece of paper) the question “Why do things move?” another two times during the topic. This gave students the expectation that they would be building and growing their learning as the topic progressed. It also signalled to students that a relationship existed between thinking and learning. An overview of the first thinking, second thinking and third thinking of the Big picture question task will be discussed in the next section.

**Key Finding 5.16**
The Big picture question task provided students with a framework and process to build and grow and deepen their thinking and learning as the unit progressed. The question *"Why do things move?"* was chosen as it required students to investigate and think deeply and encouraged students to question and to search for answers. The Big picture question sheet was a tangible way of monitoring students' thinking, learning and understanding.

***First Thinking (Lesson 1)***

The first thinking was aimed at students accessing and identifying their prior knowledge and for Christine and Melanie to see what students already knew about forces. Christine and Melanie believed it was important for students to identify and build on what they already knew. "[By building on] prior knowledge . . . they can actually develop their own understanding and reasoning of the world around them" (Christine, Pre-study interview). For the first thinking task, students were asked to think and then to write down (in red pen) all their thoughts, ideas and questions pertaining to the question "Why do things move?" on the A3 Big picture question task sheet. The importance of identifying one's previous knowledge in the process of building new understanding and the three phased structure of the learning task is conveyed in the following transcript. Capitalised words in the following transcripts and quotations symbolise strong teacher emphasis.

| | | |
|---|---|---|
| Teacher M: | We are going to <u>look at this question three times this term</u>. Today is going to be our first thinking. <u>What is first thinking?</u> | Thinking will be in three stages indicating that learning will grow. |
| Student: | Some ideas. | |
| Teacher M: | It's **what you know now, BEFORE** we've done any experiments... **BEFORE** we've watched any videos, **BEFORE** we've done any activities, **BEFORE** we've played any games, **BEFORE** we make something. | Teacher highlighting the importance of prior understanding and knowledge. |

*Personal brainstorm and recording first thinking thoughts, ideas and questions*

During the task, students were continually reminded that the purpose of the first thinking was to brainstorm any thoughts, ideas and questions regarding the Big picture question and that there are no right or wrong answers.

> So you can write down **ANY ideas** you have in your head about why things move. You might even have questions that you might need to answer to answer this big question that we have here. So you can write down **ANYTHING that you think** that answers that question, **ANY other questions** that you might already have, **ANY definitions or words** that you think might be important, **ANY and ALL ideas**. You **CANNOT BE WRONG** because it is just what you are thinking at the beginning. **YOU CAN'T BE WRONG.** We just want to see what you know now. (Teacher Melanie, Lesson 1)

The openness of the task and supportive learning environment allowed students to write down anything: any comment or words (vocabulary) that they thought were relevant to the question *Why do things move*'; and questions that they thought needed to be answered to answer the Big picture question.

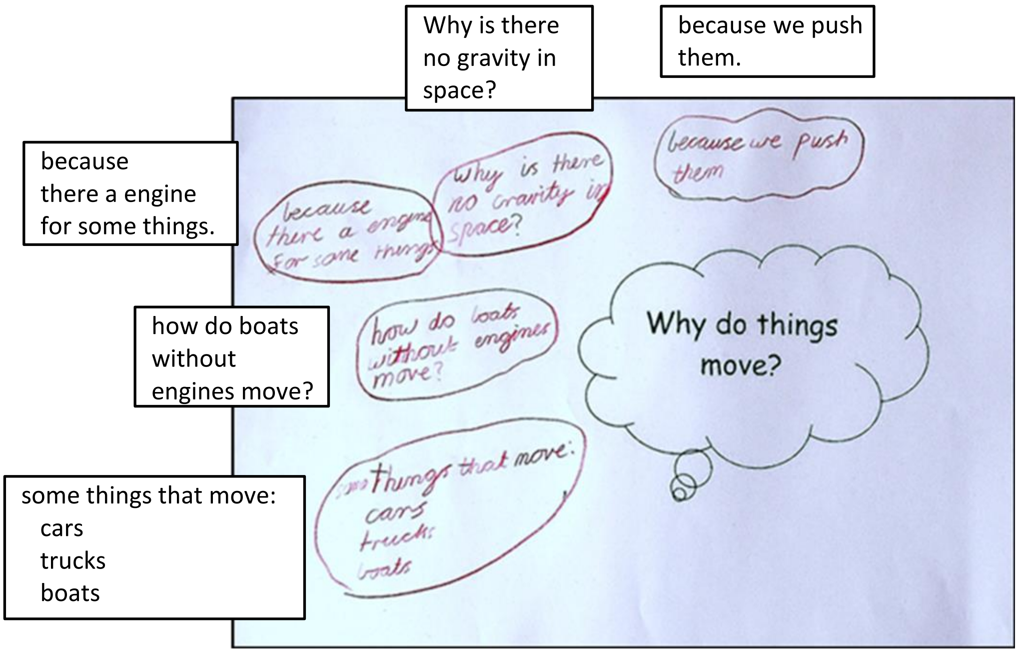



**Figure 5.14: Photograph of Student Josephine's first thinking responses**

Figure 5.14 is a photograph of student Josephine's first thinking. The photograph has been cropped for presentation purposes and Josephine's responses have been transcribed. Notice the variety in Josephine's responses. Some provide answers to the question and start with 'because', some are questions that she wanted answered and one response is a list of things that move.

*Collection of task sheets, sharing thoughts and reporting first thinking*

Following 10 minutes of writing down their thoughts, words and questions, Big picture question task sheets were collected. Students were then given two minutes to tell their partner what they had written, to listen to their partner's response and to prepare their thoughts in case they were asked to report to the class on the main points of what their partner had shared with them.

The collection of the Big picture question task sheets prior to pair and class discussions was a deliberate choice made by Christine and Melanie. Apart from observing and questioning students as they worked, the collection of the students' task sheets allowed Christine and Melanie to monitor and assess students' work. It allowed time for them to review students' prior understanding before the next activity and had the added bonus of giving students' listening, processing, memory and communication skills a workout; a process familiar to students and part of the learning culture within Christine and Melanie's classes.

### ***Second Thinking (Lesson 5)***

Students completed the Big picture question task for a second time during Lesson 5 and recorded their thinking in blue pen. In the context of being a metacognitive scaffold, the purpose of the second thinking was enable students to assess their first thinking notations, to note down what they had learnt since the beginning of the unit and to progress their thinking and learning forward. In line with social semiotic theory, student Suzie's writing of notations (Figure 5.15) scaffolded her thinking and reasoning and demonstrate an increased level of thinking and understanding from first to second thinking and how she used her first thinking as a platform for her second thinking.

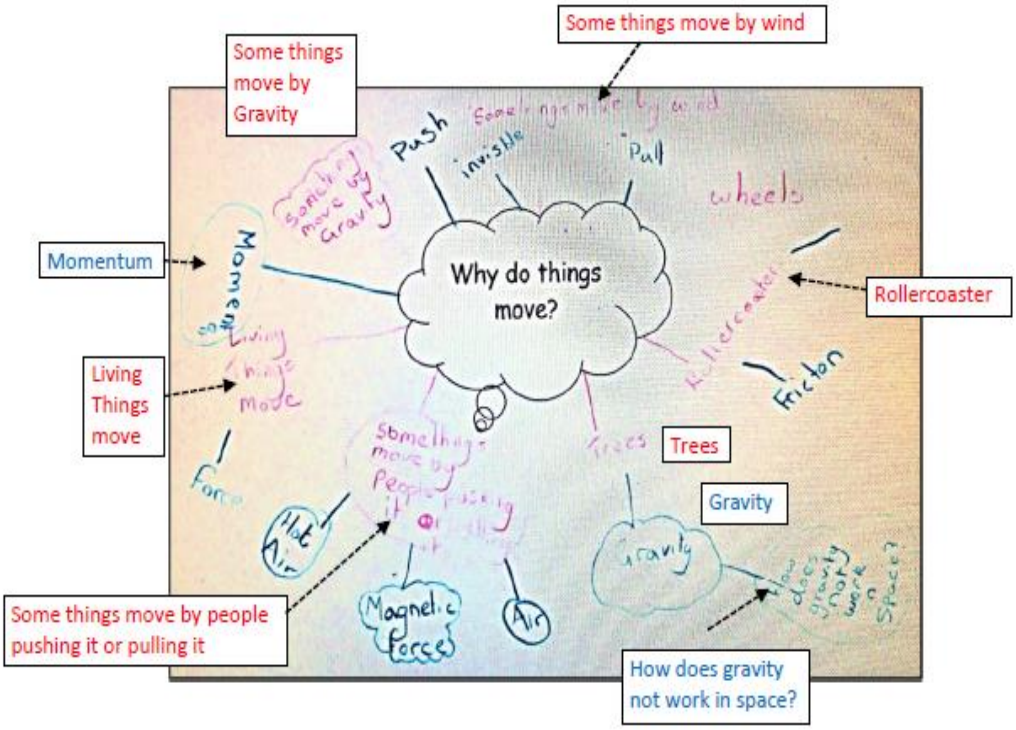



**Figure 5.15: Annotated photograph of after Student Suzie's second thinking writing *(First thinking notations are in red pen and second thinking notations in blue pen.)***

*Recording second thinking, comparing and updating first thinking*

Students were given four minutes to record their second thinking on their original A3 Big picture question task sheet. Teacher Melanie encouraged students to write down (in blue pen) any new information that they had in their head, words, answers to prior questions and new questions they had about why things move. During the second thinking task students were also encouraged to re-read, update and compare their first thinking with their second thinking notations. This process; made easier by notations being in two different coloured pens, reminded students of their prior knowledge and illustrated through their more complex second thinking notations, additional questions and knowledge and use of appropriate science terminology how their thinking and learning had progressed.

*First thinking a platform for second thinking*

For many students, their first thinking notations provided a platform or scaffold for their second thinking and the opportunity to use newly learnt scientific terms. "They went back to a lot of their original ideas and just expanded or elaborated . . . and used the right language that they hadn't been using before (Christine, Post-study interview). For an example, student Suzie; whose task sheet resembled a mind map with her use of lines (Figure 5.15), used her first thinking as a prompt for her second thinking. Typically her second thinking notations expanded upon and identified the type of force alluded to in her first thinking. This is illustrated with a thought sequence in Figures 5.15 highlighted in Figure 5.16. Her notations and connecting lines indicate that she made a connection between the rollercoaster and friction and could label the force with the correct scientific term. The lines and new notations are a graphical representation of Suzie thinking and reasoning as she updates her increase in knowledge.


**Figure 5.16: Second thinking thought sequence where Suzie relates rollercoasters and friction**

*Review of first thinking questions and new questions*

During the second thinking task, Christine and Melanie encouraged students to review whether their first thinking questions had been answered, which questions were still relevant and needed to be answered and to "pop down any questions that you have still in your head that you want answered" (Teacher M, Lesson 5). Christine and Melanie's focus on questions in this context provided a metacognitive scaffold for students. It assisted students to focus and evaluate how their learning had progressed, to extend their thinking, set informal learning goals and to direct their learning towards areas of personal interest.

Having a visual record and reminder of the progression of their thinking on their Big picture question task sheet also allowed students to think more deeply and to ask higher order questions. This is illustrated using another of Suzie's thought sequences in Figure 5.15 and highlighted in Figure 5.17.

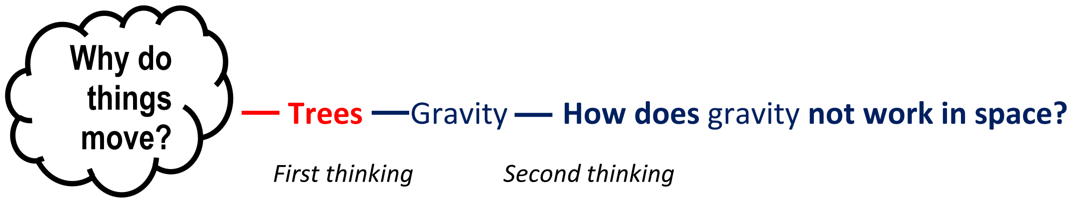



**Figure 5.17: Suzie adds a question about gravity for her second thinking in a thought sequence**

For her first thinking in this particular thought sequence, Suzie wrote 'Trees' and for her second thinking wrote 'Gravity' and the question 'How does gravity not work in space?'. By reviewing Suzie's other thought sequences in Figure 5.15, it can be seen from one of her first thinking notations, that is, 'some things move by gravity' that she had prior knowledge of gravity; albeit limited understanding in the beginning of the topic. Suzie demonstrated a greater understanding of gravity and a deeper level of thinking when she displayed an interest in finding out about the effects of gravity in Space with the question 'How does gravity not work in space?'.

It is interesting to note that Josephine (refer to Figure 5.14) wrote a similar but slightly more simplistic question 'Why is there no gravity in space?' in her first thinking. Josephine's first thinking question indicates that she wanted an explanation to why there is not gravity in space, whereas Suzie's question indicates she wants to gain an understanding of why gravity does not work in space, which is a higher order question.

***Third Thinking (Lesson 8)***

During Lesson 8, students revisited the Big picture question task for the third and final time and recorded their thinking in green pen on the same Big picture question task sheet as their previous *thinking* tasks.

Having the same purpose metacognitively as the second thinking, the third thinking task was to enable students to assess how their thinking and understanding had progressed over the unit. Additionally it was to have students to ask questions and to find areas of interest that would direct their future learning.

Encouraging a greater depth of thinking, Christine and Melanie outlined their expectations for students to use explanations, scientific terms and diagrams in their third thinking responses. They also scaffolded, supported and created opportunities for higher order thinking and scientific reasoning by verbally modelling the level of thinking required for annotations and by providing prompts, hints, comments and asking questions to students.

*Explanations, science words and diagrams with arrows*

Prior to students commencing the third thinking task, students were told that they were required to think deeply and to offer thoughtful explanations with reasons for their responses. They were encouraged to use the science words which had been put up on the Word Wall and to incorporate diagrams; with arrows in their responses, if it helped them to explain their thinking.

*Verbal modelling, scaffolding and recording third thinking responses*

Melanie modelled the complexity of thinking, reasoning and content required in students' third thinking responses. Two students were asked to share with the class what they would write about gravity to answer the big question. In order to draw the level of information required from the students for a model response, Melanie scaffolded their answers by asking clarifying questions until the answer met her expectation. The following section of Lesson 8 transcript illustrates Christine and Melanie's scaffolding and support of students' thinking and reasoning and their expectations for deeper thinking, explanations and the use of science words in third thinking responses.

| | | |
|---|---|---|
| Teacher M: | Okay, so we've had two lots of thinking now. Your first thinking right at the beginning, <u>before we knew anything about forces</u>. We did our second thinking <u>which was about half-way through</u> and <u>now we are coming towards the end.</u> | Teacher linked third thinking to prior thinking tasks |
| Teacher M: | Here's is what I would like to see, what we would like to see in your big question, your **crunchy eyebrows**. We would like to see **lots of words** from the word wall. <u>That doesn't mean you just write them down. That means</u> **you've got to tell us what it's got to do with the big question**. | Teacher expectations:<br>• Deep thinking<br>• Use of science words<br>• Explanations thought about, linked to the big question and to include reasoning. |
| Teacher M: | Gravity for example, **what might I write on my big question that it links to my big question about why do things move?** Student Suzie, what might I write? | Teacher set up the model for the type of response required from the students. |
| Suzie: | That gravity pulls you down. | |
| Teacher M: | Gravity pulls you down towards…? | Teacher scaffolds response by asking for more information. |
| Suzie: | The ground. | |
| Teacher M: | The ground good. Okay Student Peta, put it another way. | Teacher set up another student model. She asked the same question but for an alternate response. |
| Peta: | Um, gravity is the force that holds you on the Earth. | |
| Teacher M: | Fantastic, okay, so **we are looking for explanations, not just words**. We are going to give you six minutes. | Students reminded that they need to think and provide and explanation. |
| Teacher C: | And girls if **you could think of an examples if it makes it easier to explain**. | Teacher provided a hint to support student thinking, i.e. |

| | | |
|---|---|---|
| Teacher M: | Or **include diagrams**. <u>We have done so many this unit</u>. | to think of an example or include a diagram when writing their response. |

*Prompts, hints, comments and questions*

Whilst students were working on their third thinking, Christine and Melanie scaffolded and supported students' responses through prompts, hints, comments, questions and reminders of embodied experiences. Their feedback focussed, extended and helped students by to recall and link prior and new learning, to consolidate and communicate what they had learnt across the topic. This is illustrated in the following comments made by Christine and Melanie to individual students during the writing of their third thinking. Of particular interest were the metacognitive hints that were given to students, which assisted students to access, analyse and communicate their thinking, and also suggestions if students had difficulty remembering things to link it to an embodied experience. For example, if students couldn't think of the correct scientific words to communicate their thinking and learning they could use diagrams and arrows instead or if they were stuck trying to recall what they had learnt about forces to "just think about the things that you picked up and handled and how that links to a force" (Lesson 8). The notes in the right hand column of the following transcript summarise; how Christine and Melanie scaffolded and supported students' responses, and, the main ideas provided to guide students' development of thinking and reasoning skills.

| | |
|---|---|
| <u>Have a look at that</u>, <u>what's that got to do with</u> what we've been learning about? . . . Maybe **re-think it**. | • Identified irrelevant response.<br>• Redirected student's thinking by having them evaluate their response. |
| Looking for **lots of scientific vocabulary**. I've given you one which is gravity, remember **write explanations not just the words**. | • Reminder to incorporate scientific vocabulary in their response.<br>• Reminder that explanations require deeper thinking. |

And again girls if you can't think of the words you can always **draw a little picture to show us**... **arrows** or something in the picture.

- Metacognitive hint that drawing diagrams and arrows can jump start thinking.
- Thinking can be demonstrated in diagrams.

We're really looking for you to **draw on all the science** that we've been doing this term. . . . We want you to focus on **the experiments** that we've been doing this term. The **new words that you've learnt** this term. **All the** force**s** that we've been focussing on this term.

- Answers to questions and solutions to problems can be achieved through a consolidation of learning, e.g. all the forces that have been experimented with across the topic.
- Language (scientific vocabulary) aids the communication of reasoning.

Girls if you're even really really stuck just **think about** the **things that you picked up and handled** and how that links to a force.

- Embodied or hands on experiences can trigger provide a link to our thoughts.

That's good I like that.

- Identified and praised a correct response provides direction for further thinking and learning.

**Have a think** about that one. What does it do? Is it pushing is it pulling, what's it doing. Let's **get really specific** girls.

- Identified areas that need more thought.
- Asked clarification questions to extend thinking.

*Student Janet: Teacher M, you know how there's* gravity *and it's pulling it down I've forgot what the... (student used a pushing up gesture.)*
Teacher M: Air resistance it's called. **Draw a diagram** of it Student Janet.

- Provided the scientific term to assist the student with their explanation.
- Suggestion given to draw their understanding, when they find it difficult to explain it in words.
- Diagrams are alternate way of communicating ideas.

What about those, what do they do? Maybe **draw me a diagram.**

- Focussed student on a salient point.
- Asked an extension question to draw out student's thinking.
- Suggestion to draw their understanding, when they find it difficult to explain it in words.
- Diagrams are an alternate way of communicating ideas.

You've got some fantastic words on that page. Can you tell me more about these? Don't forget

- Praise used to highlight that student is on the right track.

| | |
|---|---|
| girls one of our favourite words is **because**. Fantastic. | • Extension question is asked to deepen thinking.<br>• Explanations need reasons.<br>• Reminder to use 'because' to formulate an explanation with reasoning. |

*Collection of task sheets, sharing and preparing to report*

Following the completion of the students' third thinking task, students' Big picture question task sheets were collected. Students were then asked to turn to their partner and to share three new things that they had written down for their third thinking. As with the first thinking task, students were instructed to listen carefully to their partner's response as they might be asked to report to the class on what their partner had said to them.

A conversation between two students (Student A, Student B), sharing their third thinking with each other, has been included below to illustrate how by verbally sharing one's ideas and listening to another person's ideas helps to scaffold and support students thinking and learning. Not only does verbalisation give students the opportunity to learn from each other's ideas but it assists individuals to process, form, build and back their claims in preparation for and whilst they are speaking. It also has benefits for students in that the practice exercises and thus develops their listening, memorising, thinking, processing and communication skills; all of which are important for higher order thinking and reasoning.

> *Student A*
> I think things move <u>because</u> *maybe* attraction and <u>because</u> they are magnetic <u>because</u> magnets stick together, so they *might* be magnetic. So with magnetic stuff, they *might* touch a magnet and they move. What about you?
>
> *Student B*
> Well I drew a diagram and when we pushed the tomato cans off the table, <u>gravity was pulling</u> them down to the floor when they rolled off the end of the table and that's just my picture. (Lesson 8 transcript)

Student A, for example talked about how the attractive forces of magnets causes things to move. She used the word 'because' in her explanation to link her claim and reasoning. Student A was initially a bit tentative with making her claim, which is illustrated in her explanation by her use of the words *maybe* and *might*; but step by step she built and backed her claim as she speaks. Student B explained to Student A that she drew a diagram to illustrate the force of gravity pulling down on a can of tomatoes when it rolled off a table. This directly relates to the rolling of cans activity in Lesson 2 on *push* and *pull* forces, and the gravity lesson in Lesson 3. Student B's response differed from Student A's response in that there was little verbal backing up of her claim. As Student B chose to use a diagram in her third thinking response, she may have felt more at ease expressing her ideas diagrammatically (as opposed to written and verbal) and thus her reasoning and backing of her claim may have been embedded in her diagram.

Once students had shared their third thinking with their partner, Christine and Melanie extended the discussion and sharing, to the whole class context. A number of students were selected to respond to the question, "Who was your partner and tell me one thing that she told you?" (Lesson 8 transcript). As to be expected from a multi-ability class, the student responses varied in content, complexity, understanding and the amount of cognitive processing involved in its formulation. Six responses have been selected to exemplify students' third thinking responses. When reading these responses, be aware that each response was prefaced with students stating, "My partner was (*student name*) and they told me that . . ."

- **Gravity** <u>pulls you down</u> and it <u>affects you</u>.
- **Magnets** have <u>different types of forces</u>, it <u>depends which poles you use</u>.
- **Gravity** <u>pulls things down</u>.
- **Friction** <u>slows an object down</u>.
- **Different forces** <u>do different things</u>.
- **Gravity** <u>pulls down</u>, **air resistance** <u>pushes up</u>. <u>*If parachutes are bigger they fall slower*</u>.

What is similar of all the six responses, is that they all relate to the effect of a force investigated during the unit. Unlike students' *first* and second thinking they reflect some form of higher order processing, description, understanding and application of the force concept. This demonstrates a shift from lower order recall of concrete and familiar experiences in students' first thinking to higher order thinking and reasoning of an abstract concept in students' third thinking. The force has been bolded and the effect of the force has been underlined to illustrate the complexity of these statements. The last statement, "Gravity pulls down, air resistance pushes up. If parachutes are bigger they fall slower." reflects quite complex student understanding with the referral to the opposing forces of gravity and air resistance and the application of these forces to the size of a parachute and the speed that it falls.

***An example of a completed Big picture question task sheet***

A student's completed task sheet has been included as an overview of the three thinking phases and to illustrate the role of the Big picture question task as a metacognitive tool in the development of students' thinking, reasoning and learning across the unit. Figure 5.18 (transcribed and tabled in Figure 5.19) is a photograph of average ability student Michelle's completed Big picture question task sheet.

Apart from the question 'Why do things move?' and Teacher C's comment, 'Great progression of thinking M. Well done.' all of the annotations on the task sheet are a representation of Michelle's thinking and learning across the unit. Michelle's thinking notations became more refined, complex and aligned with the Forces topic as the unit progressed. Her first thinking was simple and drew from her prior knowledge on *living things,* her second thinking indicated that she was starting to focus on *push* and *pull* forces and her third thinking annotations, which included descriptions of the effects of gravity, friction and magnetism and a diagram with arrows showing the effect of the force of gravity on a stone that was falling towards the ground, demonstrated an increased in higher order thinking and reasoning.

Christine and Melanie in the administration of the three Big picture question thinking tasks, scaffolded, supported and modelled for students, a thinking process that provided students with a framework to think and learn during the unit and into the future.

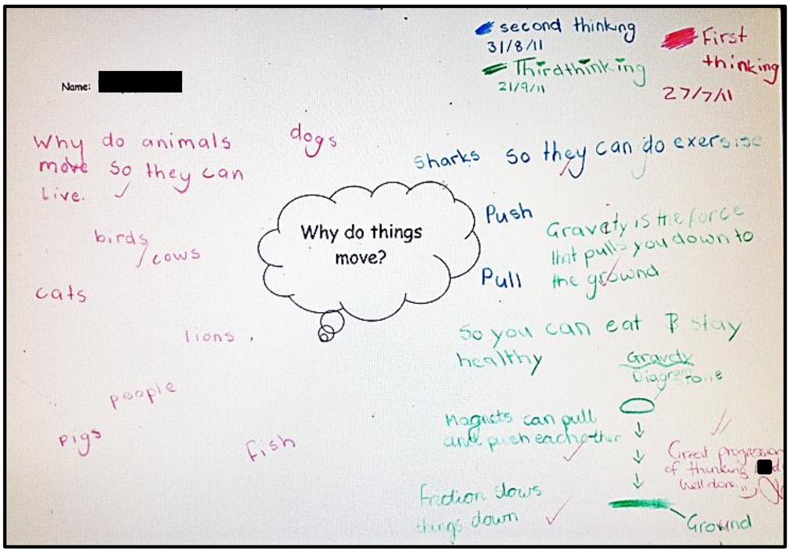



**Figure 5.18: Photograph of Michelle's completed Big picture question task sheet**

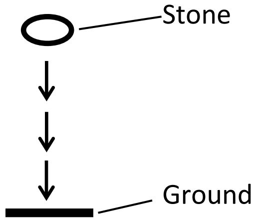
| **First thinking**<br>Lesson 1 *(red pen)* | **Second thinking**<br>Lesson 5 *(blue pen)* | **Third thinking**<br>Lesson 8 *(green pen)* |
|---|---|---|
| • Why do animals move, so they can live?<br>• dogs<br>• cats<br>• bird<br>• cow<br>• lions<br>• people<br>• pigs<br>• fish | • So they can exercise<br>• **Push**[1]<br>• **Pull**<br>• sharks | • Gravity is the force that **pulls** you down to the ground.<br>• So you can eat and stay healthy<br>• **Magnets** can **pull** and **push** each other<br>• Friction **slows** things **down**<br>• <u>Gravity</u> diagram<br><br> |

**Figure 5.19: Transcription of Michelle's Big picture question task sheet comments, [1]*force related words are displayed in bold text***

***Summary of the thinking process established during the Big picture question task***

Christine and Melanie modelled and scaffolded a thinking process during the three thinking phases of the Big picture question and throughout the unit (Figure 5.20).

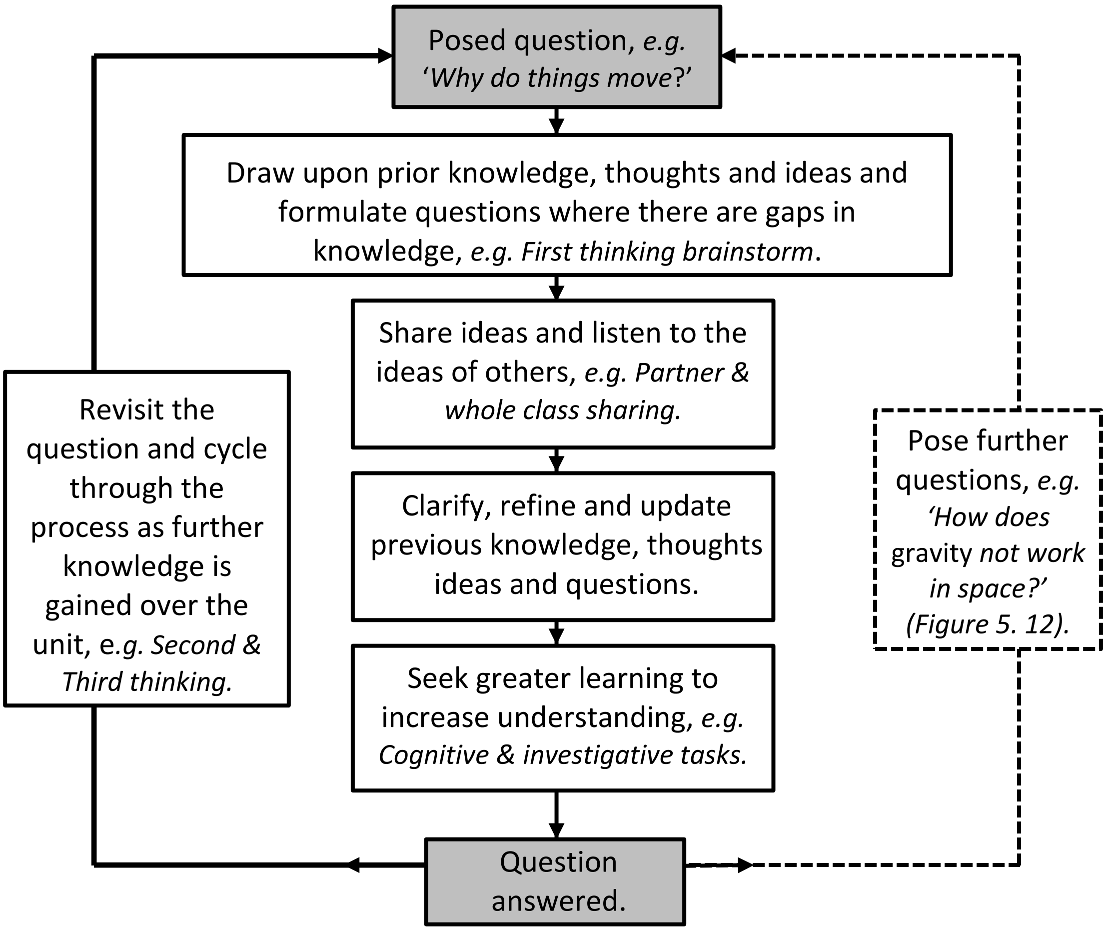



**Figure 5.20: Summary of the thinking process model established during the Big picture question task**

This thinking process; which students were able to follow independently and with less teacher scaffolding and support as the unit progressed, guided and developed students' thinking, reasoning and learning. The process enabled students to build new understanding of Force*s* upon their prior thoughts, ideas and understandings and to apply their newly built knowledge to answer the question. The main tenets of the thinking process (referred to in previous sections: *First thinking*, *Second thinking*, *Third thinking*) involved students drawing upon previous knowledge, thoughts and ideas (e.g. brainstorming during first thinking), formulating questions where there were gaps in knowledge or where interest lay; clarifying, refining, updating thoughts and ideas through sharing and listening to others' points of view; and, seeking and applying increased understanding from cognitive and investigative tasks. The model included a feedback loop, where students revisited the posed question and recycled through the thinking process multiple times (e.g. second and third thinking), to accommodate new learning and understanding gained as the unit progressed.

In conclusion, the Big picture question was a powerful metacognitive tool that enabled students to take ownership and control of their thinking and learning. Through Christine and Melanie's scaffolding and supporting of the task, students became familiar with a process for thinking and learning and the importance of 'knowing what you know' and 'knowing what you don't know' in building one's thinking and understanding. The task involved students thinking, recording and reviewing their thoughts, understandings and questions three times across the unit. Through participating and being guided through the Big picture question task students accessed, identified, worked through, compared, reinforced, updated, communicated and recorded their thoughts, ideas and questions through written notations, diagrams, graphical representations and by verbally sharing with others; all of which are important higher order thinking and reasoning skills.

**Key Finding 5.17**

The Big picture question was a three phased metacognitive and representational tool that scaffolded students' thinking, reasoning and ownership of cognitive development across the unit. Students represented their thinking and reasoning in written word, written questions, diagrams, connecting lines and verbal discussion.

- *First thinking* enabled students to access prior learning, to ask questions about what they wanted to know more about and provided a starting point for teaching and learning.
- *Second thinking* allowed students to see how far they had come in their thinking and learning, which of their questions they had found answers for and the ones that still needed answering. It also indicated to Christine and Melanie how students were progressing at the half-way point of the topic.
- *Third thinking* which was also used an assessment item, allowed both the student and Christine and Melanie to see the depth of knowledge and understanding that each student had gained over the topic.

**Key Finding 5.18**
The Big picture question task supported students' thinking, reasoning and learning across the unit and was also a tangible way for Christine and Melanie to monitor and assess students' work.

As illustrated in this section, an important part of the Big picture question strategy; but not isolated to it, was Christine and Melanie's use of partner work and talk.

**Partner work and partner talk**

Christine and Melanie's belief that talk facilitated thinking, reasoning and learning was made evident by their regular use of partner or pair work and partner talk during lessons. This section highlights how partner work and partner talk was planned for, modelled and used to scaffold, support and create opportunities for higher order thinking and scientific reasoning. It includes discussion on the context and benefits of partner work and talk; informal strategies such as "Turn to your partner and share . . ."; and, more formalised strategies such as Think-pair-share and See-saw strategies. In the context of this Case Study, partner work relates to a designated time during a lesson when students were asked to pair up and to share and discuss their ideas with a partner; and, partner talk relates to both informal non-teacher directed and teacher directed talk between two students.

***Context, use and benefits of partner work***

Partner work was incorporated multiple times into most lessons across the unit (refer back to Figure 5.2). Even though students spent only six per cent of their total class time across the unit involved in partner work or paired activity (PA) (Figure 5.2), the frequency of the use of PA instructional setting across the unit was 25 per cent (other instructional setting use was WCA 51%, SGA 8% and IA 16% (Appendix H). This anomaly was due to paired or partner work being used frequently but for short amounts of time. Quick, short sharp partner discussions were a characteristic particularly of Melanie's teaching (Figures 5.10 and 5.11). When Melanie was the lead teacher, partner work regularly occurred multiple times within lessons, as interjections embedded within whole class discussion or teacher instructional sessions. Their duration was generally under one minute but ranged from between 30 seconds to three minutes (Figures 5.10 and 5.11).

Partner work and partner talk provided many benefits for both the teaching and learning of concepts and the development of thinking and reasoning skills in this Case Study. There were many contexts in which Christine and Melanie used partner work. For example, for introducing, building and reviewing concepts, for emphasising and signposting salient points; and, for pacing, guiding, focusing and assessing students' thinking and learning. Partner work was used in the beginning of a lesson to encourage students to access their knowledge of a topic. As an example, the following text demonstrates how Christine used partner work to start students' thinking on gravity and to provide an anchor point in which to link their new learning.

> Alright girls, we're going to be exploring gravity today. Before we start, I'd like you to do an eye to eye, knee to knee, <u>tell your partner anything that you already know or think you know about gravity</u> (Teacher C, Lesson 3).

In the same lesson (Lesson 3) and two minutes after the previous example, partner work was used to pace and push forward the process of thinking. Students were asked to turn to their partner, and given one minute to make a prediction about would happen to a balloon in a game called *Going up*, where students had to keep the balloon in the air. The focus of partner work in this example; as demonstrated in the following text, was to encourage students to think for themselves and to use their prior knowledge on gravity to think through what might happen to the balloon during the game.

> In a moment you are going to turn to your partner. We're going to make a prediction, okay. You're going to predict <u>what might happen to the balloon if you don't keep it moving during the game</u>, so **you just have to think to yourself first**. Okay, turn and face your partners. (Teacher C, Lesson 3)

A major use of partner work in Christine and Melanie's lessons was for incrementally building students' conceptual understanding. Christine and Melanie strategically orchestrated, selected and sequenced the topics of partner talk to cumulatively build the facets of whole concepts. To illustrate this, refer back to Figure 5.12, to view the steps Christine and Melanie used in Lesson 2 to incrementally build the concept of Momentum. When compared with the graphical representations of Lesson 2 in Figures 5.10 and 5.11, of the amount of time used in the different instructional settings during the lesson, it can be seen that Christine and Melanie's multiple use of partner work or paired activity (PA) supported this.

Using the lenses of social constructivism and distributive cognition the following transcript taken from Lesson 2, demonstrates how Melanie (Teacher M) highlighted to the class a salient point spoken by a student during partner sharing which was integral in the building of the conceptual story on Momentum. This transcript relates to the time when students came back into the classroom; after running down a hill and stopping and walking down a hill and stopping, and were asked to express to their partner what they felt during these two activities (refer to point 3 in Figure 5.12).

| | |
|---|---|
| Teacher M: | **Turn to your partner** answer your first question. |

*Students were given 1.5 minutes to share their answer with their partner.*

| | | |
|---|---|---|
| Teacher M: | This group**, I heard a fantastic idea** from.<br><br><u>Can someone share what your idea was?</u> | Teacher identified the group that the salient point will be drawn from.<br><br>Teacher asked for a student to share the idea with the class. |
| Student: | I thought that it was easier to stop when you were walking <u>because</u> you weren't going as fast and when you were running it was a lot harder to stop <u>because</u> you were running really fast and you had to stop suddenly. | Student shared the idea that the teacher had signposted whilst listening to their partner talk.<br><br>Student used the word *because* to support her claims. |
| Teacher M: | So **what was the rule** that you . . . worked out? | Teacher asked for student to formalise their point into a rule. |
| Student A: | When you are going slow it is easier to stop than when you are going fast. | Student formalises answer into a rule. |
| Teacher M: | Who agrees with that? | Teacher engaged the rest of the class. |

| | |
|---|---|
| From that, when they went faster it was harder to stop, the slower you go the easier it is to stop. | Teacher restated the rule in her own words. |
| **Good we are going to have a look at that now.** | The rule is tested in the following rolling cans of tomatoes activity. |

***Partner work used as a metacognitive scaffold***

Partner work and partner talk provided individual students with the forum to talk through, refine, clarify, elaborate, reform and consolidate their thinking and ideas as they shared their ideas and listened to the ideas of their partner. The verbal sharing of ideas with a partner operated as a cognitive scaffold for students. Students built and developed their thinking as they shared with their partner. Due to the lack of preparation or thinking time given to students prior to this task, processing their thoughts often occurred as students were speaking. This opportunity to ‘thinking out loud’ provided a conduit for students’ to access prior understandings and to clarify and link old and new learning.

***Sharing with a partner: “Turn to your partner and tell what you . . . and why.”***

Partner sharing was part of Christine and Melanie’s learning culture. Students were used to partner sharing their thoughts and ideas with their partner and the requirements associated with these tasks. They knew that they would be asked to share their thoughts with their partner with little or no preparation time, sometimes multiple times throughout teacher instructional sessions and whole class discussions, and therefore they needed to listen carefully and keep themselves engaged and thinking about the topic being discussed. The prefacing phrase, “Turn to your partner and . . .why” provided a metacognitive cue for students’ thinking and learning and caused students to access and appraise what they thought and why they thought it, so that they could share it with their partner. Due to the time constraints and nature of the tasks, students had to access, process and formulate their thoughts ‘on the spot’ in the seconds preceding their sharing, and as they were sharing with their partner. The frequent use of this strategy benefited students by giving them practice to quickly access and process their thoughts and refining their listening skills.

Christine and Melanie's instructions were quite specific as to what students were to share with their partner. For example, in Lesson 4, students were asked to, "Turn to your partner and tell your partner what friction has to do with it and why?" and in Lesson 6, "Turn to your partner and tell them what your hypothesis would be." These examples demonstrate that partner sharing activities included a level of cognitive processing and in Lesson 4's example the expectation to state the reasons to support their claim.

Two specific partner strategies employed by Christine and Melanie to develop students' metacognition and to scaffold and support students' thinking, reasoning and learning were the Think-pair-share and See-saw strategies.

***Think-pair-share strategy, See-saw strategy and signposting***

As with the Big picture question strategy, the Think-pair-share and See-saw strategies afforded students personal accountability for their thinking. Their use were orchestrated by Christine and Melanie across the unit to draw out, structure, develop and consolidate students' thoughts, ideas and learning. Additionally, they were used as a catalyst for extending students' thinking and reasoning. As individual students participated in these strategies and listened to, processed and discussed their ideas with a partner, their thoughts were extended and refined in readiness to share them during class discussions.

| | Learning Activities | Resources | Assessment |
|---|---|---|---|
| Lesson 1 | • Big picture question 1st Thinking: Why do things move? (Red pencil)<br>• **Think-pair-share 1st Thinking (**See-saw**)**<br>• Watch videos and take notes<br>• **Think-pair-share (**See-saw**)**<br>• Create Word Wall | 1. Video: Watch Work and Energy<br>2. ClickView Video: Work and Energy | Diagnostic assessment: 1st Thinking |

**Figure 5.21: Teachers' planning for Lesson 1 highlighting the use of Think-pair-share and See-saw strategies**

Christine and Melanie deliberately planned the use of these strategies (see Figure 5.21 for an example). They were introduced and meticulously modelled in Lesson 1.

The following Lesson 1 transcript illustrates how Christine and Melanie used the two strategies to stimulate, collect and share students' first thoughts on the Big picture question: 'Why do things move?'; and, to pool students' terminology on Force*s* to create a classroom Word Wall (Figure 5.21). Prior to this, students had written their thoughts on *how things move* on their Big picture question sheet (First thinking).

| | | |
|---|---|---|
| Teacher M: | Girls in a moment I am going to ask you to turn, eye to eye, knee to knee with a person around you and you are going to share some of the things that you wrote down in your sheet. | Teacher initiation of the Think-pair-share strategy. |
| Teacher M: | So I am going to go first and **I am going to tell Janet all of my ideas and questions** and all of the fantastic information I wrote down on my big question sheet. **Then Janet would tell me all of her ideas and questions** and all of those fantastic things that she wrote down on her sheet. **Then we are going to come back together and share our information** [with the class] with a bit of a twist. You are not going to share your information. **You are going to share your buddy's information.** What is that telling you that you are going to have to do, very very well when you are working with your partner? | Teacher modelling the See-saw method for reporting.<br><br>Teacher stresses the importance of listening. |
| Student : | Listen | |
| Teacher M: | Eye to eye, knee to knee, off you go. | |
| *(Students are given 5 minutes to share with their partner.)* | | Students listen to and process their partner's ideas |
| Teacher M: | Evie, who was your partner and tell me one thing they told you. | |
| Student Evie: | Angela told me about <u>friction.</u> | |

| | | |
|---|---|---|
| Teacher M: | Friction, okay. **That's a good word**. **I like that word. That might be a new word for some people.** Charlize, what did your partner tell you? | Teacher signposts the word friction. |
| Student Charlize: | Susan told me that magnetic things sometimes make things move. | |
| Teacher M: | Okay, magnetic things make things move. **Fantastic.** | Teacher signposts the idea of and term *magnetic*. |
| Teacher M: | What about the questions? | |
| Student : | My partner was Peta and her questions were, Why do some magnetic things move things away and others not? | Teacher signposts the idea of *repelling as a* force and identified and labelled the student's repel gesture. |
| Teacher M: | You used your hands there. We called that repel, before. **Good questions**. | |
| Student : | What is force? | |
| Teacher M: | **Brilliant question. We might find out the answers to those questions right now.** Mrs C is going to tell you about two videos that we are going to watch. | Teacher signposts the question *what is a* force which leads to the viewing of videos. |

The transcript highlights Melanie's expectation for students to listen well and an explanation of the See-saw *strategy* (illustrated in Figure 5.22); a strategy that structured the process of paired students taking turns; and, gathering and summarising partner ideas in preparation for reporting them to the class.

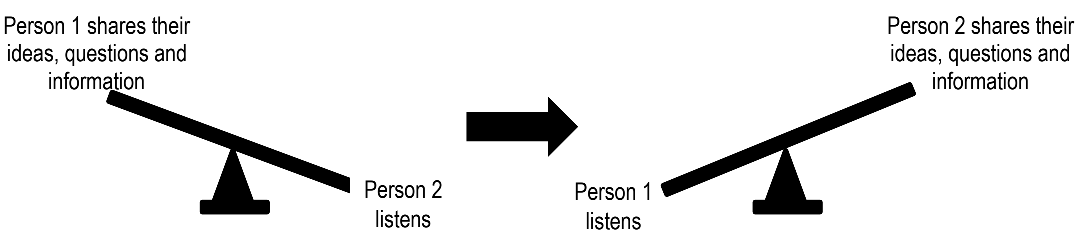



**Figure 5.22: Diagrammatic representation of the See-saw strategy**

Christine and Melanie's process for having students report back on their partners ideas was a significant scaffold for students' higher order thinking and reasoning and will be discussed in detail in the next section. The transcript also highlights Christine and Melanie's use of hints and non-direct feedback (signposts), which are frequently used in lessons across the unit to scaffold and support conceptual and cognitive development. Christine and Melanie's signposts were typically in the form of praise, gesture, repeating back and change of voice intonation. In the Lesson 1 transcript above, Christine and Melanie used the following verbal comments, "That's a good word", "Fantastic" and "Brilliant question" as signposts to highlight conceptually important and relevant student thoughts, ideas and questions.

Additionally, the transcript highlights Melanie's support of students' use of gesture (to be discussed later) and the development of scientific terminology. For example, when student Angela shared her partner's question regarding repelling forces, her response didn't contain the scientific term 'repel'. Instead the student supplemented and accompanied her verbal response of "some magnetic things move things away" with a hand gesture that symbolised repelling. Melanie accepted the answer, identified the student's gesture and enriched students' vocabulary by giving students' the term repel which the class had previously been given to use. Partner work in its many contexts provided many opportunities for Christine and Melanie to scaffold, support and create opportunities for higher order thinking.

**Key Finding 5.19**
Christine and Melanie utilised partner work and talk during the Big picture question task and multiple other times each lesson across the unit. The verbal sharing of personal ideas with a partner, provided students with a process and forum to learn from others and to access, process, review and extend their conceptual learning, thinking and reasoning. Partner work was used for introducing, building and reviewing concepts, for emphasising and signposting salient points; and, for pacing, guiding, focusing and assessing students' thinking and learning. The Think-pair-share and See-saw strategies were formalised types of partner work frequently used by Christine and Melanie in their teaching.

Another significant strategy Christine and Melanie employed to further extend students' thinking and reasoning through the working with a partner was the process of reporting back.

***Reporting back strategy***

A follow-on from students sharing and discussing their ideas with a partner was the process of reporting back to the class what has been shared and discussed. Christine and Melanie used reporting as a strategy for extending students' level of thinking and understanding across the Force*s* topic. Opportunities for students to share and report back on someone else's ideas and questions, increased students' exposure to different ideas. Reporting was a valuable strategy used by Christine and Melanie, which provided them with feedback on where students were at in their learning and for mentally challenging and extending students' thinking, learning and understanding.

*A complex set of steps and processes*

Christine and Melanie's belief that students learn by listening to and discussing with others is evident in their practice of having students report back to the class what their partner has shared with them during think, pair, share partner discussions. During each lesson across the topic (refer to Figure 5.3) students participated in Think-pair-share activities. On most of these occasions students were geared up or pre-warned by their teachers that they might be asked to report back to the class, something that their partner had shared with them. This served several purposes. Due to the large size of the class it kept the majority of students engaged and on task because they knew they might be called on to share a report. This strategy also provided the opportunity to showcase a number of student ideas, but mostly, it extended students' thinking.

Christine and Melanie extended students thinking, learning and processing of ideas by setting up situations where students had to verbally report on what their partner had shared with them. An example of this is in Lesson 1 when students were asked to prepare a report (in their head), for the class on how their partner responded to the Big picture question, 'Why do things move?'. These types of activities not only helped students expand their knowledge but helped them to practice and develop higher order processing, analytical and communication skills. Figure 5.23 describes eight cognitive/process steps that Christine and Melanie's students worked through; from verbally sharing their own response to preparing and verbally presenting a summary of their partner's responses.

| Steps | Cognitive processes | Description of task |
|---|---|---|
| 1. | Recall | Remember their thoughts and what they wrote on their Big picture question sheet. |
| 2. | Prioritise<br>Summarise<br>Condense | Condense their 10 minutes worth of thoughts and work on the task to a less than 1 minute report. |
| 3. | Verbalise | Report to a partner what they wrote. |
| 4. | Listen<br>Pay<br>Attention | Listen to start to interpret their partner's report. |
| 5. | Understand<br>Analyse | Compare and make sense of what their partner has said. |
| 6. | Prioritise<br>Summarise<br>Condense | Select which of their partner's main points to report to the class. |
| 7. | Translate | Put their partner's points that they have selected to report, into their own words. |
| 8. | Verbalise | Report on their partner's response to the Big picture question. |

**Figure 5.23: Cognitive steps and processes involved in students sharing and then reporting on their partners' responses to 'Why do things move?' during Lesson 1**

The cognitive processes relating to students sharing their own responses with a partner included: recalling, prioritising, summarising, condensing and verbalising; followed by: listening, paying attention, understanding, analysing, prioritising, summarising, condensing, translating, prior to verbalising a report of their partner's ideas. Students were not allowed to refer to notes for these tasks. They were mental tasks and required concentration and analysis. They had to listen well, rely on their memory; and mentally process what their partner had said, and then wait to see if they were selected to report on their partner's answers to the class. This would be a challenge for most students their age (and many adults) but the students in Christine and Melanie's class were confident and practiced in this level of thinking, processing and responding in this manner.

As previously mentioned, students were given a 10 minute session to complete their individual Big picture question sheet, their sheets were collected and students were given two minutes to share what that had written on their sheets. As highlighted by Melanie, the shortness of time given to students to share their ideas, listen to their partner's idea and prepare what they could report of their partner's ideas indicated to students that only a summary of the main points were required. During this time students had to share, listen and prepare a report in their head. Melanie pointed to various individuals to report. She asked, "Who was your partner and what did she tell you?" The following responses were given:

Student Suzie said magnetic things make things move.
My partner said that some man-made things move.
My partner told me that forces and gravity move.
My partner, told me that some things don't move - they are stuck to the ground.

Students were then asked about the questions that their partners had shared with them and the following questions were shared.

Why do planes move?
Why do some magnetic things move things away and others not.
Why do people move?
How do boats move when an engine isn't on?
What is force?

Reporting strategies were frequently used in Christine and Melanie's combined and individual classes. As a consequence of this, and the safe environment and collaborative culture established in Christine and Melanie's class, students were very comfortable sharing and discussing and having their thoughts and ideas reported, and discussed by others in front of the class. Students were active participants in their own learning and knew that thinking, sharing, discussion and reporting was a part of the learning process in Christine and Melanie's classes.

**Key Finding 5.20**
Reporting back on someone else's thoughts was a prominent strategy in Christine and Melanie's teaching. Reporting back was a verbal representational challenge that enabled students to review their prior knowledge, to ask themselves questions, to learn from others and to extend their thinking. Through sharing and reporting activities students developed listening, memorising, thinking, processing and communication skills; all of which are important for higher order thinking and reasoning.

**Investigation planners promote thinking and reasoning through inquiry**

During the Forc*es* unit, investigation planners were used as graphical organisers and as frameworks or metacognitive scaffolds for the process of inquiry. They were a metacognitive tool because they modelled and helped students to internalise the thinking processes required to go through when approaching an investigation, for instance: planning, conducting, analysing, evaluating and communicating.

An essential part of students being self-sufficient and creative learners is their ability to investigate and to find solutions to problems. Throughout the unit, Christine and Melanie focused on developing students' ability to design, conduct and report on fair test investigations using an inquiry approach. The steps of the approach to inquiry adopted by Christine and Melanie during the topic were:

1. Ask a question
2. Discuss what we know already or do some background research
3. Formulate and write a hypothesis
4. Design, test and carry out an investigation to test the hypothesis
5. Analyse results
6. Make conclusions
7. Identify if hypothesis is supported or rejected
8. Communicate results written (and/or diagrammatically) and verbally

Christine and Melanie used investigation planners from the *Primary Connections* unit *Smooth moves*, Stage 2, Energy and Change (https://www.primaryconnections.org.au/curriculum-resource/smooth-moves) to scaffold and support students' investigations. The planners supported their inquiry approach and used the following headings and questions that guided students' investigations and scientific thinking and reasoning:

1. What are you going to investigate? (Can you write it as a question?)
2. What do you predict will happened? Why? (Give scientific explanations for your prediction i.e., hypothesise.)
3. What things are you going to change (Change only one thing.), measure/observe, and keep the same to make this a fair test?
4. What equipment do you need?
5. Describe how you will set up your investigation (Use a drawing if necessary.)
6. Write and draw your observations.
7. Write your conclusions. (Refer back to your prediction.)
8. Was your hypothesis correct or not and why?

Following their general trend of decreasing their level of scaffolding and support as students' skills increased, which is referred to as fading in the cognitive apprenticeship model (Woolley & Jarvis, 2007) (Figure 5.7), Christine and Melanie reduced the time they spent going through, prompting and explaining each step on the planners as students became more proficient and self-sufficient in adopting this process. This was evident with the greatest support and scaffolding given to students during the Explore and Explain lessons (Lessons 2 – 5) and the amount of support tapering off during the Elaborate lessons (Lessons 6 and 7) and further with the Evaluation lesson (Lesson 8).

The formalised teaching of scientific methods of inquiry was initiated during Lesson 4 on friction, when students were asked to make a prediction about what would happen if they wore rubber washing-up gloves during a Tug of War activity (Figure 5.27). Christine and Melanie emphasised to students that they needed to give reasons in the form of scientific explanations for their prediction and used the prompt "I predict that . . . because" to scaffold students' predictions and their scientific justification of those predictions. This encouraged students to think deeply not only about the investigation but what they already knew. Students were also questioned in regards to variables and the importance of controlling them during a fair test investigation. It was not until Lesson 5 on magnetism, however, that students were given a blank investigation planner to fill out. Students were given the challenge to investigate how they could move a miniature car without touching it. Whilst the design of the investigation was left up to each small work group, Melanie modelled how to complete each step of the investigation planner on her own planner, which was projected on the IWB, before students were allowed to fill in their own. This was quite a lengthy process as each individual step was modelled firstly by Melanie prior to students being allowed to complete that step on their individual planners. Being left to play with the resources supplied (miniature cars, bar magnets and elastic bands), students investigated ways of moving their car using magnets. Melanie commented that it was important not to lead students in the design of the investigation.

> I didn't want to lead them too much because then we'll be taking away some aspects of the learning, just telling them to do it and then they do it, but they really had to think about how they were going to do, go about doing it and why they were going to do it and a lot of them actually did the experiment differently to how we had envisaged (Lesson 5, Post-lesson discussion)

The degree of teacher scaffolding and support given to students was noticeably less in Lesson 6. Students were given the same planner template as used in previous lessons as a scaffold to plan, conduct, analyse and make conclusions from their investigation. The difference in this lesson from the preceding one is that there was not the start-stop step by step modelling from Christine or Melanie.

In Lesson 6, students worked in small groups to design (using the provided resources) and conduct a fair test investigation to examine the effect of mass on the speed on a small toy car rolling down a ramp. This particular investigation was more complex and challenging than the one in the previous lesson and required students to think more deeply and to reason as they incorporated their previously taught concepts and knowledge of push, pull and gravity into their design. Christine and Melanie provided some guidance as they moved between groups during the design phase of the investigation and assisted students when they requested help with completing their investigation planner.

For Lesson 7 students were given a blank investigation planner, materials and the question "Does the size of a parachute affect the speed it falls?" to investigate. The only support students were given in the design of this investigation was instruction on how to make a parachute out of the materials supplied. By Lesson 8, the amount of scaffolding of the investigative process provided by Christine of Melanie had decreased to a point where students working in small groups were given an open task, complete autonomy to design (having access to a wide range of resources) their own investigation and weren't required to use a formalised investigation planner. The challenge involved making and demonstrating a game that incorporated at least three different forces.

The open and unscaffolded investigation gave students the opportunity to not only recall and utilise their knowledge of the forces which had been taught during the topic but to apply and use their knowledge in a creative way to design, make, demonstrate and communicate how their game worked and the forces at play that made their game work.

**Key Finding 5.21**
Investigation planners were used as graphical organisers and a metacognitive scaffold for the process of inquiry. Investigation planners together with Christine and Melanie's reminders helped students to internalise the thinking steps required when approaching an investigation. Formulating hypotheses' and deciding whether then were accepted or rejected required reasoning. Teacher scaffolding and the use of the formalised investigation planners was decreased, and the openness of the investigations were increased, as the unit progressed.

Christine and Melanie's teaching featured three metacognitive scaffolds that scaffolded, supported and created opportunities for higher order thinking and scientific reasoning. The Big picture question was used across the unit to help students to identify and progress their thinking as their conceptual knowledge increased. Partner work and talk provided a forum for students to identify, share their thoughts and develop their thoughts further through listening and discussing with others. Investigation planners provided a formalised process for students to follow that scaffolded their approach to inquiry when conducting investigations.

**Verbal scaffolds**

As previously discussed talk and discussion were prominent features in Christine and Melanie's lessons. When guiding students' thinking and reasoning during these occasions, Christine and Melanie often used verbal prompts like "because…" and

"Why?" and asked students well thoughts out questions that scaffolded, supported and created opportunities for thinking and reasoning.

***Because and why?***

During instructional times, discussions and when providing feedback on student answers, Christine and Melanie often responded with "because…" and "why?" to remind, prompt and scaffold students to give reasons for their claims. When students didn't provide reasons, Christine and Melanie's response of "because…" acted as a syntactical scaffold (Hackling & Sherriff, 2015) to prompt students to access their thinking and to complete the sentence so that it became a fully justified response.

To emphasise the importance of providing reasons, Christine and Melanie would also ask students to make sure they commence their response with "Because". Christine and Melanie's instructive talk in Lesson 2, which was aimed at having students think and then to give reasons regarding how and why they felt a particular way when they ran down the hill and stopped, illustrate these. Christine and Melanie verbally emphasised the words 'why' and 'because' in their instructions by stating them with more force and by pointing to them in the questions displayed on the white board.

| | |
|---|---|
| Christine: | Okay girls, you are going now turn to your partner, . . . and you are going to talk about what you did, what did you feel when you were running and what did you feel when you were walking and was it easier to stop running or was it easier to stop after walking **and why? <u>Why you think</u> <u>whichever way you think it was</u>?** |
| Melanie: | One of my favourite words is that one and **why**. (Melanie pointed to 'why' in the question written on the white board.) |
| Christine: | **Why**. Is it is a great, great word, that one. |
| Melanie: | . . . and **because**. **Why** and **because**. . . . Was it easier to stop running or walking? Put your hand up if it was easier for you to stop running. Hand up if it was easier for you to stop walking. That's a very overwhelming majority. **Why? <u>You must start your sentence with because</u>**. . . . This group I heard a fantastic idea from. Can someone share what your idea was? |
| Student: | **Because** I thought that it was easier to stop when you were walking **because** you weren't going as fast and when you were running it was a lot harder to stop **because** you were running really fast and you had to stop suddenly. |

The students' response in this example demonstrates how the student understood that they had to use the word 'because' to justify their claim. Their response as requested commenced with "Because…", and the students also used 'because' two more times: to link her claim and justification and to back up her justification with more reasons. Christine and Melanie also scaffolded students' higher order thinking and reasoning by asking questions.

***Open questions***

Christine and Melanie also asked opened ended questions that promoted creativity, critical thinking and reasoning. They posed questions that encouraged students to reflect on their own and the thinking of others. They used questions and comments like "Why?", "Tell me more.", "What is another way?", "What did you think about . . .?" and "What did your partner think about . . .?" when teasing out students' ideas and thoughts particularly during investigations.

Their verbal questioning and feedback process was sometimes quite extended; they would ask a question, wait for a response, repeat back the response and couple this with another question to have students think more deeply.

From the perspectives of sociocultural and social semiotic theories and distributed cognition, the following transcript from the introduction and design phase of the rolling cans of tomatoes activity (Lesson 2), illustrates how Christine and Melanie used a variety of open questions to draw out and extend students' thinking, reasoning and understanding.

| | | |
|---|---|---|
| Teacher C: | Different sized push and pull. What does that mean? What is a different size push and pull? | Teacher asked clarification questions to ascertain if students understand the conceptual background to the task. |
| Student: | When you push it can be gentle. | |
| Teacher C: | Okay, so a gentle push? | Teacher waits for more explanation and then repeats the answer to extend student's thinking. |
| Student: | Yes | |

| | | |
|---|---|---|
| Teacher C: | Yes? | Answer is repeated to tease out more information. |
| Student: | When you pull, you pull really hard and you . . . | Student finds it difficult to explain. |
| Teacher C: | Okay, so we can have a soft pull and a soft push, okay. What else could we have? What other different pushes and pulls could we have? | Teacher waits and then scaffolds student's answer with further questions. |
| Student: | You could have a really strong push and a really strong pull. | Student responds after thinking more deeply with different sized push and pull forces. |
| Teacher M: | What flat surfaces do we have around here that you could use? | |
| Student: | The lino. | |
| Teacher M: | The lino. Yes, what else? | Teacher repeats the answer signalling to students that is one answer. She asks for alternate answers which requires further thinking. |
| Student: | The carpet. | |
| Teacher M: | What are we thinking about the carpet? | Teacher prompts for more depth of thinking from students with her question. |
| Students: | No. | Student response with no justification. |
| Teacher C: | It's a flat surface, what's interesting about the carpet though? | Teacher asks another question for students to justify their response. |
| Student: | It doesn't really roll. It's a bit rough. | Student justify answer. |

Christine and Melanie also used questions projected on the white board to scaffold and support thinking and reasoning during and at the end of lessons. The questions in Figure 5.24 illustrate the reflective type of higher order questions used at the conclusion of Lesson 2.

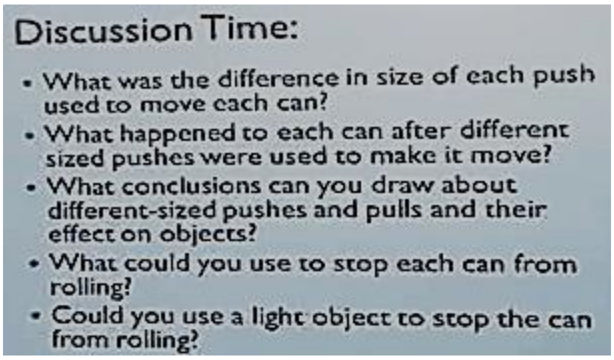



**Figure 5.24: Questions projected on the board at the end of Lesson 2 on Momentum**

In these questions students were asked to recall, compare, draw conclusions from, predict and apply their newly gained knowledge on the effects of different sized forces on moving objects. Students first discussed them with a partner before the discussion was opened up to the whole class. The questions were sequenced so that the level of thought and reasoning required from students increased with each question. During whole class discussions, when students were having difficulty answering the set questions, Christine and Melanie scaffolded students' answers by adding additional questions so that the cognitive load was broken down and was more manageable for students.

**Key Finding 5.22**
Christine and Melanie used a variety of question types to scaffold and support student's thinking and reasoning skills. Teacher initiated prompts, questions and comments like "Because…?""Why?", "Tell me more.", "What is another way?", "What did you think about . . .?" and "What did your partner think about . . .?" teased out students' ideas and thoughts particularly during investigations which assisted with justification of ideas and the formulation of arguments.

**Embodiment and embodied experiences**

A feature of Christine and Melanie's teaching was their highly embodied approach to teaching and learning and their use of embodiment and embodied experiences to scaffold, support and create opportunities for higher order thinking and reasoning. Embodiment was incorporated multiple times into each lesson. For this study the terms embodiment and embodied experiences refer to the use of the body or part of the body to experience a phenomenon. This also includes gestures where the body or part of the body is used as a symbol to communicate meaning.

***Types of embodied experiences***

From a social semiotic perspective it was evident that Christine and Melanie incorporated a range of embodied experiences into their lessons to scaffold, support and create opportunities for thinking and reasoning. They used real time, recalled, observed, mirrored or copied, imagined embodied experiences, role play, gesture and object manipulations as a basis for conceptual development and the development of students' thinking and reasoning. Figure 5.25 characterises and exemplifies these different types of embodied experiences incorporated into lessons. Photographs have been included (Figures 5.26 – 5.32) to demonstrate examples of situations where embodiment was used by Christine and Melanie during activities.

| **Type of embodied experience** | **Examples showing the intent of the embodied experience** |
|---|---|
| Real time | Running then walking down a hill and coming to an abrupt stop to feel different sized forces of momentum (Lesson 2) (Figure 5.27 and 5.28). |
| Re-enacted | Role playing pushing a full then an empty shopping trolley up and down a ramp to recall how mass affects the speed of objects (Lesson 6). |
| Recalled | Recalling the feeling of forces of attraction and repelling felt during the previous topic on Magnetism (Lesson 5). |
| Observed | Slamming the brakes on in the car (Lesson 2). |
| Mirrored or copied | Copying teacher's gesture of rolling hands around each other at different speeds to symbolise different amounts of momentum (Lesson 3). |
| Imagined | Riding a bicycle in sand and on ice to conceptualise friction (Lesson 3). |
| Role play | Drinking choc milk in space with no gravity (Lesson 3). |
| Gesture | Pull down gesture communicating the pull force towards the Earth of gravity (Lessons 3, 6, 7 and 8) (Figure 5.29 and 5.30) and two fist gestures symbolising the North and South polar magnetic forces of attraction and repelling (Lessons 5 and 8) (Figure 5. 31 and 5.32). |
| Object manipulation | Making different sized parachutes from plastic bags, dropping them from a height to observe the effect of gravity and air resistance (Lesson 7). |

**Figure 5.25: Types of embodied experiences incorporated into lessons**

**Figure 5.26: Students running down a hill and stopping**

**Figure 5.27: Students walking down a hill and stopping**

**Figure 5.28: Melanie highlighted a student's pull down gesture**

**Figure 5.29: Christine reinforced pull down gesture**

**Key Finding 5.23**
A feature of Christine and Melanie's teaching was their use of embodiment. Christine and Melanie's lessons were highly embodied and each lesson had some form of embodiment incorporated into it. Embodied representations were used to engage students and provide a platform for conceptual development and a basis for thinking and reasoning.

***Affordances of embodiment and embodied experiences***

Christine and Melanie utilised embodiment and embodied experiences during lessons to provide a context for students to talk about and to build conceptual understanding, thinking and reasoning; to make the abstract force concepts accessible, to engage students' interest, for hands-on exploration by physically engaging students into their learning, as a memory hook to recall prior knowledge and ideas, as a semiotic tool for making meaning and as a form of and promoter of communication. An overview of these and the context of how they scaffolded, supported and created opportunities for general and higher order thinking and reasoning follows.

1. *To introduce, explore, review, build, rein*force*, link to real life situations, consolidate, and apply their knowledge of concepts.*

For example, students running then walking down a hill and coming to sudden stop (Figures 5.26 and 5.27) was foundational in introducing the existence of forces, students rubbing their hands together was used to introduce friction and role playing how their parents would slam on the car brakes when travelling fast consolidated students' understanding of the relationship between speed and momentum.

2. *Render abstract and difficult concepts accessible to students of all abilities.*

Abstract concepts are often difficult to access and understand. Christine and Melanie often preceded the building of conceptual understanding of the main force concepts with students first using their body to experience the phenomenon.

3. *For engaging students' interest and for kick starting students' thinking and reasoning.*

In Lesson 4 students played Tug of War (Figure 5.30) with and without wearing rubber washing up gloves to experienced different levels of friction.

**Figure 5.30: Students playing Tug of War to feel the effect of friction**

4. *Catalyst for remembering conceptual understanding and for solving problems.*

Christine and Melanie used gestures and embodied experiences to cue, trigger and to activate students' recall of stored conceptual understanding from their episodic memory. Recall was enhanced when connected to physical experiences. For example when Melanie required students to recall their understanding of magnetic forces of attraction and repulsion she used the same two fist gestures that had been used when magnetism was taught in a previous topic.

Figures 5.31 and 5.32 illustrate Melanie using the two fist gestures. The two fists represented two magnets, the two thumbs represented the North pole and the two 'pinkie' fingers represented the South pole. Students had to simulate the forces of repulsion and attraction through the orientation of their two fists.

**Figure 5.31: Melanie and students gesturing that opposite poles of magnets attract**

**Figure 5.32: Melanie and students gesturing that like poles repel**

Another example of when embodied experiences and gestures were used to trigger recall was in Lesson 8, for the final assessment task. Students were required to draw upon their understanding of all of the forces covered in the topic to complete the open task. Prior to the task Christine and Melanie conducted a physical review of the embodied experiences, gestures, object manipulations and role plays associated with each of the concepts. The recalling of embodied experiences and conceptual understanding attached to those memories, allowed students to demonstrate their innovation and creativity as they showcased to the class how they designed, made, played and identified the three forces at play in their game.

5. *Promote communication and sharing.*

Embodied experiences provided a context for students to share, discuss and build their understanding with others.

6. *Assist with communication when students don't have the language to express themselves adequately.*

For example in Lesson 2, when a student was asked what she felt when she was running down the hill and coming to a sudden stop, she started to explain but had difficulty expressing the feeling. She finished her answer off with an embodied action.

| | |
|---|---|
| Student Courtney: | When I was running, I was running as fast as I could and when I stopped my feet stopped except it was hard for me... |
| | *[Courtney completed her answer with pushing her body forward simulating the stopping action she experienced]* |
| Teacher Melanie: | Your body kept going. Who had a bit of this happening? |
| | *[Melanie leant forward and arms held out to the side simulating stopping fast at a line]* |

7. *Provide succinct ways to communicate and represent conceptual knowledge and ideas.*

The symbolic and representational nature of gestures and embodied experiences also provided a quicker, more succinct way of communicating about concepts. For example the student initiated pull down gesture (Figure 5. 29 and 5.30), was adopted by both teachers and the rest of the class as a quicker way to communicate that gravity is a pull down force. Similarly the two fist gestures (Figures 5.31 and 5.32) previously referred to and used by Melanie to revise the laws of attraction and repulsion, were used as a succinct way to communicate the behaviour of magnetic forces throughout the topic.

8. *Semiotic tools to help link facets of concepts for making meaning.*

In the early Explore and Explain lessons Christine and Melanie adopted some conceptual based gestures to complement their verbal scaffolding of concepts. The push (Figures 5.26, 5.33 and 5.35) and pull down gestures (Figures 5.27, 5.28 and 5.34) for example were adopted in Lesson 1 and Lesson 3 respectively. These gestures were used throughout the unit by Christine and Melanie to review, prompt students' memory and to link facets of concepts to build students' understanding of whole concepts. They helped Christine and Melanie remind students; without a lot of talk, of the foundational principle of the unit, that all forces are either push or pulls. It is interesting to note that whilst students did initiate their own embodied examples to show their understanding, it was not until Lesson 6 and Lesson 7 (Elaborate lessons) that students started to use the push and pull gestures in their conversations without being prompted by Christine and Melanie. They were using them for communicating their ideas with others and in the formation of reasoning during the investigative challenges given to students in Lessons 6, 7 and the Evaluation lesson, Lesson 8.

**Figure 5.33: Student initiated push gesture**

**Figure 5.34: Student initiated pull down gesture**

***Implementation of embodiment and embodied experiences into lessons***

Christine and Melanie's implementation of embodiment and embodied experiences into lessons followed a general pattern.

1. Verbally prompting of embodied experience
2. Student formulation and demonstration of embodied experience
3. Debrief of embodied experience – students' feelings and thoughts
4. Transfer of salient points to other representations
5. Referring back to previous embodied experiences

***"Show me . . ." a prompt and verbal stimulus for thinking***

The verbal prompt "Show me . . ." was regularly used by Christine and Melanie to have students demonstrate an action, concept, idea or scenario with their whole or part of their body. The words "Show me" like the prompt previously discussed "Turn to your partner and . . .why" also acted as a stimulus for students to access their prior knowledge and to kick start and focus their thinking. Apart from situations where students mirrored the actions of the teachers or students copied the actions of peers, most embodiment requests to students required a level of thinking. Students drew upon their previous experiences, knowledge, imagination and thinking to formulate and enact embodiment action requests.

In the beginning of Lesson 2, Melanie prepared students' conceptual development of momentum by reviewing students' thoughts on push and pull, which had been introduced in the previous lesson. She lead students through a series of embodied actions that involved push and pull forces. Each request was prefaced with "Show me" and was followed by a request to show either the push or pull action associated with various physical tasks. The following section of text illustrates Melanie's use of "Show me". Words have been bolded to show emphasis in Melanie's speech.

> **Show me** that you are **pushing** your hands both together, . . . **show me** your right hand **pulling** your left hand, . . . **show me very gently pushing** the shoulder of the person next to you, **very gently**, . . . **show me very gently pulling** that person towards you, . . . **show me** pushing a **big boulder** and moving it, . . . **show me** pulling in a fishing net. (Melanie, Episode 1, Lesson 2 transcript)

What was also illustrated in this example is that requests for students to demonstrate an embodied experience were not singular events. They occurred in multiples or bundles to give students a selection of experiences to relate to and to practice with. The multiple tasks in the previous example created for students a physical memory that forces were either push or pulls.

***Modelling of embodied experiences***

As embodiment was an integral part of Christine and Melanie's instructional approach and formed the basis for students' understanding of particular concepts, they ensured that all students were afforded the information from the experience that was required. They did this by modelling embodiment experiences in front of students which supported those may not have been familiar with or lacked confidence in demonstrating what was requested.

Christine and Melanie also added sound effects to their modelled actions which added interest and reality and cued students to the amount of force associated with the embodied task. Having this information gave students a more complete experience to build understanding of the concept being taught. In turn this enabled students to think about and represent the concept in additional ways and apply what they had experienced to new situations.

**Figure 5.35: Melanie modelling in front of students the pushing a big boulder and moving it**

An example of Melanie modelling the amount of push force required to move a big boulder is illustrated in Figure 5.35. During her modelling she demonstrated the huge effort required to push the rock with her voice. The photo also illustrates her students using her same action.

***Debriefing of an embodied experience***

An important observation when analysing Christine and Melanie's lessons was that they debriefed embodied experiences immediately following the experience. Christine and Melanie assisted students to translate their physical experiences directly into words by having them talk and discuss their experience with a partner and then with the whole class. This required students to think and to access the memory of the felt experience and to re-represent it verbally. Access to their thoughts, promotion of talk and the drawing out of salient points; leading to the building of the conceptual story, was stimulated by carefully selected and sequenced focus questions which were projected on the white board (for example, Figure 5.24).

### ***Referring back to embodied experiences***

Christine and Melanie often referred back to embodied experiences regularly over the unit to scaffold the building of more complex science ideas. For example, recognising that students were having difficulty with the abstract cognitive demand of the request to formulate a prediction for 'how mass affects the speed of an object' for their investigative task in Lesson 6, Christine and Melanie referred students back to the embodiment examples in Lesson 2. Extending those examples, and to relate more to the investigative task students were then asked to role play what it would be like to push a heavily laden and then an empty shopping trolley up and down a ramp. The recall and memory of the embodied experience from Lesson 2 and the science ideas translated from that experience; that forces can be felt and can vary in size and the greater the force the harder it is to stop provided a link and basis on which students could build new understanding of the phenomenon being investigated.

The use of embodiment and embodied experiences was a signature pedagogy of Christine and Melanie's teaching. Embodied experiences provided a basis for students' conceptual development and thinking and reasoning (Figure 5.23). Christine and Melanie scaffolded and supported students' thinking and reasoning through prompts such as "Show me", modelling, debriefing and referring back to embodied experiences. Christine and Melanie used embodied experiences to introduce students to the unit's abstract force concepts, to assist students' recall of episodic memory which was used as a platform for building further understanding and a way of communicating when language was not so accessible to students.

**Key Finding 5.24**
Christine and Melanie used embodiment and embodied experiences to: introduce, engage with, explore, review, build, reinforce, link to real life situations, consolidate, represent conceptual knowledge and ideas and apply their knowledge of concepts. They were also used to: render abstract and difficult concepts accessible to students of all abilities, as a catalyst for remembering conceptual understanding and for solving problems, to promote and assist with communication and sharing of ideas, and as semiotic tools to link facets of concepts for meaning making.

**Key Finding 5.25**
Christine and Melanie's prompting, modelling, referring back to previous embodied experiences and guiding of students to interpret, translate and transfer their feelings, thoughts and what they learnt from embodied experiences to other representational and re-representational challenges, engaged students in more complex thinking and reasoning.

**Representational activities and re-representational challenges**

From social semiotic and distributed cognition perspectives Christine and Melanie also used representational activities and challenges to scaffold, support and to create opportunities for higher order thinking and scientific reasoning. This section describes how Christine and Melanie's implementation of complex representational tasks engaged students in deeper thinking and reasoning and how gesture and verbal prompts supported the scaffolding of these tasks. Examples to illustrate these will be provided.

***Implementation of simple and complex representational tasks***

In addition to embodied and verbal representations, drawing and the use of arrows were used to represent the size, type and direction of forces and the changes to each of these. The complexity of representational tasks varied across the unit. Simple representational tasks were used to record, consolidate and revise students' conceptual understanding, for example illustrating and writing notes about aspects of forces learnt from videos. More complex tasks engaged students in deeper levels of thinking and reasoning where they had to apply their knowledge to formulate explanations and solutions to problems. These included:

- Recording of investigation findings in a story board and the use of arrows to explain the effect of different sized push and pulls on rolling a can of tomatoes (Lesson 2) (Figure 5.36).
- Drawing diagrams with arrows showing the direction and type of forces at play to explain how opposite forces of magnetism were used to move a car without touching it (Lesson 5) (Figure 5.37).
- Drawing pictures of people in different countries throwing up a balloon on a world globe represented on a sheet of paper and using arrows to explain that

it's the force of gravity that causes balloons to fall towards the Earth and stops people from falling off the world. (Lesson 3) (Figure 5.38 – 5.43).

- Drawing diagrams of different sized parachutes with arrows representing the type and direction of the different forces acting upon them, to construct an explanation for why different parachutes fell at different rates (Lesson 7).

Analysis of Christine and Melanie's implementation of representational tasks revealed the following general patterns and points relating to the development of students' higher order thinking and reasoning skills.

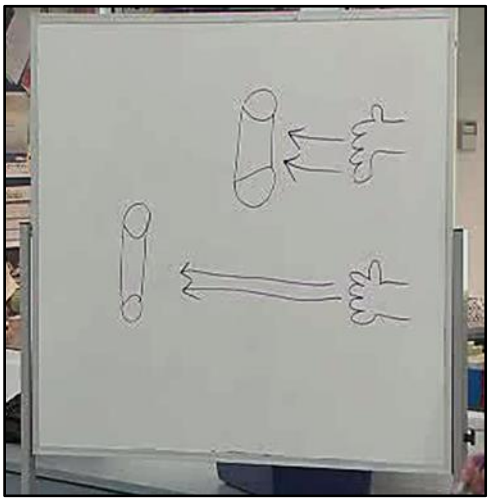
- The representational and re-representational challenge activities provided the conceptual and cognitive context for students' thinking and reasoning.
- Students were left on their own initially to tackle the tasks and challenges. Prior to being supported students were more focused on doing the task, rather than thinking about the task.
- The cognitive demand of representational challenges increased over learning activity sequences and as the topic progressed. For example, representational activities early in learning activity sequences focused on building, reviewing, refining and reinforcing facets of concepts through a variety of multimodal experiences, and, later representational and re-representational activities were more complex and challenging, and required students to apply their conceptual knowledge and deeper thinking and reasoning in order to complete the tasks.
- During higher level conceptual and cognitive representational challenges students' thinking and reasoning appeared minimal until Christine and Melanie provided scaffolding and support via talk (e.g. questions and discussion), gesture, modelling and the use of parallel less cognitive demanding examples.
- Christine and Melanie's dialogue prior to, during and after representational and re-representational activities was essential in scaffolding and supporting students thinking and reasoning. Teacher talk, teacher initiated questions and discussion focused students' thinking, highlighted salient points and brought essential prior knowledge and experiences to the fore in students' minds, to build and develop new understandings, thinking and reasoning.
- Christine and Melanie referred back and forth to prior representations to scaffold and support thinking and reasoning. They provided links between representations

by highlighting and bringing out the salient points and ideas from previous activities that needed to be transferred to the new task in order to build understanding and develop thinking and reasoning.

***Diagrams, arrows, gesture and verbal prompts***

Diagrammatic representational challenges; many of which incorporated the use of arrows, were used throughout the unit to scaffold and support conceptual understanding, thinking and reasoning. When students were asked to represent or re-represent their understandings in the form of a diagram with arrows, students had to think deeply in order to translate their knowledge into another mode or representation. Students found it quite challenging in the beginning of the topic to do this, due to the abstract nature of the force concepts, the complexity and newness of the concepts and the difficulty of representing three dimensional features of forces (e.g. speed, size, direction and type) on a one dimensional page. As their students hadn't had any formal instruction regarding arrows prior to this topic, the majority of students required scaffolding and support to incorporate arrows into their diagrams.

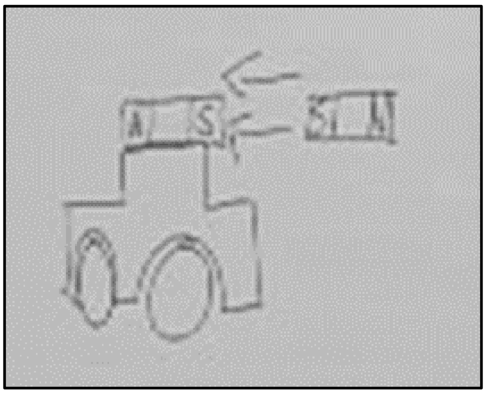
For example in Lesson 2, students were given the task to represent what they had they learnt about applying different sized push and pulls to a rolling can of tomatoes in a story board. Until prompted with the question, "How do you show different sized forces using arrows on a diagram?", students did not use arrows in their story board diagrams to represent the different sized push and pulls applied to the rolling cans (Melanie, Lesson 2 transcript). Figure 5.36 and the related text illustrates how Melanie modelled the use of different sized arrows on the white board at the same as she verbally scaffolded students with her pointed instructions, highlighting of students' work and guiding questions.



1. "I want you to open up your books and draw three different ways you could show a big push and a small push."
2. "How could you do it so you can tell the difference between them?"
3. "I can see some interesting ideas here, some people are starting to use arrows."
4. "Can you tell me which one is my big push and which one is my small push?"
5. "Tell me how you knew the top one is my small push and the bottom one is my big push?"

**Figure 5.36: Lesson 2 instruction on how to use arrows to show different sized pushes**

Another example of a diagrammatic representational challenge involving arrows is found in Lesson 5. When having a class debrief of the investigation where students used a toy car and two bar magnets to determine how to move a toy car without touching it, several students were asked to share their design and science ideas with the class. One student was asked to show the effect of two same poles facing each other on the movement of the car. She confidently drew the diagram but was a bit hesitant with the placement of the arrows. Melanie supported the student by gesturing with her fists with her two thumbs facing each other. This gesture reduced the difficulty of the task by prompting and triggering the student's previous knowledge about magnetic forces which allowed her to represent on the diagram on the white board with arrows (Figure 5.37).



1. "Draw what happened when the two cars with magnets on their roofs had two poles facing each other."
2. Teacher scaffolded student by gesturing with her two thumbs facing each other representation.

**Figure 5.37: Student representing their understanding using arrows that like poles repel**

***Scaffolding of diagrammatic representational challenge: "So why don't people fall off the Earth?"***

Christine and Melanie provided detailed scaffolding and support during complex representational tasks when students appeared to be struggling. An example to illustrate this can be found in Lesson 3. Students were given a diagrammatical representational task that focused on the science ideas that gravity is a pull down force and gravity affects people the same way on all parts of the Earth.

Prior to the task students had shared with a partner what they knew about gravity, played a balloon game to physically experience the effect of gravity and had discussed as a class; with the aid of a plastic world globe, that gravity affects people all around the world. Christine then asked the question "So why don't people fall off the Earth?". She had students draw a large circle on a page in their science journal to represent the world and set the following task to complete:

> Draw what would happen if you were standing in Australia with a balloon and you let it go . . . and then I want you to draw three other people in different places around the world that are standing with a balloon and dropping it, and I want you to draw what happens. What could you use in your diagram to help show what happens? We used these last week. . . . Arrows. (Christine, Lesson 3).

This was a challenging representational challenge for students. When Christine and Melanie moved around the room, they observed that students were having difficulty with drawing the countries on a world globe represented as a circle on paper; and, with drawing arrows to demonstrate the direction that the balloon would fall. As the difficulty appeared widespread Melanie called the class to attention and scaffolded the task by modelling the task on the white board. This was a 16 step process and involved Melanie drawing a stick figure on a particular part of the circle representing the world and a small circle representing the balloon above the stick figure and asking the class which way the balloon would fall. She drew the arrow according to what they answered and asked questions until students' provided the correct direction.

Melanie then strategically chose another position on the world to test whether students had really understood the concept that the direction that the balloon was falling on each occasion was towards the centre of the Earth. Once Melanie focused students' attention on the centre of the Earth, and after several practises, students were able to identify that the direction the balloon would fall on each occasion, was towards the centre of the Earth. She then dismissed students to complete the task in their science journal. A summary of the steps and diagrams Melanie used to scaffold the task is included in Figures 5.38 – 5.43.

Steps 1 – 3 Melanie drew herself on Australia and wanted to know from students what direction she should draw the arrow to demonstrate where the balloon should fall. Student said to "point it down". Melanie drew the arrow going down. The student corrected the direction and Melanie drew it facing upwards. Melanie told the students that the arrow should point **downwards** <u>towards the ground</u> (Figure 5.38).

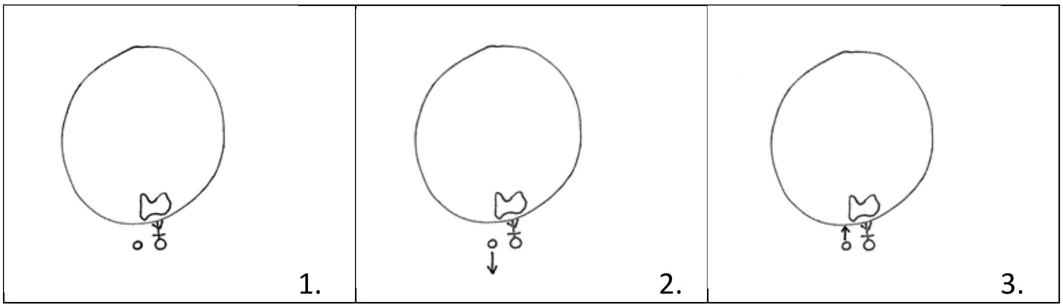



**Figure 5.38: Scaffolding of students' thinking and understanding of gravity, Steps 1 - 3**

Steps 4 – 5    Melanie drew another person on the other side of the world to test whether students understood that the correct description for the direction of the arrow is downwards towards the Earth. At the second attempt the correct direction was given for the arrow (Figure 5.39).

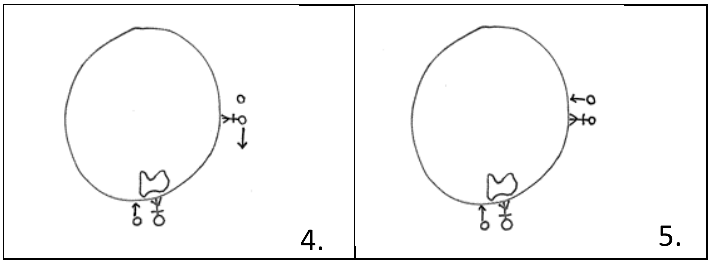



**Figure 5.39: Scaffolding of students' thinking and understanding of gravity, Steps 4 & 5**

Steps 6 – 7    Melanie drew another person on top of the globe diagram. The direction of the balloon was easier this time because "towards the Earth" is a downward direction. The student gave the correct answer, "Downwards" (Figure 5.40).

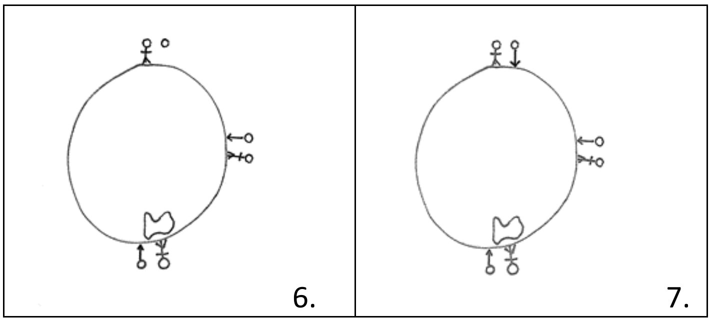



**Figure 5.40: Scaffolding of students' thinking and understanding of gravity, Steps 6 & 7**

Steps 8 – 10    Melanie pointed to another place on the globe and asked what direction the balloon will fall. A students said "downwards" and so Melanie drew a downwards arrow. As there still appeared to be confusion with the use of terminology, Melanie pointed to the centre of the Earth and then put a dot in the centre of the globe to focus students' attention that the arrow direction should face the centre of the Earth (Figure 5.41).

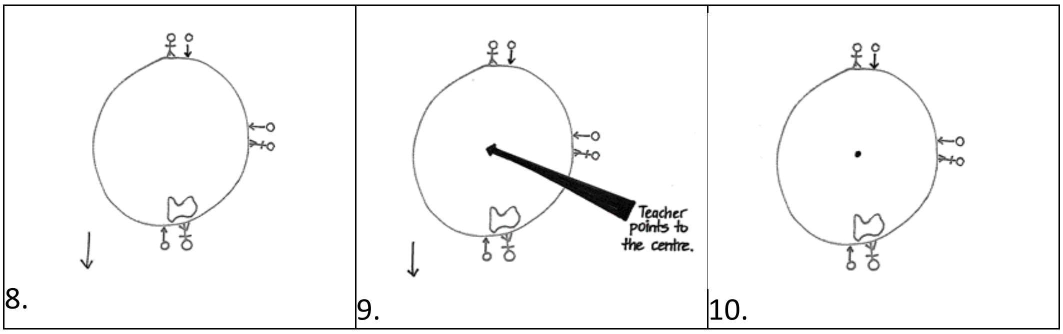



**Figure 5.41: Scaffolding of students' thinking and understanding of gravity, Steps 8 – 10**

Steps 11 – 12 Checking students' understanding by drawing the balloon in another position and the students gave the correct direction (Figure 5.42).

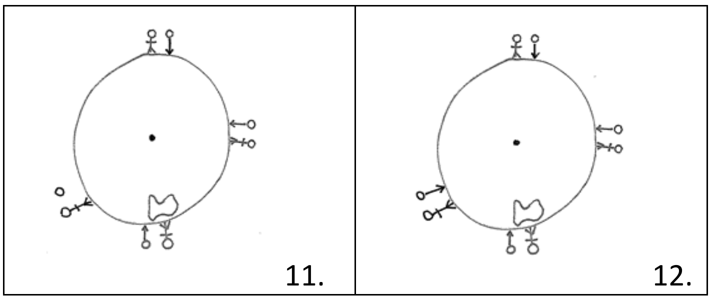



**Figure 5.42: Scaffolding of students' thinking and understanding of gravity, Steps 11 &12**

Steps 13 – 16 Re-checking students' understanding by drawing the balloon in another position a student said the arrow should point "downwards". With the prompting "Towards the . . ." the student corrected herself and said that "the balloon will fall towards the centre of the Earth". Melanie drew the correct direction and then rubbed off the incorrect arrow (Figure 5.43).

Christine and Melanie's detailed scaffolding and support of the gravity representational task assisted students to complete the task. This increased students' understanding of gravity and developed their thinking and reasoning skills.

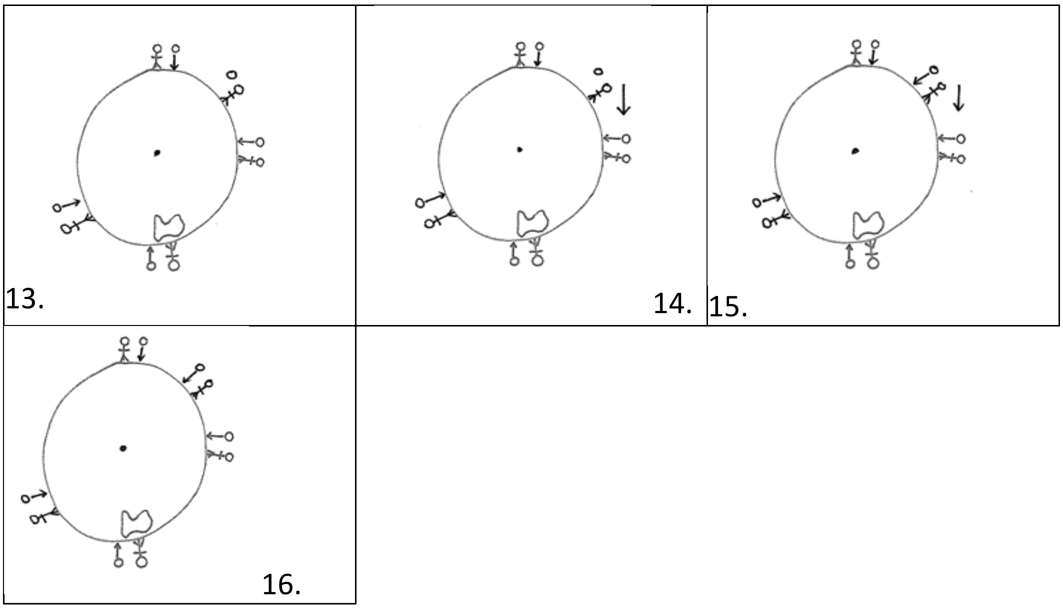



**Figure 5.43: Scaffolding of students' thinking and understanding of gravity, Steps 13 – 16**

Christine and Melanie used representational activities to provide the conceptual and cognitive context for students' thinking and reasoning. The cognitive demand of their representational challenges increased over learning activity sequences within lessons and as the topic progressed. Representational activities early in learning activity sequences focused on building, reviewing, refining and reinforcing facets of concepts through a variety of multimodal experiences. Later more complex and challenging representational and re-representational activities required students to apply their conceptual knowledge and deeper thinking and reasoning in order to complete the tasks.

Christine and Melanie monitored students' understanding continuously during representational challenges. When students were left on their own to tackle the tasks and challenges they appeared more focused on doing the task rather than thinking about the task. When required Christine and Melanie provided scaffolding and support via talk (e.g. questions and discussion), gesture, modelling and the use of parallel less cognitive demanding examples. Christine and Melanie's dialogue prior to, during and after representational and re-representational activities was essential in scaffolding and supporting students thinking and reasoning. Teacher talk, teacher initiated questions and discussion focused students' thinking, highlighted salient points and brought essential prior knowledge and experiences to the fore in students' minds, to build and develop new understandings, thinking and reasoning. Christine and Melanie referred back and forth to prior representations to scaffold and support thinking and reasoning. They provided links between representations by highlighting and bringing out the salient points and ideas from previous activities that needed to be transferred to the new task in order to build understanding and develop thinking and reasoning.

Complex representational and re-representational tasks were used by Christine and Melanie to create opportunities for students to think and reason. Many of these activities challenged students because of the abstractness of the force concepts, the need for students to transfer their understanding across modalities and dimensions and the newness of using arrows, which were used across contexts and for multiple purposes; that is, to represent the type of force, size, direction and motion (speed) or a combination of these. It was through students' conceptual understanding and Christine and Melanie's effective scaffolding and support and that students were engaged in higher order thinking and reasoning.

**Key Finding 5.26**
Complex representational and re-representational tasks were used by Christine and Melanie to create opportunities for students to think and reason. They challenged students to formulate explanations and solutions to problems and required a higher level of thinking and reasoning from students. Continual monitoring, modelling of diagrams, verbal prompts in the form of instructions, hints, questions, and gestures were used in the scaffolding and supporting of these tasks.

In conclusion, this section described and analysed a selection of Christine and Melanie's pedagogies and strategies that scaffolded, supported and created opportunities for higher order thinking and reasoning. Analysis revealed that Christine and Melanie scaffolded and supported the use of embodiment and embodied experiences, representational activities and re-representational challenges; supported by metacognitive and verbal scaffolds and underpinned by a safe, positive, thinking, collaborative classroom culture and learning environment, to build and create opportunities for higher order thinking and scientific reasoning.

| **Key Finding 5.27** |
| --- |
| Representational activities and re-representational challenges, were sequenced, supported by metacognitive and verbal scaffolds and underpinned by a safe, positive, thinking and collaborative classroom and learning culture, to build and create opportunities for higher order thinking and scientific reasoning. |

| **Key Finding 5.28** |
| --- |
| Embodiment and embodied experiences were foundational in building conceptual development, conceptual development provided the context for representational activities and lower level thinking and reasoning and re-representational challenges created the opportunities for students to be engaged in higher order thinking and scientific reasoning. |

## Summary

This chapter focused on Christine and Melanie and their co-teaching, and how they scaffolded, supported and promoted higher order thinking and scientific reasoning whilst teaching a Forc*es* unit to their combined Year 4 classes (KF 5.1, 5.2). The Chapter comprises five sections: the contextual setting of the case study; Christine and Melanie's beliefs and philosophies; topic and unit overview; overview of instructional approach; and, pedagogies and strategies supporting thinking and reasoning. A brief summary of these sections and Key Findings (KF) will be given in this summary. (Appendix I provides a list of the Key Findings for Chapter 5.)

Christine and Melanie taught at a Western Australian private (non-government) junior kindergarten to Year 12 boarding school for girls with an above average ICSEA rating. Although not trained as a specialist Science teacher Christine took on the role of Junior School Science Coordinator and managed the teaching of the Science curriculum across year levels, supported teachers with professional development and resourced and coordinated whole school science activities and community projects. Melanie enjoyed teaching Science and looked forward to becoming more involved in College science initiatives (KF 5.1). Christine and Melanie co-taught two classes which were combined for science lessons (KF 5.1). Their Year 4 students demonstrated above average literacy skills; developed computer literacy, confidence in speaking in front of others, advanced general and science knowledge and vocabularies for their age and an awareness of contemporary science issues (KF 5.2). Their classroom was an open floor area with little furniture and students mostly worked on the floor. The work space allowed students to be in close proximity with peers and resources and supported by a safe classroom environment and learning culture, this made it conducive for students to talk, share, question, discuss, test and refine ideas together (KF 5.3, 5.4).

Christine and Melanie believed that the purpose of primary science education is to develop students' scientific literacy and thinking and reasoning skills. Their instructional approach was that Science should be life based, student centred and involve hands-on inquiry learning (KF 5.5). They believed in a constructivist, sociocultural approach to teaching and learning science, in using multiple modes and representations for teaching Science and that talk and discussion are central to learning (KF 5.6, 5.9). They also believed strongly in kinaesthetic learning and in the merits of embodied learning; that students learn best by physically being a part of their learning (KF 5.7). They believed that science language and vocabulary are important for meaning making and that each lesson should contain some form of literacy task in order to help students' to communicate their ideas with others (KF 5.8).

Christine and Melanie structured lessons for collaboration and discussion and 85% of classroom time was spent in talking, discussion and collaboration with others (KF 5.4, 5.13). They used a wide range of instructional settings and instructional setting changes to pace, scaffold and build students' thinking, reasoning and learning. The number of setting changes correlated with the amount of support and scaffolding afforded to students (KF 5.14). Students spent most of their time in the whole class and small group settings and were frequently conferring with partners in short bursts multiple times within lessons as part of the process for scaffolding and supporting students' higher order thinking, reasoning and learning (KF 5.13).

Thinking, questioning and reasoning were an engrained part of Christine and Melanie's classroom culture and was reinforced as a focus for the Force*s* alongside conceptual development (KF 5.10). Students were continuously reminded of the expectation that they had to think, question and justify claims with reasons during each lesson (KF 5.10). Conceptual understanding provided the basis for development of thinking and reasoning and lessons and activities within lessons were sequenced and structured to cumulatively build conceptual understanding (KF 5.11). Within lesson sequences which consisted of multiple multimodal learning activities and representations incrementally built the conceptual story and developed students' thinking and reasoning skills as each lesson sequence progressed (KF 5.15). As conceptual understanding increased, the expectation for thinking and reasoning increased. Lessons 1 – 5 focused on building conceptual understanding, in Lessons 6 and 7 students applied understanding to solve problems and in Lesson 8 students used their knowledge and innovation and creativity skills to make a game on Force*s* (KF 5.12).

Christine and Melanie utilised a variety of pedagogies and strategies to scaffold, support and create opportunities for higher order thinking and scientific reasoning during the unit. These can be broadly classified as: metacognitive scaffolds; partner work; embodiment; and, representational and re-representational challenges (KF 5.16 – KF 5.27). The Big picture question strategy was a significant pedagogical strategy that scaffolded and supported the development of students' conceptual and cognitive understanding and skills across the unit (KF 5.16 – KF 5.18). The Big picture question "Why do things move?" was chosen by Christine and Melanie to promote deep student thinking (KF 5.16). The task consisted of a three thinking phase process (KF 5.17). It was an important metacognitive strategy that allowed students to have ownership of their learning and provided a framework on which students accessed prior understandings that were used as a basis to build new learning, thinking and reasoning KF 5.16 – KF 5.19).

Christine and Melanie frequently used partner work during the Big picture question tasks as well as throughout lessons across the unit (KF 5.17 and KF 5.18). The verbal sharing of personal ideas with a partner, provided students with a process and forum to access, process, and review and extend their conceptual learning, thinking and reasoning. Partner work was used by Christine and Melanie for introducing, building and reviewing concepts, for emphasizing and signposting salient points; and, for pacing, guiding, focusing and assessing students' thinking and learning. The Think-pair-share and See-saw strategies were formalised types of partner work frequently used by Christine and Melanie across the unit (KF 5.19). Students often were tasked to report back on what their partner had said. Reporting back enabled students to review their prior knowledge, to ask themselves questions, to learn from others and to extend their thinking. Through sharing and reporting activities students developed complex cognitive skills and processes required for higher learning and scientific reasoning (KF 5.20).

The formal investigation planner was another form of metacognitive scaffolding used by Christine and Melanie to guide students through the inquiry and investigation processes. Students were highly scaffolded in the commencement of the unit in the use of investigation planners. As the unit progressed and students became familiar with the method of inquiry outlined in the planners and investigations became more open, the scaffolding decreased (KF 5.21).

Christine and Melanie provided constant verbal scaffolding and support to assist with the development of students' conceptual learning and thinking and reasoning skills. Teacher initiated prompts, questions and comments like "Why?", "Tell me more.", "What is another way?", "What did you think about . . .?" and "What did your partner think about . . .?" teased out students' ideas and thoughts particularly during investigations (KF 5.22).

The use of embodiment was a signature pedagogy in Christine and Melanie's teaching. Their lessons were highly embodied with each lesson having some form of embodiment incorporated into it (KF 5.23). Christine and Melanie used embodiment and embodied experiences to develop students' conceptual understanding which formed the foundation and context for the development of students' higher order thinking and reasoning skills. Embodied experiences helped students to apply their knowledge to real situations, rendered abstract and difficult concepts accessible to students of all abilities, acted as a catalyst for remembering conceptual understanding and for solving problems, and to promote and assist with communication and sharing. They were also used by students as semiotic tools to help with meaning making (KF 5.24). Christine and Melanie's prompting, modelling, referring back to previous embodied experiences and guiding of students to interpret, translate and transfer their feelings, thoughts and what they learnt from embodied experiences to other representational and re-representational challenges, engaged students in more complex thinking and reasoning (KF 5.25, KF 5.28).

Another noteworthy pedagogy and strategy was the use of representational and re-representational challenges in lesson activity sequences. Students were challenged to translate their embodied experiences and conceptual understandings gained through investigation activities into verbal, written, graphical and diagrammatic (incorporating arrows) representations (KF 5.26, 5.27 and 5.28). Complex representational challenges were used to formulate explanations and solutions to problems and required a higher level of thinking and reasoning from students. Modelling of diagrams, verbal prompts in the form of instructions, hints, questions, and gestures were used in the scaffolding and supporting of these tasks (KF 5.26, 5.27 and 5.28).

Christine and Melanie's teaching of the Force*s* unit was underpinned by their science education philosophy and beliefs, the establishment and of a positive and supportive classroom environment and learning culture; and their use of pedagogies and strategies, namely: metacognitive scaffolds, partner work, verbal scaffolds, embodiment and representational activities and re-representational challenges incorporated within and across instructional settings. Together all of these factors contributed to their scaffolding, supporting and creating opportunities for the development of higher order thinking and scientific reasoning skills within their combined Year 4 class (KF 5.27, 5.28).

# Chapter 6: CROSS-CASE ANALYSIS AND DISCUSSION

## Introduction

The previous two chapters described the context, teacher beliefs and pedagogical strategies Sandra (Chapter 4), and Christine and Melanie (Chapter 5) employed to scaffold, support and create opportunities for higher order thinking and scientific reasoning during the teaching of a Year 4 physical science topic. This chapter presents a cross-case analysis and discussion of the key findings drawn from each of these two case studies. The cross-case analysis enables the Researcher to set out and explain similarities and differences between the case studies, to consider and make sense of their relationships and to conceptualise from the analysis. Themes emerging from the cross-case analysis will be discussed in relation to the existing research literature and the conceptual framework guiding the study (Figure 6.1).

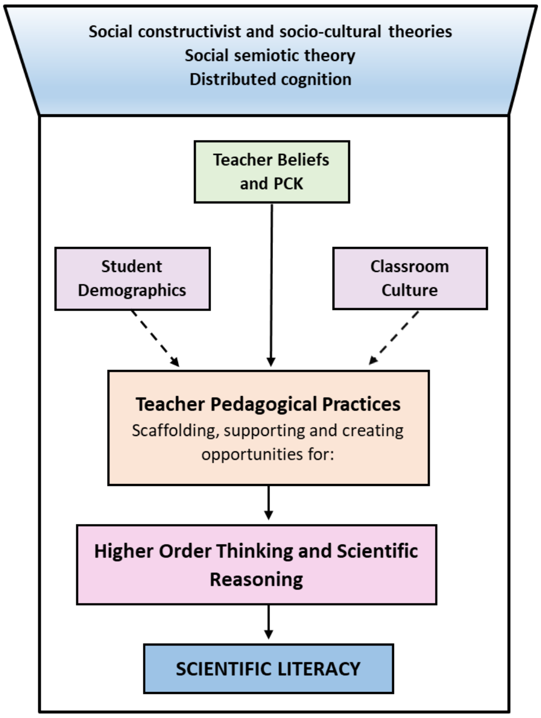



**Figure 6.1: Conceptual framework for the study**

Assertions (A) formulated from these themes will then inform the conclusions and implications for teacher practice in the final chapter. The following sections compare and contrast the context, teacher beliefs, instructional approach and pedagogical strategies exhibited in both case studies. To make it easier for the reader, on occasions Sandra's case study is referred to as Case Study 1 (CS 1) and Christine and Melanie's case study is referred to as Case Study 2 (CS 2) in this chapter.

## Context

Denscombe (2017) asserts that when adopting a cross-case approach to research it is important to take into consideration the contextual relationships and social processes surrounding the phenomenon being studied. For this reason, the contextual factors influencing the case study teachers' choice of pedagogies and strategies that scaffold and support higher order thinking and scientific reasoning will be discussed.

From a broad perspective Sandra's (CS 1) and Christine and Melanie's (CS 2) case studies were contextually similar. They both involved exemplary primary school teachers teaching a physical science topic to their class of Year 4 students; in the same time period, at metropolitan schools in Perth, Western Australia. Taking a more analytical view, there were; however, some noteworthy differences with the type of school, number of teachers instructing each class, class size, student cohort, classrooms and the physical science topic being taught. The contextual factors surrounding both case studies will be compared using the following headings: Teacher context, School context, Classroom context and Topics.

### Teacher context

Sandra (CS 1), and Christine and Melanie (CS 2) were considered exemplary teachers of primary science by their peers, school administration and researchers (Ramseger & Romain, 2017). They were generalist trained primary school teachers, with similar qualifications, teaching backgrounds and science teaching experience. Although none of them were specifically trained as Science teachers nor had tertiary qualifications in Science (KF 4.2, 5.1), they were all very passionate about science and science teaching and committed to developing their students' science understanding and thinking and reasoning. A foundational factor influencing their teacher practice was their respective school settings.

**School context**

The schools involved in the study differed in a number of ways. Sandra's (CS 1) school was a government co-educational K-7 school which catered for children living in the suburbs surrounding the school. The school ICSEA value was 1140 and students typically came from families with medium to medium-high socio-economic and educational levels (KF 4.1). Christine and Melanie's school on the other hand was an exclusive private (fee charging), religious based, K-12 (Junior and Secondary) boarding and day school for girls. The school ICSEA value was 1197. Students came from suburbs across the Perth metropolitan area and rural WA, and were typically from families with medium-high to high socio-economic and educational levels (KF 5.1). Despite these obvious differences in type and social advantage of each school, both case study schools were committed at the school level to the development of Science within their schools and featured Science as a priority in their respective school plans. Additionally, both schools adopted a whole school approach to Science teaching and learning and had appointed a Science Coordinator who was a regular classroom teacher, with additional responsibilities to: attend science professional learning workshops on behalf of their school, introduce and mentor new science initiatives to the rest of the staff, administer the science budget, and source and manage school science resources (KF 4.2, 5.1). Understandably, the difference in school contexts translated into differences in classroom context and student cohorts of the two case studies.

**Classroom context**

There were clear differences between both case study classes and classrooms. Sandra's (CS 1) class was made up of male and female students whereas Christine and Melanie's class comprised only female students. As this difference didn't appear to have any significant influence on the topic being researched it will not be discussed in this study. Other factors like the number of teachers instructing each class, the number of students in each class, the knowledge and ability of students and the instructional space for each case study class were considered important differences that affected the teachers' pedagogies and strategies and will now be discussed.

Sandra (CS 1) taught Science on her own to her regular class of 29 students (KF 4.1), whereas Christine and Melanie (CS 2) combined their regular classes and co-taught Science lessons to their combined class of 45 students (KF 5.2). They both took equal responsibility for teaching all the students in the classroom and took turns facilitating instruction and leading activities as described by Kluth and Straut's (2003) duet model of co-teaching. As to be expected with the different sized classes, the instructional space and configuration of furniture in the two case study classrooms differed. Sandra (CS 1) used her typical Australian home room classroom (Hubber & Ramseger, 2017) for Science, with groups of tables taking up most of the classroom space. Apart from when students sat on the small carpeted floor area at the front of the room to receive instructions, her students sat at tables in the same group for the majority of class time during Science. When more space was required Sandra (CS 1) took the class outside to the grassed area adjacent to the classroom (KF 4.6, 4.7 and 4.8).

In contrast, Christine and Melanie's (CS 2) science lessons were conducted outside of their regular classrooms, in a large inside communal open-space area in between a group of four classrooms. This area was chosen because Christine and Melanie (CS 2) needed a larger area to accommodate their combined classes. For the majority of time students sat on the floor during lessons as one big group. For paired work students worked with the person sitting next to them which could change from lesson to lesson; and, for small group work students gathered together on the floor in pre-selected work groups which were kept constant for the duration of the topic (KF 5.4). Similar to Sandra's (CS 1) class, Christine and Melanie (CS 2) utilised the grassed areas outside their classroom when particular activities required more space.

Another factor to be considered in this analysis is the makeup of the two case study classes which were both unstreamed mixed ability classes. There was a noticeable but not extreme difference with the overall ability and amount and variety of life experiences of the two case study cohorts. This is indicated by the previous year's

Year 3 NAPLAN assessment results when Christine and Melanie's (CS 2) student cohort performed above the national average in the areas of reading, writing, spelling, grammar and punctuation and numeracy (KF 4.1), whereas Sandra's (CS 1) student cohort performed slightly below the national average scores in these areas (KF 5.2). Another difference observed throughout the filming of the case studies and evident during discussions was that Christine and Melanie's (CS 2) students also appeared to have more developed general and science knowledge bases, vocabularies for their age, as well as a greater awareness of contemporary science issues (KF 4.3, 5.2), than Sandra's (CS 1) class. This could have been attributed to the family backgrounds of the students. Despite these differences, the majority of students in each class appeared to be confident speakers, comfortable and used to discussing and expressing their ideas in front of and with others (KF 4.4, 5.2). This could be attributed to an already established positive classroom environment and learning culture in both case study classrooms and the case study teachers' instructional approach that favoured collaborative work and discussion. In addition to the contextual classroom differences between the two case studies, the difference in topic taught by Sandra (CS 1), and Christine and Melanie (CS 2) also influenced how students were scaffolded and supported to think and reason.

**Topics**

The case study teachers taught different physical science topics which varied not only in content but in the level of abstractness and cognitive demand. Sandra's (CS 1) unit on Materials and their uses was less cognitively demanding than Melanie's Force*s* unit and covered properties of materials; such as absorbability, opacity and tensile strength (KF 4.7, 5.9). These properties were directly accessible to students because of their visibility to students. In contrast, the main concepts in Christine and Melanie's Force*s* unit, such as momentum, friction and magnetism were abstract in nature and were not directly visible or as accessible for students to observe. Understanding these force concepts required the use of pedagogies and strategies that involved students building a picture of each concept through indirectly observing or experiencing the effects or influence of the force at play.

**Contextual discussion**

When comparing teacher practice across and within countries; and, across schools within the same metropolitan area such as in this study, it is important to consider contextual factors (Denscombe, 2017; Hackling, Chen, et al., 2017; Hackling, Ramseger, et al., 2017; E. Johnson, 2008). As the review of the literature in Chapter 2 has indicated, school context, school philosophy (Hackling, Chen & Romain, 2017; Johnson, 2008; Ryan & Paquette, 2001), curriculum organisation (Chittleborough, Ramseger, Hsiung, Hubber, & Tytler, 2017; Tytler, Ramseger, Hubber, & Freitag-Amtmann, 2017), student demographics (Hackling, 2014; Martin, Mullis, Foy, & Stanco, 2012; Stewart, 2012), classroom culture (Alexander, 2008) and physical learning environments (Hubber & Ramseger, 2017) have the potential to influence teacher practice and students' thinking, reasoning and learning.

Each of the cases in this study had a unique set of contextual factors and social processes associated with it. Contextual factors such as science teaching background, experience and expertise; school's science focus, class year level, and the area of science being taught were similar in both case studies. School type, number of teachers per class, class size, topic, instructional space, students' ability, knowledge, exposure to contemporary science issues and level of language development set the two case studies apart and; albeit their differences were relatively small, lead to differences in how Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for higher order thinking and reasoning.

Hackling, Chen and Romain's model (2017) (illustrated in Figure 2.6 and replicated in Figure 6.2 for ease of comparison) has been adapted (Figure 6.3) for the more localised and specific focus of this study, to illustrate the influence of contextual factors on how Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for higher order thinking and scientific reasoning. In Figure 6.3, the inner layers of Hackling et al.'s model, have been replaced with localised contextual factors relating to school, teacher, class and students relevant in this study. These layers have been situated inside the original wider outer layers of Figure 6.2.

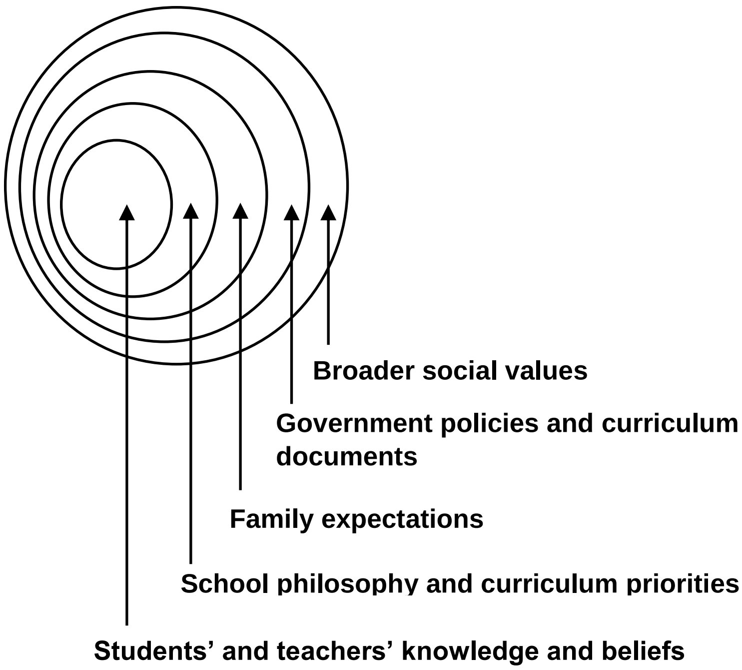



**Figure 6.2: Hackling, Chen and Romain's (2017) layers of social and cultural factors influencing classroom culture and pedagogy (Fig. 2.1, p. 20)**

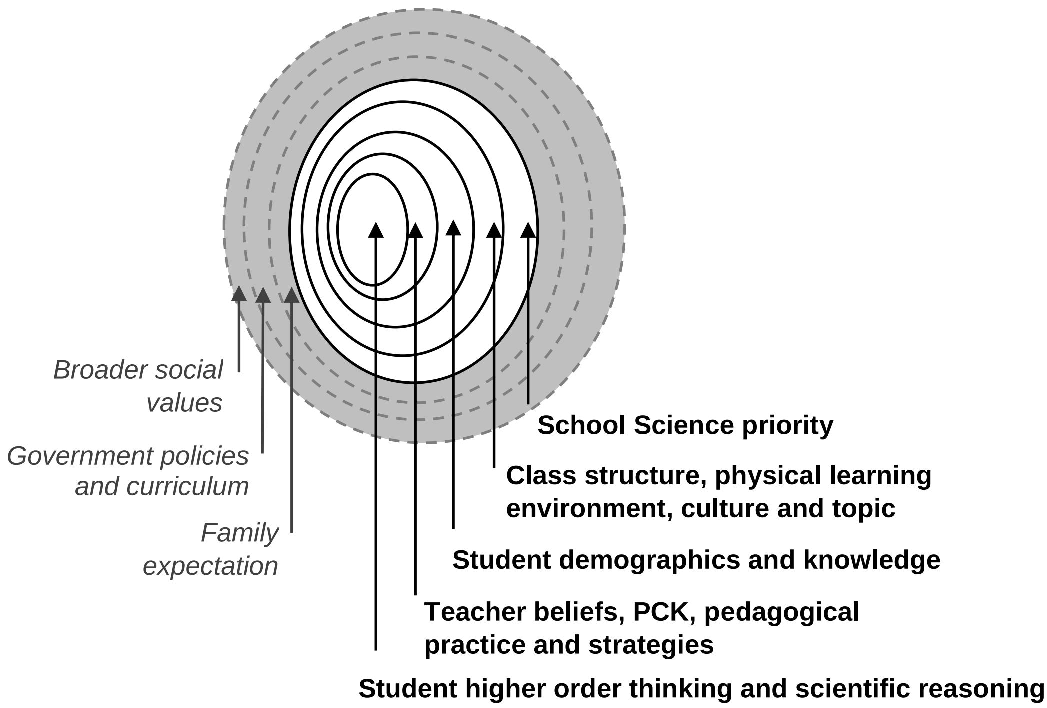



**Figure 6.3: Layers of contextual factors influencing students' higher order thinking and reasoning, *adapted from Figure 2.1* (Hackling, Chen, et al., 2017, p. 20).**

This allows the reader to focus on the specific contextual factors at play in this study whilst recognising the influence of broader social issues, government policies and curriculum documents and family expectations on teacher practice. The inner layers of the model identify contextual factors such as school science priority, class structure, physical learning environment and classroom culture, student demographics and knowledge, and teacher beliefs and PCK; and, pedagogical practice and strategies, as layers of influence on the development of students' higher order thinking and scientific reasoning.

Please note, due to the constraints of the doctoral study no data were collected about Sandra's (CS 1), and Christine and Melanie's (CS 2) PCK. Whilst PCK has been included in Figure 6.3 to acknowledge its influence on what and how Sandra (CS 1), and Christine and Melanie (CS 2) taught, it will be omitted from models, assertions and conclusions formulated from the cross-case analysis. This is acknowledged as a limitation of the study.

**Assertion 6.1**
Contextual factors influenced Sandra's (CS 1), and Christine and Melanie's (CS 2) choice of pedagogies and strategies. In addition to the broader social factors; school contextual factors including the priority given to science, the physical and social environment of the classroom, student demographics and prior knowledge; teachers' beliefs and pedagogical practices and the topic being taught framed the opportunities for students to engage with higher order thinking and reasoning.

A discussion of Sandra's (CS 1), and Christine and Melanie's (CS 2) beliefs concerning the teaching and learning of science follows.

## Teacher beliefs

Previous research has indicated that teacher beliefs have a profound influence on teacher practice. As related by Fitzgerald, Dawson and Hackling (2012) and Mansour (2009) and discussed by Hackling, Ramseger and Chen (2017) a teacher's practice is shaped and framed by their beliefs. These very experienced and highly competent teachers shared common beliefs about best practice science teaching and learning. Analysis of the key findings from their pre-study teacher interviews reveals that their beliefs relate to four themes:

- development of scientific literacy through authentic hands-on collaborative inquiry learning;
- language and talk as mediators for thinking, learning and reasoning;
- use of body-based experiences and strategies to assist students with developing conceptual understanding and cognitive skills; and,
- provision of a safe and supportive classroom environment and culture that supports thinking and reasoning.

A brief description and discussion of these themes follows.

**Development of scientific literacy through authentic hands-on collaborative inquiry learning**

Consistent with the *Australian Curriculum: Science*, Sandra (CS 1), Christine and Melanie (CS 2) believed that the main focus for primary science education was the development of students' scientific literacy through hands-on, activity-based inquiry learning. They believed that lessons need to be student centred, engaging, age appropriate and authentic for science to be meaningful and useful in students' present and future lives. They also believed for students to become scientifically literate citizens, they need to be able to think, reason and problem solve with their science knowledge. These skills need to be taught and scaffolded in parallel with the teaching of concepts through investigations and problem solving activities that are linked to the real world (KF 4.3, 5.5). They also believed in collaborative learning as a context for inquiry learning and that meaning is jointly constructed in a social environment. Sandra (CS 1) highlighted this belief when she identified small group work as a characteristic of her teaching. Working together and sharing ideas requires students to share, talk about and discuss their ideas with others (KF 4.3, 4.6, 4.8, 5.3, 5.4, 5.6 and 5.7).

**Talk and language are mediators of thinking, learning and reasoning**

Sandra (CS 1), Christine and Melanie (CS 2) believed that talk and language are fundamental for communication, instruction and for building students' understanding and reasoning in science and the combination of lots of talk, discussion, questioning and reasoning are characteristic of quality science lessons (Alexander, 2014; Gillies, 2016; Scott & Meiers, 2009)(KF 4.3, 5.3 and 5.6). This is evidenced by the way the case study teachers set up their classrooms to facilitate talk and discussion (KF 4.8, 4.11 and 5.4); a characteristic of a quality learning environment highlighted in Hubber and Ramseger's (2017) study of primary science classrooms in Australia, Germany and Taiwan.

Consistent with social constructivist and social cultural approaches to teaching and learning; Sandra (CS 1), and Christine and Melanie (CS 2) believe that when students talk and interact with others (including the teacher) they draw upon prior understandings to co-construct meaning and knowledge; and, through teacher questions and prompts, talk and discussion provide the vehicle for students to think-out-loud and to reason (KF 4.4, 4.12, 5.7). Additionally the case study teachers believed that language and science vocabulary are important for students' reasoning and scientific literacy. Christine and Melanie believe that every lesson requires a literacy task incorporated into it (KF 5.8). This general literacy requirement is mandated by the School and even though vocabulary development supports communication of ideas and is a focus of their lessons, they believe that specific science language is not essential for developing conceptual understanding. Sandra (CS 1) on the other hand believed that it is important to give students the vocabulary and language to question, discuss and to reason in science and that access to relevant science language is necessary to connect and build science ideas and to reason in science (KF 4.12).

Complementing Sandra's (CS 1), and Christine and Melanie's (CS 2) belief in the centrality of talk and language for mediating thinking, learning and reasoning, is their shared belief that body-based experiences assist in the development of thinking and learning.

**Body-based experiences**

Sandra (CS 1), and Christine and Melanie (CS 2) shared the belief that whole body and part body-based experiences support the development of students' thinking and learning. Sandra (CS 1) has an interest in brain training and believes that strategies like chanting and movement assist students with retrieval of prior learning, reviewing of concepts and application of knowledge to new situations; all of which are important for thinking, reasoning and problem solving (KF 4.5). Christine and Melanie's (CS 2) belief in the use of body-based experiences is focused more on kinaesthetic learning and the use of the body as a semiotic tool as described in Ibrahim-Didi, Ramseger, Hackling, and Sherriff (2017) providing the bodily experiences from which concepts can be developed (KF 5.7). To encourage the participation of students in hands-on inquiry, talk and discussion and body-based experiences, all of the teachers believed it was essential to create a positive classroom environment and learning culture.

**Classroom environment and culture**

Sandra (CS 1), and Christine and Melanie (CS 2) shared the belief in the importance of creating and maintaining a safe and supportive classroom culture and learning environment that supports deeper learning and reasoning. Believing in collaborative learning they agreed that students need to feel safe to share and have their ideas discussed by others; to ask questions and to be creative in their thinking. Sandra's (CS 1) belief in a respectful classroom environment, however, was more pronounced than Christine and Melanie's (CS 2) belief. This was because Sandra (CS 1) believed in incorporating student-student critique into her lessons; and, having a safe and supportive learning environment facilitated and encouraged students to compare, analyse and respectfully critique other students' ideas and to accept their peers' critique (KF 4.4, 5.3).

**Belief discussion**

Teacher beliefs are a driving force behind a teacher's pedagogical practice and strongly influence the way a teacher scaffolds and supports student learning (Hattie, 2003; Holroyd & Harlen, 1996; Martin, Mullis, Foy, & Stanco, 2012; Skamp, 2012; Tytler, 2012). Sandra (CS 1), and Christine and Melanie (CS 2) shared four key beliefs regarding science teaching, learning, thinking and reasoning (Figure 6.4).

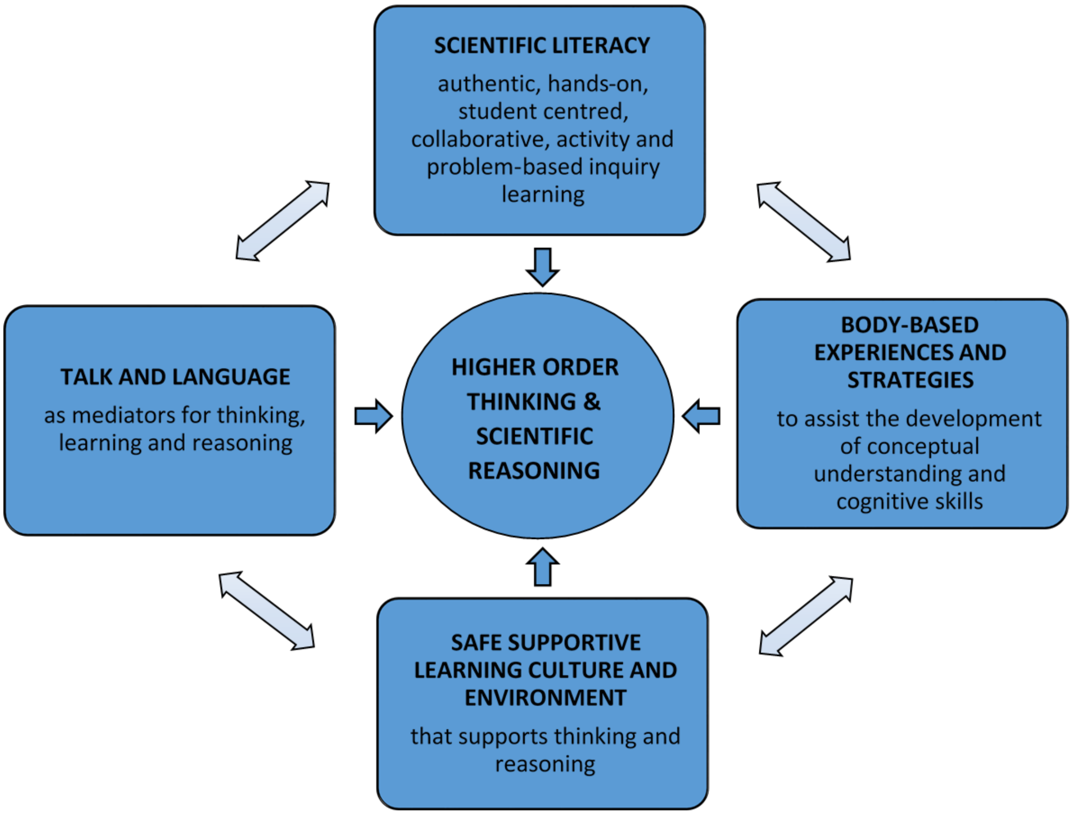



**Figure 6.4: Sandra's (CS 1), and Christine and Melanie's (CS 2) key science teaching and learning beliefs**

They espoused beliefs that are totally consistent with the contemporary literature about inquiry-based science education (Chen & Tytler, 2017; Goodrum et al., 2001; Osborne, 2007; Skamp, 2012). Their beliefs relate to the development of scientific literacy through authentic hands-on inquiry learning, discussion and small group collaboration, and development of skills such as higher order thinking and scientific reasoning which are the basis of inquiry as described by the Inter-Academies Panel (IAP) (2010), Chen and Tytler (2017) and ACARA (2016).

Sandra (CS 1), and Christine and Melanie (CS 2) have very well developed beliefs and philosophies around the role of talk, language and embodiment and various forms of modalities as vehicles for teaching and learning. Christine and Melanie's (CS 2) focus is on the semiotic potential of using body-based strategies and Sandra's (CS 1) is on language development being foundational for building understanding and reasoning.

As Tytler and Prain (2010), Hackling and Sherriff (2015), Ibrahim-Didi, Ramseger, Hackling and Sherriff (2017) and Hackling, Murcia and Ibrahim-Didi (2013) would argue, these are critical for providing opportunities for higher order thinking and reasoning.

Another strong belief held by Sandra (CS 1), and Christine and Melanie (CS 2); which is foundational to their teaching and students' learning; thinking, reasoning and justification of ideas, is the provision and sustaining of a safe and positive classroom environment where students can publicly share their ideas without fear of ridicule. They believed; as do many who view teaching and learning through sociocultural and social constructivist perspectives, in the importance of collaboration; with students working together, sharing, listening, discussing, disagreeing and adapting ideas through listening and discussing with others (for example, Alexander, 2017; Brown et al., 1989; Hackling et al., 2013; Mansour, 2009; Pieczura, 2009).

They also believed that a supportive environment facilitates the process of argumentation as espoused by Toulmin (1958), by providing an environment where students of all abilities feel safe to present their ideas and make and justify claims with reasons which might be at various stages of development and or correctness. This belief is supported by Bennett and colleagues (2004), Alexander (2014) and Mercer (2008) who assert that argument and conflict can be positive and beneficial in the science classroom as long as students feel respected, supported and follow the ground rules for working together (Alexander, 2008) and speaking and listening (Hackling et al., 2010).

**Assertion 6.2**
Sandra (CS 1), and Christine and Melanie (CS 2) held similar beliefs on scaffolding, supporting and creating opportunities for thinking and reasoning, but they had a slightly different focus. Their shared beliefs related to the importance of scaffolding the development of scientific literacy through hands-on authentic problem-based collaborative inquiry learning tasks, investigations and activities; that talk and language mediate thinking, learning and reasoning; that body-based experiences assist with conceptual and cognitive development and the importance of providing a safe and supportive learning culture and environment. The difference between the nature of the Materials (CS 1) and Force*s* concepts (CS 2) may explain Sandra's (CS 1) belief in and the emphasis on talk and language as mediators of thinking and reasoning; and, Christine and Melanie's (CS 2) belief and emphasis on body-based experiences as mediators of thinking and reasoning.

Having compared contextual factors and teacher beliefs, it is also important to consider Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches.

## Instructional approach

It became evident during this study that in order to understand how pedagogies and strategies scaffolded, supported and created opportunities for higher order thinking and reasoning it was necessary to understand Sandra's (CS 1), and Christine and Melanie's (CS 2) overall instructional approaches that drove and provided the foundations for their pedagogies and strategies. Analysis of Sandra's (CS 1), and Christine and Melanie's (CS 2) teaching revealed that their instructional approaches were similar, mirrored their beliefs (Figure 6.4) and were typical of quality primary teachers of science across Australia and internationally (Chittleborough et al., 2017). Cross-case analysis revealed four common themes in their instructional approaches that supported the development of students' higher order thinking and reasoning. These facets or factors provided the critical building blocks necessary for successful implementation of their pedagogies and strategies employed to scaffold and support higher order thinking and reasoning. They are:

- The provision of a safe and supportive classroom learning environment
- Hands-on inquiry supported by the 5Es instructional model
- Facilitation as a way of instruction
- Opportunities for lots of talk and collaboration

**Provision of a safe and supportive learning environment**

Sandra (CS 1), and Christine and Melanie (CS 2) provided and maintained a safe and supportive learning environment during their case studies (KF 4.4, 4.19, 4.20, 4.22. 5.3 and 5.28). A safe and supportive learning environment is a prerequisite for higher order thinking, reasoning and argumentation (Gerber, Cavallo, & Marek, 2001; Gillies, 2016; Hubber & Ramseger, 2017; Pieczura, 2009; Roskos & Neuman, 2011). Closely aligning with Pieczura's (2009) claims of the benefits of having a safe and supportive classroom environment, Both case study classroom learning environments allowed their students to feel supported to share their ideas, to support their opinions with reasons, to take risks in speaking their minds, to question, debate, change their minds and use evidence to support conclusions ( KF 4.3, 4.4, 4.19, 4.20, 4.23, 4.25, 4.26, 5.2, 5.3, 5.4, 5.6, 5.22 -5.24).

An interesting observation from the cross-case analysis, is that Sandra (CS 1), and Christine and Melanie (CS 2) managed and maintained their learning environments quite differently and provided different levels of scaffolding according to their students' level of confidence, experience with sharing and exposure to the process of argumentation. Sandra's class (CS 1) was confident with sharing but hadn't had much exposure to argumentation. Having a supportive environment was critical, especially as she openly encouraged her students to verbally critique, disagree and give constructive criticism to each other (KF 4.19, 4.20 and 4.25). Sandra (CS 1) was proactive in her approach to building students' confidence to share, to argue their points of view and to take criticism. During the initial stages of the unit she frequently reassured students that is was okay and safe to 'have a go' because they were a member of supportive team and were on the same learning journey as everyone else in the class (KF 4.8, 4.13). Additionally Sandra (CS 1) supported students' by reviewing, reminding and reinforcing the 'ground rules' for sharing and arguing; prior to and throughout activities and then faded this support as students became more confident (KF 4.4, 4.5, 4.24 and 4.25).

In contrast, Christine and Melanie's (CS 2) approach was more reactive. Her class didn't require the level of confidence building that Sandra's (CS 1) students required, as they were already very confident with sharing their ideas and opinions and had been exposed to argumentation, both during class and outside of school (KF 5.2). Christine and Melanie (CS 2) consequently did little in the way of formal confidence building during class and generally only reminded students of the 'ground rules' for sharing and argumentation when students breached the rules (KF 5.3).

**Assertion 6.3**
Sandra's (CS 1), and Christine and Melanie's (CS 2) pedagogical practice of maintaining a safe and supportive learning environment throughout their units was critical for the promotion of talk, collaboration, hands-on inquiry and for students to feel safe and confident to share their ideas, support their opinions with reasons, take risks in speaking their minds; question, debate, critique and be critiqued; to argue, change their minds and use evidence to support conclusions.
Initial levels of student confidence differed between the two case study classes due to contextual differences relating to students' prior knowledge, vocabularies, awareness of contemporary science issues and amount of exposure students had previously with sharing ideas and the process of argumentation. These factors influenced Sandra's (CS 1), and Christine and Melanie's (CS 2) choice of pedagogies and strategies, starting points for cognitive development and how they scaffolded and supported higher order thinking and scientific reasoning.

**Hands-on inquiry, 5Es Instructional Model**

Another facet of Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approach that supported higher order thinking and reasoning was their commitment to inquiry learning and their use of the 5Es constructivist instructional model. Basing their lessons on *Primary Connections* resources and the 5Es constructivist inquiry model (Bybee et al., 2006; Hackling et al., 2007; Skamp, 2012), Sandra (CS 1), and Christine and Melanie (CS 2) fostered student inquiry through the use of hands-on, student-focused, activity based, authentic activities and investigations that required students to find solutions to problems (KF 4.3, 4.5, 4.7, 4.15, 5.5, and 5.09). They constructed lesson and activity sequences, which provided students with greater structure and support earlier in the units; which tapered off as conceptual understanding and students' thinking and reasoning skills were becoming more refined (KF 4.7, 4.9, 4.10, 5.5, 5.6, 5.9, 5.10, 5.11 and 5.16), opportunities to explore and investigate phenomena and science ideas prior to teacher explanation of them (Chen & Tytler, 2017) (KF 4.9, 4.10, 5.5, 5.16) and opportunities to extend and apply their new understandings to new situations that required more complex levels of thinking in the form of creativity, innovation and reasoning (KF 4.15, 5.15 and 5.25).

**Assertion 6.4**
Sandra (CS 1), and Christine and Melanie (CS 2) facilitated students' thinking, reasoning and conceptual development through the use of the 5Es model and by monitoring, scaffolding, supporting, guiding, modelling and responding to students' ideas rather than simply delivering information. Students in both case studies were given the responsibility for their own thinking and learning through hands-on inquiry, student-focused activity-based investigations and problem solving activities that engendered exploration, problem solving and creativity.

**Facilitation, modelling and opportunities for lots of talk and collaboration**

Sandra's (CS 1), and Christine and Melanie's (CS 2) adoption of facilitation (KF 4.8 and 5.6), modelling and provision of lots of time for students to talk and collaborate, strongly contributed to the development of students' higher order thinking and reasoning. Supporting the contemporary notion that transmissive education hinders higher order thinking, creativity and inquiry (Stewart, 2012), Sandra (CS 1), and Christine and Melanie (CS 2) facilitated students' active participation in exploring ideas and reasoning and "monitored, shaped, and responded to students' ideas rather than simply delivering knowledge" (Chen & Tytler, 2017, p. 95). When students struggled with tasks, Sandra (CS 1), and Christine and Melanie (CS 2) often modelled processes and skills that students lacked, in order to bring tasks within the students' zone of proximal development (Vygotsky, 1978); being careful to only give students a step-up rather than all the skills and knowledge required to complete the tasks, which ensured students' autonomy of their learning (KF 4.12, 5.26 and 5.27).

In both case studies talk and collaborative learning played key roles in stimulating and extending students' thinking and learning (Alexander, 2014; Gillies, 2016). Favouring a dialogic type approach to teaching and interacting with their students (Alexander, 2014; Gillies, 2016; Scott & Meiers, 2009) (KF 4.24), Sandra (CS 1), and Christine and Melanie (CS 2) orchestrated opportunities and time for students to collaboratively talk, discuss and think through science ideas, to reason and to engage in meaning making with others (Mortimer & Scott, 2003) (KF 4.3, 4.5, 4.6, 4.8, 4.11, 4.21, 4.26, 5.3, 5. 4, 5.6, 5.10 5.13, 5.14, 5.15 and 5.20). To facilitate this Sandra (CS 1), and Christine and Melanie (CS 2) set up their respective classroom spaces for students to move between multiple configurations and instructional settings (Roskos & Neuman, 2011) that supported paired, small group and whole class talk and discussion (KF 4.6, 4.8, 4.11, 4.26, 5. 4, 5.6, 5.13, 5.14, 5.15 and 5.20) (Figures 4.3 and 5.2).

It is interesting to note that Sandra (CS 1), and Christine and Melanie (CS 2) used instructional settings (i.e., paired work, small group work and whole class work), quite differently to create opportunities for collaboration and higher order thinking and reasoning. Sandra's class (CS 1) for example, spent nearly double the amount of time engaged in small group work than Christine and Melanie's class (CS 2) (CS 1 - 32%, CS 2 - 19%) (KF 4.8, KF 5.4), whilst Christine and Melanie's class (CS 2) spent just over 10% more time in whole class collaboration than Sandra's class (CS 1) (CS 1 – 49%, CS 2 – 60%) (KF 4.8, 5.4). Teacher preference, for example Sandra's (CS 1) preference for small group work (KF 4.6) and contextual differences between the two case studies such as class size and room set-up, for example Christine and Melanie's (CS 2) large class and lack of furniture (KF 4.8 and 5.4) influenced this.

To compensate for their large class, Christine and Melanie (CS 2) adapted their instructional approach to optimise student participation and collaboration by giving students many opportunities during whole class activities to turn to their partner and quickly share and discuss their ideas before whole class sharing and discussion (KF 5.4, 5.6, 5.13 and 5.14).

**Assertion 6.5**
In both case studies talk and collaboration played key roles in stimulating and extending students' thinking and reasoning. Students were given many opportunities to talk and discuss their ideas throughout the unit. Due to contextual differences between the case studies relating to class size and classroom settings, the orchestration of these opportunities differed between the two case studies. In CS 1 much of the talk and collaboration occurred during small group work and class discussions. In CS 2; with the class size double that of CS 1 and the classroom being a large communal space devoid of furniture, Christine and Melanie (CS 2) favoured whole class discussions interspersed with many quick think-pair-share sessions to maximise talk and collaboration opportunities.

**Metacognition**

Sandra (CS 1), and Christine and Melanie (CS 2) explicitly taught and scaffolded the development of students' metacognitive skills and utilised metacognitive strategies to scaffold and support thinking and reasoning. Sandra (CS 1), and Christine and Melanie (CS 2) supported and guided the development and application of students' metacognitive knowledge of tasks and thinking strategies. This was particularly evident during the early stages of open investigations and problem solving tasks with Sandra (CS 1), and Christine and Melanie (CS 2) observing students' strategies. Using open-ended questions and neutral responses they encouraged students to reflect on their thinking, ascertained whether students were on the right track; and, if students required assistance, they were guided and scaffolded in relation to "what thinking strategies they can accomplish, about when, why, and how to use these strategies and about the goals and requirements of tasks" (Zohar & Barzilai, 2015, p. 230) (KF 4.7, 4.9, 4.10, 4.18, 4.20, 4.21, 4.22, 4.23, 5. 10, 5.12, 5.16 -5.18, 5.20 and 5.22).

Sandra (CS 1), and Christine and Melanie (CS 2) also supported and guided the development and application of students' metacognitive skills such as monitoring and self-regulation throughout their lessons. Research indicates that metacognitive awareness and self-regulation are essential for the development of higher order thinking and reasoning (Flavell, 1979; Gillies, 2016; Murray, 2014; Zohar & Barzilai, 2015). Sandra (CS 1), and Christine and Melanie (CS 2) promoted self-regulation in their classes especially in the area of students taking responsibility for their own thinking and learning (KF 4.13 and KF 5.16). Students were reminded throughout activities to draw upon their metacognitive skills to monitor, control and regulate their own learning (Zohar & Barzilai, 2015) (KF 4.21, 4.24, 5.21 and 5.22). Murray (2014) suggests that helping students to be aware of how they learn and their capacity for learning, helps them to self-monitor and self-assess. Zimmerman (1986) adds to this by stating that when students are actively engaged in metacognition they also self-evaluate during the learning process.

To progress beyond the level of self-evaluation and self-regulation it is also important to train students to be independent learners who can critically think. The metacognitive skill of questioning enhances inquiry learning by helping students think about what they think and to ask the right questions, for example the 'Why' questions, the 'What if' questions and 'How' questions (Chesser, 2014).

During both case studies metacognitive strategies were taught, modelled, scaffolded, reinforced and practiced; to support and scaffold students' reasoning, argumentation, metacognitive awareness, self-regulation and questioning (KF 4.18 and 5.17). Strategies such as thinking-out-loud (KF 4.19, 4.26 and 5.3); sharing of thinking processes (KF 4.4, 4.21, 5.3, 5.6, 5.17, 5.19 and 5.20) and students asking the right question, were scaffolded and supported through teacher prompts and questions (KF 4.17, 4.18, 4.19, 4.21, 4.22, 5.3, 5.11, 5.17, 5.20, 5.22, 5.25 and 5.26), teacher modelling (KF 4.15, 4.18, 4.20, 4.24, 5.18, 5.21, 5.25 and 5.26) and the showcasing of expert students' thinking processes (KF 4.20 and 5.8). These strategies made thinking and metacognition accessible and visible (A. Collins et al., 1991) and provided frameworks for students to build their thinking (KF 4.19, 4.20). For example, Hot seat and Fish bowl strategies used by Sandra in CS 1 showcased 'expert' students' thinking, reasoning and use of metacognitive skills; and, afforded students opportunities to observe and then trial the skills that they observed. In CS 2, Christine and Melanie used frequent think-pair-share sessions to achieve similar aims to those of the Hot seat and Fish bowl strategies in CS 1.

The Think-pair-share strategy used in CS 2 however differed from the Hot seat and Fish bowl strategies in CS 1 in that it was conducted multiple times in short sharp bursts across lessons instead of a concentrated chunk of time (KF 4.19, 4.20, 4.26, 5.6 and 5.19).

Additionally Sandra (CS 1) promoted metacognition through strategies such as the Learning train, Sticky note fact graph, WILF and TIB (KF 4.13, 4.14, 4.16 and 4.18) and the Big picture question (KF 5.17, 5.20 and 5.21). The Learning train in CS 1 was particularly interesting. When students appeared to be off track or were having difficulty, Sandra typically would call out, "Who's fallen off the Learning train?"(KF 4.18). Sandra used WILF and TIB in a similar way. These were very successful real time prompts for students to assess where they were at in their learning and to change tack if necessary. Similarly in Christine and Melanie's (CS 2) lessons the Big picture question strategy provided students with a framework to anchor their prior knowledge, to focus and monitor their learning and to make connections between concepts and cognitive skills (KF 4.15, 4.16 and 4.18).

The Big picture question provided a framework and a process for students to build and deepen their conceptual knowledge and cognitive skills across the whole unit (KF 5.16). Students updated their A3 Big Picture sheet with new knowledge, thinking and ideas three times across the unit and as they did this, Christine and Melanie (CS 2) scaffolded their metacognition by asking students questions similar to "How am I going?" "Where am I going?" and "Where to next?" which enhanced their self-regulation (Hattie & Timperley, 2007) (KF 5.16 – 5. 18).

In summary, metacognition was a feature of both case studies and was an integral part of the scaffolding and supporting of higher order thinking and reasoning in Sandra's (CS 1), and Christine and Melanie's (CS 2) case studies. Metacognition was encouraged and metacognitive skills were taught, modelled, scaffolded, reinforced and practiced to support and scaffold students' reasoning, argumentation, metacognitive awareness and self-regulation.

**Assertion 6.6**
Metacognition featured prominently in each case study and was a crucial component in the development of high order thinking and reasoning. Sandra (CS 1), and Christine and Melanie (CS 2) taught, supported and guided the development and application of students' metacognitive knowledge to tasks and metacognitive strategies such as reflective thinking, monitoring and self-regulation through the use of informal pedagogies and strategies such as thinking-out-loud; sharing of thinking processes; teacher prompts and questions; teacher modelling and the showcasing of expert students' thinking processes; and, formal pedagogies and strategies such as Hot seat, Fish bowl, Learning train, Sticky note fact graph, WILF and TIB and Big picture question.

A strong thinking learning environment and metacognitive awareness and strategies were vital for the successful implementation of teaching learning and tasks. Learning tasks in both case studies were planned and sequenced to scaffold and support students' higher order thinking and reasoning skills.

**Instructional approach discussion**

Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches were similar, reflected their beliefs (Figure 6.4) and provided a foundation for their pedagogies and strategies, which supported higher order thinking and reasoning. They shared the following features: a safe and supportive classroom learning environment, hands-on inquiry supported by the 5Es instructional model, facilitation as a way of instruction and lots of talk and collaboration. A key finding of this study is that both case studies' instructional approaches closely aligned with the tenets of inquiry teaching and learning, which the Inter-Academies Panel (2010) states "goes beyond manipulation of materials to the key factor of engaging students in identifying relevant evidence, in critical and logical reasoning about it and reflection on its interpretation" (p. 4); and, therefore enhances higher order thinking and scientific reasoning.

| Anderson's (2002) characteristics of inquiry teaching and learning | | Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches |
|---|---|---|
| **Teacher's role:** as a coach and facilitator. | • Helps students process information<br>• Communicates with groups<br>• Coaches students' actions<br>• Facilitates student thinking<br>• Models the learning process<br>• Flexible use of materials | • Facilitation, coaching, scaffolding, supporting and modelling of students' thinking, reasoning and learning (KF 4.8, 4.9, 4.11, 4.12, 4.15, 4.17, 4.18, 4.20, 4.24, 4.26, 5.4, 5.9, 5.10, 5.12-14, 5.17-19, 5.22-5.23 & 5.26-28)<br>• Promoter of lots of talk, discussion and collaborative work (e.g. pairs, small group and whole class work) (KF 4.3-5, 4.8, 4.11, 4.21, 4.26, 5.3, 5.4, 5.6, 5.10, 5.13, 5.17, 5.19 & 5.27) |
| **Student's role:** as a self-directed learner. | • Processes information<br>• Interprets, explains, hypothesises<br>• Designs own activities<br>• Shares authority for answers | • Actively engaged in reasoning and exploring ideas (KF 4.6, 4.11, 4.15-18, 4.20, 4.21, 4.23, 4.25, 4.26, 5.3, 5.5, 5.10, 5.12, 5.13-16(a-c), 5.18 & 5.19-5.25)<br>• Responsible for their own learning and thinking journey (KF 4.11, 4.13-15, 4.19, 4.20, 4.24, 5.12, 5.17 & 5.28)<br>• Self-directed explainer and interpreter of knowledge (KF 4.13, 4.18, 5.16 & 5.25)<br>• Designs own investigations (KF 4.9, 5.16, 5.21, & 5.22) |
| **Nature of student work:** student-directed learning. | • Directs own learning<br>• Tasks vary among students<br>• Design and direct own tasks<br>• Emphasises reasoning, reading and writing for meaning, solving problems, building from existing cognitive structures, and explaining complex problems | • Hands-on, student-centred, activity-based inquiry learning (KF 4.3 & 5.5)<br>• Students free to explore and investigate (KF 4.21 & 5.25)<br>• Emphasis is on argumentation and justification of ideas with reasoning (KF 4.9, 4.15, 4.17-19, 4.23, 4.25, 5.3, 5.10 & 5.22)<br>• Application of knowledge to solve authentic and engaging real life problems (KF 4.5, 4.15, 5.15 & 5.24) |

**Figure 6.5: Case study teachers' instructional approach mapped alongside Anderson's (2002) description of inquiry adapted from Table 1, (Anderson, 2002, p. 5)**

This is demonstrated in Figure 6.5 where the common features of their instructional approaches have been mapped alongside Anderson's (2002) characteristics of inquiry teaching and learning and fit comfortably into his framework which delineates inquiry teaching and learning according to teacher's role, student's role and nature of student work (See also Figure 6.6, Levels 1 -3). During the cross-case analysis it also became evident that the facets of Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches (Caine & Caine, 2014b); highlighted in the above sections, worked in combination and at different levels to underpin the implementation of pedagogies and strategies that were employed to develop higher order thinking and reasoning.

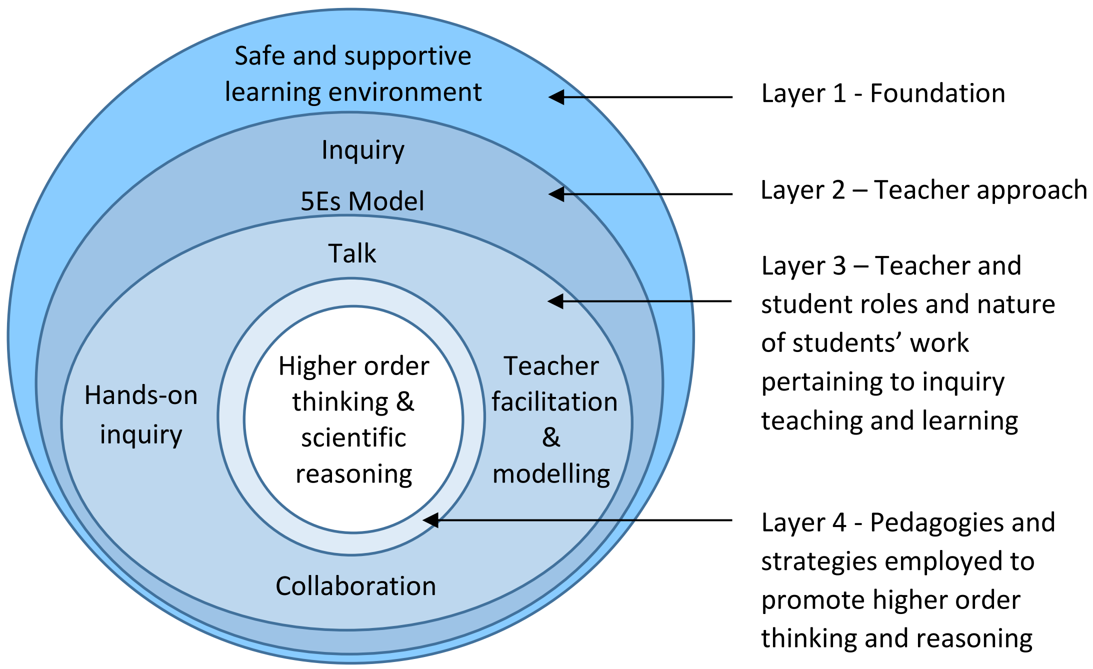



**Figure 6.6: Layers in Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches contributing to the development of higher order thinking and reasoning**

A converging concentric circular model diagram (Figure 6.6) (Bronfenbrenner, 1989; Hackling, Chen, et al., 2017) illustrates how the different facets or layers of Sandra's

(CS 1), and Christine and Melanie's (CS 2) instructional approaches interacted and collectively influenced the development of higher order thinking and reasoning during the teaching of their units.

Layer 1 represents the importance and foundational role of having a safe and supportive learning culture and environment upon which all of the other facets of their instructional approaches (Layers 2 and 3) and the success of pedagogies and strategies (Layer 4, which will be addressed in depth in the following section) were dependent upon. Layer 2 of the model represents the teachers' overall focus on inquiry learning and adoption of the 5Es model for sequencing activities and lessons for building students' knowledge and thinking and reasoning skills. Layer 3 highlights the complementary nature of teacher and students' roles and the nature of student work (Anderson, 2002), where facilitation and modelling were the main modes of teacher instruction and students were self-directed learners engaged in talk, hands-on inquiry and collaboration (refer back to Figure 6.5). Layer 4 of the model represents pedagogies and strategies employed to scaffold, support and create opportunities for higher order thinking and reasoning. Key to the success of these pedagogies and strategies was the solid foundation provided by the instructional facets in Layers 1-3.

It was through the combination of instructional factors underpinning Sandra's (CS 1), and Christine and Melanie's (CS 2) pedagogies and strategies that students were able to be scaffolded, supported and given opportunities to develop higher order thinking and reasoning skills.

**Assertion 6.7**
Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches reflected their beliefs and closely aligned with the characteristics of inquiry teaching and learning, which engages students in evidence finding, interpretation and critical and logical reasoning and therefore enhances higher order thinking and scientific reasoning.

**Assertion 6.8**
Facets common to Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches, namely: the provision of a safe and supportive classroom learning environment; hands-on inquiry supported by the 5Es instructional model; facilitation as a way of instruction and lots of talk and collaboration, worked in combination and at different levels of influence, as a foundation for pedagogies and strategies employed to scaffold, support and create opportunities for higher order thinking and reasoning.

The following section compares pedagogies and strategies Sandra (CS 1), and Christine and Melanie (CS 2) employed to scaffold, support and create opportunities for higher order thinking and scientific reasoning.

## Pedagogies and strategies

A strong focus in this study was to identify what pedagogies and strategies scaffold, support and create opportunities for higher order thinking and scientific reasoning; and, how they were used. Cross-case analysis revealed that there were six categories of pedagogies used by Sandra (CS 1), and Christine and Melanie (CS 2) that worked in combination to scaffold and support the development of their students' thinking and reasoning.

- Overt thinking and reasoning culture
- Metacognition
- Learning tasks
- Representations
- Discourse-based pedagogies and strategies
- Body-based experiences

As previously discussed a major feature of both case study classrooms was an established safe and supportive learning environment and classroom culture. An extension to this, is that the teachers established a strong and overt thinking and reasoning learning culture in their respective classrooms, which permeated across activities and lessons and was pivotal in scaffolding and supporting the development of students' thinking and reasoning skills.

**Overt thinking and reasoning culture**

There is an abundance of research literature relating to the positive influence of classroom culture on student learning and achievement and the development of thinking, reasoning and argumentation (for example, Alexander, 2014; Hackling, 2014; Jimenez-Aleixandre et al., 2009; Martin et al., 2012; Naylor et al., 2007; Stewart, 2012). However, there appears to be little discussion in the literature on how classroom culture; beyond it being influential in helping students to feel safe to share and have their ideas critiqued, can actually be directly involved in developing students' thinking and reasoning. An original feature of this study is that it identifies that a strong and overt thinking and reasoning learning culture or focus can play an integral role in the development of students' higher order thinking and reasoning skills.

Sandra (CS 1), and Christine and Melanie (CS 2) built upon their existing safe and supportive classroom environments, and, created strong and overt thinking and reasoning learning cultures in their classrooms that were central and foundational to the development of their students' thinking and reasoning (KF 4.17, 4.19, 4.20, 5.3, 5.10 and 5.27). In both case studies students were immersed in a culture where thinking and reasoning were commonplace and the development of these skills was as much a part of their learning as the development of conceptual understanding. With thinking and reasoning engrained in their classroom learning cultures, students were provided with an environment and platform that encouraged them to think deeply, to question, to verbally share their thoughts, to co-construct arguments with others (KF 4.17-4.19, 4.22, 5.19, 5.22, 5.25) and to justify their claims with reasons (KF 4.13, 4.18, 4.19, 5.3, 5.10).

Creating, establishing and maintaining a thinking and reasoning learning culture was very much a part of Sandra's (CS 1), and Christine and Melanie's (CS 2) lesson planning, activity selection, instructions and discussions (KF 4.8, 4.10, 5.9, 5.10 and 5.21). The processes of thinking and reasoning were prominent features in lessons and were continually talked about and included in discussion of intended learning outcomes at the commencement of lessons (KF 4.15 and 5.16,). Thoughts and reasons were requested, highlighted, modelled (KF 4.12, 5.10, 5.25 and 5.26), scaffolded (KF 4.9, 4.11, 4.17,4.18, 4.26, 5.12-5.14, 5.17, 5.18, 5.20, 5.26 and 5.27), prompted (KF 4.17- 4.19, 4.21, 4.22, 5.22, 5.25 and 5.26), discussed (KF 4.3, 4.8, 4.21, 4.25, 4.26, 5.3, 5.4 and 5.6), questioned (4.19-4.22, 5.6, 5.10, 5.16, 5.20, 5.22 and 5.26), challenged (KF 4.28 and 5.25-5.28), drawn out (KF 4.12, 4.26 and 5.19) and extended (KF 4.19, 4.22, 4.25, 5.19 and 5.20).

Sandra's (CS 1), and Christine and Melanie's (CS 2) thinking and reasoning cultures placed the ownership of thinking directly on the students. Students were consciously aware of the expectation for them to be involved in and to develop their own thinking and reasoning skills. This was communicated continually (verbatim and/or inferred) during lessons across both case study units via four key teacher messages: "I'm interested in what you are thinking", "I'm interested in how you are thinking" and "I'm interested in you developing your thinking and reasoning" and "It is important for now and later life to learn how to think and reason". These messages were reinforced by allocating time to students for the processing and development of their thinking and reasoning. Students were given 'talk time' (Mercer, 2008), which encouraged students to think-out-loud; 'sharing time', for students to work collaboratively (Gillies, 2016) with others in pairs, small and whole class groups (KF 4.4, 4.19, 4.21, 4.26, 5.1, 5.3, 5.6, 5.19, 5.27) and 'thinking time' and 'wait time' (Rowe, 1972; Smith, 2013) to access, process, formulate and build their thoughts and ideas.

**Assertion 6.9**

In both case studies a strong overt thinking and reasoning culture played an integral role in the development of students' thinking and reasoning skills by promoting thinking and reasoning as an important outcome of lessons alongside the development of conceptual understanding. It placed the responsibility for thinking and reasoning on the student and provided an environment and platform that encouraged students to think deeply, to question, to verbally share their thoughts to co-construct arguments with others and to justify their claims with reasons. Speaking about, highlighting, modelling, discussing, prompting, scaffolding and extending thinking and reasoning continually during lessons also heightened students' awareness of the importance of these skills for their education and as necessary life skills.

The strong and overt thinking and reasoning learning culture in both cases immersed students in a thinking and reasoning environment. The teaching of metacognitive skills and use of metacognitive strategies further supported students' development of higher order thinking and reasoning skills. It helped them to take responsibility for their own learning and to become independent thinkers and learners.

**Learning tasks**

Sandra (CS 1), and Christine and Melanie (CS 2) also scaffolded and supported their students' thinking and reasoning through their selection and sequencing of learning tasks. Their choice of learning tasks was consistent with the *Australian Curriculum: Science* aims; in that they coupled the development of students' science knowledge with a strong focus on the development of students' thinking and reasoning skills. In both case studies students' conceptual understanding and cognitive skills were developed together in learning tasks. The coupling of these processes was in itself a form of scaffolding and support for the development of students' thinking and reasoning.

***Coupling of cognitive and conceptual development***

As previously stated , when teaching through inquiry "thinking skills are embedded in rich science contents and are also addressed as explicit educational goals" (Zohar & Dori, 2003, p. 153). Without having something to think about and to think with; that is content or conceptual knowledge, it is difficult to teach higher order thinking and reasoning skills. To develop Blooms' higher-level cognitive skills of applying, analysing, evaluating and creating, students require conceptual knowledge to work with. Analysis of CS 1 and CS 2 revealed that learning tasks and activities were purposely planned and sequenced to build students' cognitive skills and conceptual understandings concurrently (KF 4.9, 4.10, 5.9 and 5.15).

Studies have indicated that there are benefits from teaching conceptual understanding and cognitive skills together. Bao, Fang, et al. (2009) for example, reported that the development of students' content knowledge can have a significant impact on students' ability to solve analytical problems and "that a balanced method of education, such as incorporating more inquiry-based learning that targets both [cognitive and conceptual] goals" should be invested in by educators (Bao, Cai, et al., 2009, p. 587). It also interesting to note that studies have also indicated the reverse relationship; that is cognitive skill development can have a positive effect on content understanding. Venville and Dawson (2010), for example, reported that when argumentation skills were taught to Year 10 students, not only were there improvements in students' argumentation and informal reasoning skills but there was also an improvement in the students' conceptual understanding of science. Both case studies were similar in that their learning tasks had outcomes, which related to conceptual and cognitive skills development. They also followed a similar sequential pattern consisting of three broad types of learning tasks (Figure 6.7).

| Task type | Focus of the task | Aim of task | Examples |
|---|---|---|---|
| Type 1 | ***Main focus:*** Conceptual development ***Minor focus:*** Thinking and reasoning. | Building a conceptual base with some expectation for lower level of thinking and reasoning. | Investigations of properties of materials concepts (CS 1) and Investigation of force concepts (CS 2). |
| Type 2 | ***Main focus:*** Thinking and reasoning ***Minor focus:*** Conceptual development. | Development of thinking and reasoning skills through modelling, practice, metacognitive and collaborative tasks. | Fish bowl and Hot seat strategies (CS 1) and Big picture question, Think-pair-share and See Saw strategies (CS 2). |
| Type 3 | ***Shared focus:*** Conceptual development and thinking and reasoning. | Application of knowledge and thinking and reasoning skills to create and evaluate solutions and new knowledge. | Curtain design brief (CS 1) and designing, making, demonstrating and explaining a board game using three forces (CS 2). |

**Figure 6.7: Three types of learning tasks**

### *Sequencing of learning tasks*

Collins, Brown and Holum (1991) suggest three key principles for the effective sequencing of tasks: build a conceptual model of the whole task before separating the tasks into smaller portions, gradually increase the complexity of tasks over the sequence; and, introduce a variety of situations for students' to practice their newly acquired set of skills. These principles were adhered to in Sandra's (CS 1), and Christine and Melanie's (CS 2) activity and lesson sequences (KF 4.9, 4.10, 5.11, 5.13, 5.15 and 5.27). Emerging from the cross-case analysis was the realisation that they utilised and sequenced three types of learning tasks (Type 1 -> Type 2-> Type 3), within and across lessons to cumulatively build students' conceptual understanding and higher level cognitive skills (Figure 6. 7) (KF 4.9, 5.11 and 5.27).

The main focus of Type 1 tasks was to develop conceptual understandings with some focus on thinking and reasoning. They were introduced early in both units as diagnostic or engagement tasks and when concepts were being introduced. During these tasks, students were mostly engaged in lower order thinking such as remembering and understanding. Type 1 tasks also included investigative or exploratory tasks, for example investigating properties of materials (CS 1) (KF 4.7) and investigating of force concepts (CS 2) (KF 5.9 and 5.11). During investigations students engaged in thinking and reasoning such as applying, to explore and understand concepts. Building of conceptual understanding provided a context or something for students to think and reason with; and, something to think and reason about (KF 4.9, 4.10, 5.12, 5.19 and 5.28).

Type 2 tasks, which were introduced shortly after the initial engagement lessons focused on developing students' thinking and reasoning skills with some focus on conceptual development. These tasks utilised students' pre-existing and newly acquired understanding of concepts as a context for thinking and reasoning; and employed modelling (KF 4.12, 5.22 and 5.23), metacognitive (KF 4.14, 4.15, 4.18, 5.15, 5.17, 5.27) and collaborative (KF 4.4, 5.3, 5.6 and 5.27) tasks to provide opportunities for students to learn, practice, develop and extend their cognitive skills. Examples of Type 2 tasks and activities include Fish bowl*,* Hot seat*,* (CS 1) (KF 4.19 and 4.20), Big picture question (KF 5. 16 and 5.16a-c), Think-pair-share and *See Saw* (CS 2) (KF 5.22) strategies.

Type 3 learning tasks had a shared focus on conceptual and cognitive development and were introduced towards the end of the units when students had been exposed to the full complement of the unit's concepts and had attained and practiced their thinking and reasoning skills during Type 1 and Type 2 tasks. Type 3 tasks had the highest cognitive load of all the three types of tasks. These tasks encouraged students to apply their new knowledge to different situations, to problem solve and to create and evaluate new knowledge and solutions. In both case studies, the final task of the unit was a Type 3 task (for example, Curtain design brief (CS 1) (KF 4.9) and development of a game using forces (CS 2) (KF 5.12).

The sequencing and nature of the three types of learning tasks were used to teach, scaffold and support the development of students' higher order thinking and reasoning skills. This was achieved in three ways:

1. increasing the cognitive load of learning tasks within and across lessons over learning task sequences (Type 1 -> Type 2 -> Type 3),
2. increasing the expectation for students to think and reason independently as the unit progressed, and,
3. fading or reducing the level of scaffolding and support given to students as they became more proficient in their thinking and reasoning abilities (Woolley & Jarvis, 2007).

**Assertion 6.10**
Sandra (CS 1), and Christine and Melanie (CS 2) sequenced learning tasks to build conceptual understanding and to scaffold and support the development of thinking and reasoning. The building of conceptual understanding in learning tasks was integral, which was demonstrated in that all learning tasks had a conceptual and cognitive component. The expectation for students to think and reason independently increased as tasks along the learning sequences became cognitively more demanding moving from lower order thinking and reasoning tasks in the beginning of the sequences to higher order thinking and scientific reasoning tasks at the end of the sequences. In the beginning of learning sequences students were highly scaffolded and supported but as students became more proficient conceptually and cognitively the support and scaffolding was proportionally reduced or faded.

Many of the learning tasks spoken about in this section were representational tasks. The following discussion will relate to how Sandra (CS 1), and Christine and Melanie

(CS 2) used representations to scaffold, support and create opportunities for thinking and reasoning.

**Representations**

Consistent with sociocultural, social constructivist and social semiotic theories (Hackling et al., 2013; Tytler & Prain, 2010) and similar to quality teachers throughout Australia and internationally (Tytler, Murcia, et al., 2017), Sandra (CS 1), and Christine and Melanie (CS 2) routinely incorporated and coordinated the use of multiple representations across modalities (for example, verbal, written, graphical and body-based or embodied) in their teaching (Ibrahim-Didi et al., 2017; Waldrip et al., 2010) (KF 4.9, 4.11, 4.12, 4.14, 4.26, 5.3, 5.7, 5.15, 5.17, 5.18, 5.20 and 5.23-5.28).

Representations were used in both case studies for motivating students, to accommodate different student learning styles, for communicating ideas and for monitoring and assessing students' work. In relation to the research questions they were also used by Sandra (CS 1), and Christine and Melanie (CS 2) to build and mediate students' conceptual understandings and to develop and create opportunities for thinking and reasoning (Hackling et al., 2013; Tang et al., 2014; Tytler et al., 2009; Tytler, Murcia, et al., 2017; Tytler, Prain, Hubber, & Haslam, 2013; Waldrip & Prain, 2017; Waldrip et al., 2010) (KF 4.9, 4.11, 4.12, 4.14, 4.26, 5.3, 5.15, 5.17, 5.18, 5.20, 5.21 and 5.26-5.28).

Due to the differences in topics and teachers' beliefs and practices, it was not surprising that there were some distinguishable differences in the use of representations between the two case studies. In CS 1 for example, there didn't appear to be a stand-out or dominant mode of representation used during the unit but overall, representations appeared to be highly verbal and promoted language-based thinking and reasoning (KF 4.3, 4.11, 4.12, 4.16 and 4.26). In contrast, the majority of representations in CS 2 were highly embodied or body-based (KF 5.7, 5.23, 5.24, 5.25, 5.27 and 5.28), which was to be expected due to the abstract nature of the Force*s* concepts and Christine and Melanie's (CS 2) belief in kinaesthetic learning and 'putting students into their learning' (Hackling et al., 2013) (KF 5.7 and

5.23). This discussion focuses on representations at the macro level and how representational challenges such as representation generation, construction and re-representations that create opportunities for higher order thinking and reasoning are built upon students' conceptual knowledge and lower order thinking and reasoning skills developed during teacher generated, constructed and directed representations. The specifics and affordances of verbal discourse and body-based strategies as representations will be discussed following this section.

***Representations promoting lower level thinking and reasoning***

Inspection of representational use across the two case studies revealed that the type, structure, function and level of thinking and reasoning afforded by representations changed across both units of study in similar ways. Similar to general learning tasks (A 6.7), representations in the first half of both case studies were largely utilised for the development of students' conceptual understandings and lower level thinking and reasoning (KF 4.9 and 5.28).

Early in conceptual development, representations were mostly teacher generated and directed; and, linked together in sequences particularly when complex concepts were being taught (Prain & Tytler, 2012) (KF 4.5, 4.8-4.10, 4.14, 4.19, 4.20, 5.15, 5.16, 5.7 – 5.18 and 5.21). Opportunities for thinking and reasoning (albeit lower level thinking and reasoning) occurred during Sandra's (CS 1), and Christine and Melanie's (CS 2) interactions with students as they worked through representations. Congruent with other studies, (for example, Tang et al., 2014; Tytler, Murcia, et al., 2017; Waldrip & Prain, 2017), thinking and reasoning occurred in both case studies during teacher initiated conversations regarding: the interpretation of representations; the linking and transferring of salient points of understanding between representations; the referring back and forth to representations to highlight key and common features of and between representations; and, when establishing relationships between representations and the phenomenon being taught (Tytler, Murcia, et al., 2017) (KF 4.9-4.11, 5.13, 5.15, 5.24, 5.26 and 5.27).

Teacher generated and directed concept building representations used early in CS 1 and CS 2 were rudimentary for students' later development of higher order thinking and reasoning skills. Sandra's (CS 1), and Christine and Melanie's (CS 2) exemplification and use of representations and representation construction demonstrated to students how representations could be used as a "thinking tool" (Waldrip et al., 2010, p. 69), and how they could learn, think and justify claims through representations (Waldrip & Prain, 2017) (KF 4.17, 4.19, 4.20, 5.10, 5.16 – 5.18). Their use also modelled "the modes, forms, conventions and interpretations" of representation construction (Waldrip et al., 2010, p. 72) which was essential for students to generate and construct their own representations and to engage in higher order thinking and reasoning (Tytler, Prain, Hubber, & Waldrip, 2013).

***Representations promoting higher order thinking and reasoning***

After students developed a level of conceptual understanding and low level thinking and reasoning, Sandra (CS 1), and Christine and Melanie (CS 2) created opportunities for students to apply their new knowledge and to extend their thinking and reasoning skills. This was done by shifting the focus of representations from teacher generated, teacher constructed and teacher directed to student generated, student constructed and open task representations that received little teacher direction. In both case studies opportunities for higher order thinking and reasoning were created through the introduction of representational challenges, which included students generating and constructing their own representations and re-representations (KF 4.9, 5.12, 5.21 and 5.26).

Research indicates that representational challenges involving generation and construction of representations and re-representations, promotes quality learning by stretching students' thinking, reasoning, learning and creativity (Prain & Tytler, 2012; Tytler et al., 2009). It promotes thinking and reasoning by affording gains in student argumentation and reasoning, particularly when students "explain, justify, and refine their own representations of scientific processes" (Prain & Tytler, 2012, p. 2768) and also encourages students to engage in higher levels of thinking and reasoning such as critical and creative thinking and problem solving (R. Collins, 2014; Tytler et al., 2009; Tytler, Prain, Hubber, & Waldrip, 2013; Waldrip & Prain, 2017).

Higher order thinking and reasoning largely occurred during student-teacher interactions or negotiations (Tytler, Prain, Hubber, & Waldrip, 2013) regarding students' planning, construction, interpretation, explanation and evaluation of their newly constructed representations (KF 4.9, 4.17, 5.12, 5.22, 5.25 and 5.26,). Similar to the process of fading described in the cognitive apprenticeship model (Woolley & Jarvis, 2007), students were scaffolded for initial representational challenges but the level of scaffolding was incrementally reduced , to a minimal amount in the final lessons of both units as students learnt the conventions and skills for representation construction and re-representations and were becoming adept at higher order thinking and reasoning skills such as problem solving and critical thinking (KF 4.9, 4.11, 4.17, 4.26, 5.12, 5.13, 5.21, 5.22 and 5.26).

***Final assessment tasks***

The final assessment tasks in both case studies were the ultimate representational challenge and created the greatest opportunity for higher order thinking and reasoning in each unit (KF 4.9 and 5.12). Students needed to draw upon their conceptual understandings; thinking and reasoning skills (Krathwohl, 2002); and, skills in representation construction and re-representing practiced during the units, to complete the tasks (KF 4.11, 4.15, 4.17, 4.18, 4.20, 4.25, 5.14, 5.20, 5.26-5.28).

Both assessment tasks involved creating (refer to the middle of Figure 6.8), which Bloom classifies as the highest order cognitive skill. A comparison of the two final assessment tasks suggests that due to the nature of the CS 1 curtain task (KF 4.9) being more teacher generated, directed and scaffolded that the CS 2 game task (KF 5.12) was the more cognitively challenging of the two; nevertheless both tasks resulted in students applying their knowledge and engaging in higher order thinking and reasoning (Figure 6.8). It was also interesting that Sandra (CS 1) reduced the cognitive challenge of the curtain task by providing some general steps for students to follow, supplied a range of resources for students to choose from, gave students several opportunities to receive advice from a critical friend and questions to scaffold their written explanations and reasoning (KF 4.9). In direct contrast Christine and Melanie's (CS 2) final assessment task was more open in every way and apart from the brief given to students, little scaffolding or support was given to students to complete the task (KF 5.12).

***Determination of cognitive challenge of representations***

A finding that emerged from the cross-case analysis of representations used in the two case studies is that there were four interacting factors, namely: thinking level; representation generation; amount of teacher direction; and, level of scaffolding that affected the cognitive challenge of representations and it is the combination of where those factors lay on their individual continuums that influenced the overall cognitive challenge of representations. Figure 6.8 illustrates how each of the four factors worked in combination to influence the cognitive challenge of representations. Bloom's (revised) hierarchy of cognition (Krathwohl, 2002) illustrated as a converging concentric circle model has been used as an underlay in Figure 6.9 to indicate the cognitive level of different locations on each continuum.

When Sandra (CS 1), and Christine and Melanie (CS 2) used representations to build conceptual understanding and lower level thinking such as remembering and understanding, the factors structuring their representations were on the outer ends of the four continuums (i.e., representations were teacher generated, teacher directed, had a high level of scaffolding and an expectation for low level thinking and reasoning) (KF 4.11, 4.15, 4.17, 4.18, 4.20, 4.25, 5.14, 5.20 and 5.26-5.28). As continuums work, when mid-level thinking such as applying and analysing were required from students, the representational were mid-way along continuums; and, when higher levels of thinking such as evaluating and creating were required from students, the factors structuring representations lay near the arrow end of the four continuums or the middle of the converging circle of Bloom's hierarchy. This is also evidenced in Figure 6.7 in relation to the final assessment tasks in each case study unit where the four factors structuring representations lay at the arrow end on their individual continuums and towards the inner circle of creating in Bloom's model of cognition (Krathwohl, 2002).

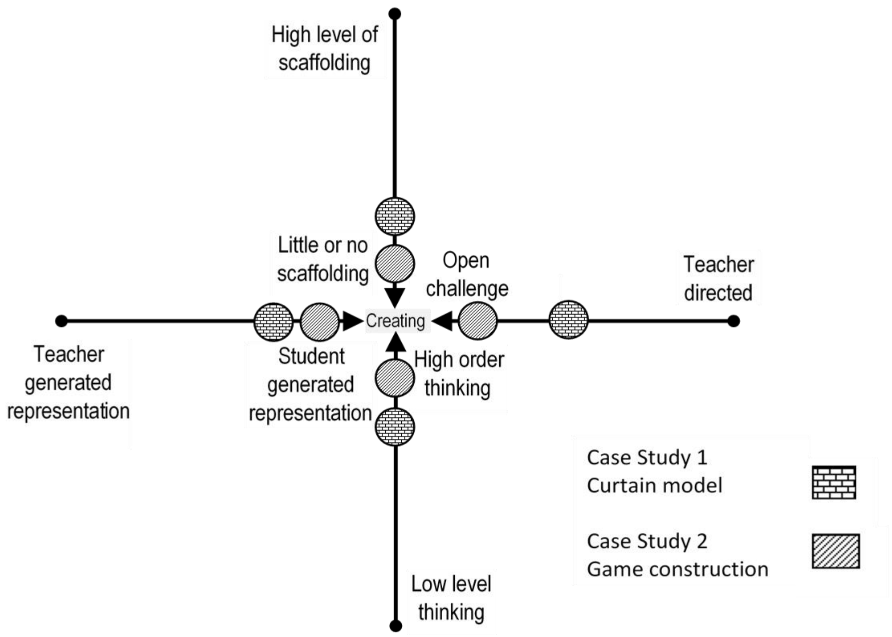



**Figure 6.8: Differences in the structure and cognitive challenge of the final assessment representational challenges in the two case studies**

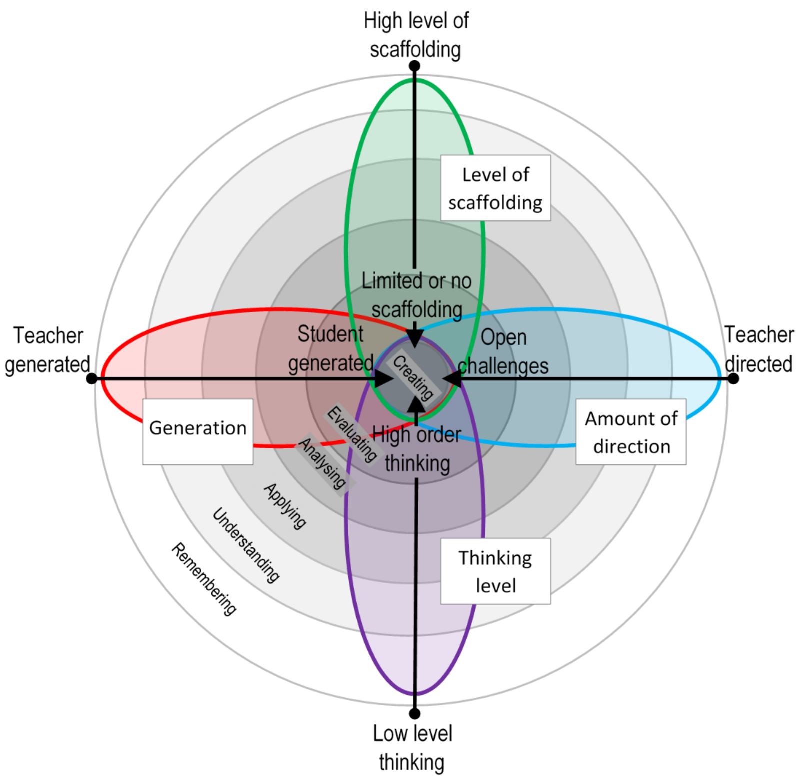



**Figure 6.9: Illustration of the four areas interacting and influencing the structure and potential cognitive outcomes of representations, overlaid on Bloom's revised taxonomy**

This section focused on representations at the macro level and how teacher directed, constructed and scaffolded representations provided an important foundation for higher order thinking and reasoning in that they built conceptual understandings and developed lower level thinking and reasoning skills necessary for higher order thinking and reasoning. Midway in the two case study units the structure of representations moved towards student generated, constructed and more open representations and scaffolding and support was faded as students level of conceptual understanding, skill in constructing and using representations and thinking and reasoning increased. Emerging from the cross-case analysis was an unexpected outcome that four factors; generation, expectation for thinking, amount of teacher direction and level of scaffolding to determine the cognitive challenge of representations.

**Assertion 6.11**
The use of representations were important for conceptual development and the scaffolding, support and creation of opportunities for thinking and reasoning in both case studies. The sequencing of representational tasks of increasing cognitive demand, the combination of teacher and student generated representational tasks, the modelling and practice of representation construction; together with, teacher-student negotiations regarding the planning, construction, interpretation, explanation and evaluation of students' constructed representations provided opportunities for the development of thinking and reasoning. Final assessment tasks, which involved students representing and constructing their own representations were the ultimate cognitively challenging task in both units and created the greatest opportunity for higher order thinking and reasoning in both case studies.

The specifics and affordances of verbal discourse and body-based strategies as representations will be now be discussed in the following sections. The verbal mode is an important and central mode of instruction. Many of the tasks Sandra (CS 1), and Christine and Melanie (CS 2) implemented into their units involved discourse and dialogic interactions (Alexander, 2014). The following section discusses Sandra's (CS 1), and Christine and Melanie's (CS 2) discourse-based pedagogies and strategies.

**Discourse-based pedagogies and strategies**

The majority of pedagogies and strategies employed by Sandra (CS 1), and Christine and Melanie (CS 2) to scaffold, support and create opportunities for higher order thinking and reasoning were discourse–based and involved dialogic interactions between teachers and students (Gillies, 2016) (KF 4.5, 4.21, 4.26, 5.4, 5.6, and 5.19). Research indicates that teacher and student discourse interactions are fundamental for engagement and communication (Alexander, 2014; Kaya, 2014); for accessing prior understandings, for meaning making (Mortimer & Scott, 2003), talking science ideas into existence (Lemke, 1998) and for making thinking visible (A. Collins et al., 1991); for shaping thoughts and for moving thinking and reasoning forward (Bruner, 1966; Gillies, 2016; Hoffmeyer, 2014; Mercer et al., 2017). There is a clear association between quality discourse, quality learning and quality thinking and reasoning (Alexander, 2017; Chin & Osborne, 2010; Gillies, 2016; Scott & Meiers, 2009; Smith, 2013; Smith & Hackling, 2016).

Sandra (CS 1), and Christine and Melanie (CS 2) harnessed the power of discourse and stimulated and extended students' critical thinking, problem solving, meaningful argumentation (Venville & Dawson, 2010) and scientific reasoning through a variety of discourse-base pedagogies and strategies (Alexander, 2014) across small group and whole class settings (KF 4.9, 4.10, 4.23, 4.24, 4.25, 5.4, 5.6, 5.27).

***Small group dialogic interactions and modelling language-based reasoning***

In CS 1, which was in contrast to CS 2, the majority of scaffolding and support of thinking and reasoning occurred during small group work through collaborative interactions resembling dialogic interactions, in that they were: collective, reciprocal, supportive and cumulative (Alexander, 2008; Gillies, 2016). Sandra (CS 1), and her students worked on tasks together, learnt from listening to and sharing ideas with each other and considering alternative viewpoints, felt safe and supported to express their ideas and worked together to reach common understandings; and, together they built on each other's ideas to formulate lines of thinking and inquiry (KF 4.3, 4.4, 4.6, 4.19, 4.21 4.22, 4.24, and 4.26).

Due to the large amount of small group work, Sandra (CS 1) was able to spend significant time interacting with individuals in small groups; monitoring and promoting collaborative and quality discourse and generating more extended and reflective thinking, essential for building the knowledge foundation required for thinking and reasoning (Mercer, 2003; Smith & Hackling, 2016) (KF 4.3-4.6, 4.8, 4.21, 4.22, 4.24 and 4.26). Taking the Vygotskian perspective that language helps us to learn ways to think (Vygotsky, 1978), Sandra (CS 1) focused strongly on language-based reasoning and built students' language and vocabulary in unison with conceptual development (KF 4.3, 4.12 and 4.16). She scaffolded students' higher order thinking and reasoning by modelling (herself and using more experienced learners) ways of asking questions, offering explanations and providing reasons (Mercer, 2003), which had a positive effect on students' problem solving and reasoning (Hackling & Sherriff, 2015) (KF 4.12, 4.18, 4.19, 4.20 and 4.24).

Whilst Christine and Melanie (CS 2) did focus on literacy and building students' language with the highlighting of new vocabulary terms on the Word Wall, language-based reasoning was not a focus in their teaching or scaffolding of higher order thinking and learning (KF 5.5 and 5.8). The context for Christine and Melanie's (CS 2) use of discourse-based and strategies differed from Sandra's (CS 1).

***Whole class interactions, think-pair-share and reporting back***

Christine and Melanie (CS 2) did not immerse themselves as fellow learners in their students' learning as was done in CS 1. They did however, promote and monitor substantive discourse interactions (Smith & Hackling, 2016) between students. This occurred mainly during whole class instructional times, discussions and investigations; which were interspersed with multiple quick think-pair-share sessions, used to maximise individual student discourse and to pace students' thinking, reasoning and learning (KF 5.6, 5.13 and 5.20). An added dimension of the Think-pair-share strategy in CS 2; which was not observed in CS 1, was the requirement for students to report back on their partner's thinking and reasoning to the class (KF 5.23). This strategy; which was frequently utilised throughout the unit (for example, during the Big picture question activity), required students to draw upon a greater set of complex cognitive skills and processes, in comparison to those needed for students to report on their own ideas (Refer to Figure 5.23) and consequently supported the development of students' thinking and reasoning skills.

***Consensus***

Another standout collaborative discourse-based strategy used in both case studies that promoted collective and individual reasoning and developed students' critical thinking, argumentation and problem solving skills, was the requirement that students work together with the purpose of reaching agreement or a consensus (Waldrip & Prain, 2017) during problem solving, investigations and discussions (KF 4.23 and 5.13). Similar to the strategy of reporting back in CS 2 (KF 5.23), this strategy required students to critically engage with each other's ideas and to justify their positions as they cooperated, considered and challenged alternate perspectives and ideas. The process and dialogue used to achieve consensus in both cases studies was very similar to Exploratory Talk (Mercer et al., 2017; Rojas-Drummond & Zapata, 2004), which is characterised as follows:

- everyone engages critically but constructively with each other's ideas;
- everyone offers the relevant information they have;
- everyone's ideas are treated as worthy of consideration;
- partners ask each other questions and answer them, ask for reasons and give them;
- members of the group try to reach agreement at each stage before progressing.
  (Littleton & Mercer, 2013, p. 16)

Sandra's (CS 1), and Christine and Melanie's (CS 2) instruction, encouragement and scaffolding of peer critique; disagreement as long as it is backed up with justification and reasons (Pieczura, 2009) (KF 4.20, 4.25 and 5.13) and students' identification and resolution of differences of opinion and defending points of view (Rojas-Drummond & Zapata, 2004) required to achieve consensus, promoted individual and group reasoning and students' capacity to argue (KF 4.18, 4.19, 4.20, 4.23, 4.25, 5.19 and 5.20). A key factor in supporting students to come to a consensus, is to ensure that students feel comfortable about sharing and arguing their ideas (Mercer et al., 2017; Rojas-Drummond & Zapata, 2004). Sandra (CS 1), and Christine and Melanie (CS 2) achieved this by providing and maintaining safe and supportive classroom environments and ensuring that students followed the 'ground rules' (Mercer et al., 2017) (KF 4.4, 4.19, 4.20, 5.3 and 5.4).

***Open questions, verbal prompts and cues***

Sandra (CS 1), and Christine and Melanie (CS 2) purposefully planned and led students through a regime of open questions (Hackling et al., 2010; Mortimer & Scott, 2003) and utilised verbal prompts and cues to build conceptual understandings and to extend students' thinking and reasoning. Open questions, verbal prompts and cues were utilised in both studies to scaffold concept development, to clarify misconceptions, to support the verbalisation of students' understandings and to afford students opportunities to extend dialogic interactions (Chesser, 2014; Chin, 2006; Chin & Osborne, 2010; Gillies, 2016) (KF 4.3-4.5, 4.8, 4.21, 4.254.26, 5.3-5.6, 5.19, 5.20, and 5.24). Open questions, verbal prompts and cues were also used to encourage students to think-out-loud and to engage, guide, focus and make explicit students' thinking and reasoning; to assist with problem solving, to provide reasons and justification for conclusions, to help students analyse, evaluate and formulate arguments, to think critically and creatively, to assist with the transfer and application of knowledge to new situations and to ask further questions; all of which are important 21st century skills required for the future workplace (Brookhart, 2010; R. Collins, 2014; Gillies, 2016; Wooi, 2014) (KF 4.5, 4.9, 4.10, 4.13, 4.15, 4.17, 4.21, 4.22, 4.25, 5.3, 5.12, 5.17, 5.19, 5.20, 5.24and 5.26).

***Scaffolding argumentation with Why? and because . . .***

In particular Sandra (CS 1), and Christine and Melanie (CS 2) frequently used the question 'Why?' and prompts and cues 'I think' and 'because' as syntactical scaffolds or language links (Hackling & Sherriff, 2015) to link claims with reasons and to assist students with verbally formulating and sharing their arguments. To illustrate how these prompts were used to scaffold argumentation in both case studies, the terms Grounds, Claim and Warrant; three essential elements from Toulmin's argumentation model (Toulmin, 1958) (Figure 6.10); a model often referred to when analysing argumentation in educational settings (Jimenez-Aleixandre et al., 2009;

Toulmin, 1958), have been used to illustrate the format of a typical reasoning and argumentation prompt sequence used by Sandra (CS 1), and Christine and Melanie (CS 2) (Figure 6.11).

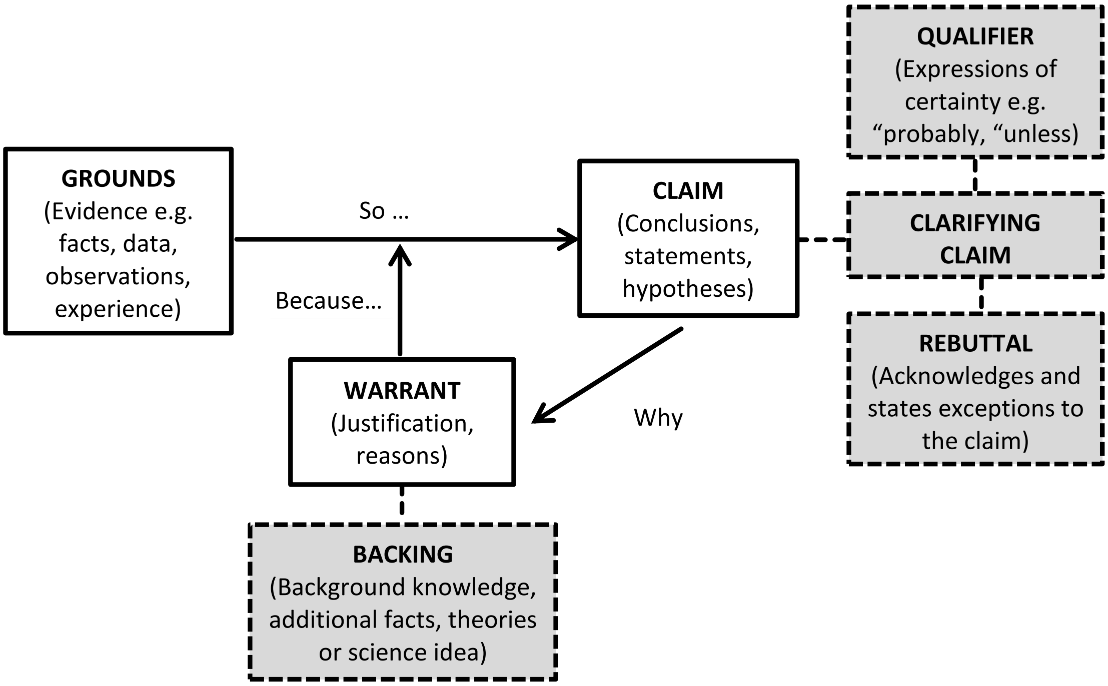



**Figure 6.10: A representation of Toulmin’s argumentation model (Hackling & Sherriff, 2015, p. 15)**


**Figure 6.11: Typical reasoning and argumentation prompt sequence used in CS 1 and CS 2**

The ‘Claim’, is a statement to be supported or disproved by evidence or data; ‘Grounds’, is evidence, for example: data, observations, facts or experiments used to evaluate a claim; and, ‘Warrant’, which is the justification or reasons relevant to the claim put forward (Jimenez-Aleixandre et al., 2009). The three additional elements in Toulmin’s argumentation model, namely: ‘Backing’, ‘Qualifiers’ and ‘Rebuttal’, which are used to clarify and support claims (Jimenez-Aleixandre et al., 2009;

Toulmin, 1958) were not focused on by Sandra (CS 1), and Christine and Melanie (CS 2) as this level of argumentation was not required for Year 4 students. A few of the more capable students in both case studies did, however, include them in the formation of their arguments.

| **Assertion 6.12** |
| --- |
| Discourse-based pedagogies and strategies in both case studies; encouraged thinking aloud, reflective thinking, language-based reasoning (particularly in CS 1 due to Sandra's belief in giving students the language to reason), and scaffolded, supported and created opportunities for higher order thinking and reasoning. Facilitated by safe learning environments, dialogic interactions between teacher and students and between students; having students come to a consensus; modelling, coaching and scaffolding of the steps involved in argumentation; challenged, shaped, extended students' individual and collaborative thinking and reasoning from lower order thinking and reasoning to higher order thinking and more complex reasoning such as critical and creative thinking. |

Sandra's (CS 1), and Christine and Melanie's (CS 2) use of discourse-based pedagogies and strategies were fundamental in scaffolding, supporting and creating opportunities for higher order thinking and reasoning. Their use of body-based pedagogies and strategies also made a significant contribution to the development of higher order thinking and reasoning during both case studies by facilitating conceptual learning, particularly in CS 2 with the abstract nature of the Forces topic.

**Body-based experiences**

Supported by the literature and studies, (Hackling & Sherriff, 2015; Lemke, 1990; Smith & Hackling, 2016; Vygotsky, 1987), the incorporation of body-based experiences or embodiment played an important part as a separate entity; and, in complement with other representational modes; such as verbal, graphical and concrete representations, in the scaffolding, support and creation of opportunities for higher order thinking and reasoning in both case studies (for example, Ibrahim-Didi et al., 2017; Ionescu & Vasc, 2014; Lindgren & Johnson-Glenberg, 2013; Wellsby & Pexman, 2014) (Figure 6.12). Real time, retrospective and imagined whole-body (KF 4.5, 4.7, 5.12, 5.23 and 5.27 and part-body experiences, such as gestures and object manipulations (KF 4.5, 4.12, 5.7, 5.24 and Figures 4.1, 4.5, 5.5 and 5.27), were incorporated into both case studies to support the building of conceptual understandings and to move thinking and reasoning forward, which was essential for higher order thinking and reasoning (KF 4.5, 4.12, 5.7, 5.24-5.26, 5.28 and 5.29). It is interesting that the frequency of use and how body-based experiences were used to achieve this, differed between the two case studies. This was due in part to differences in the case study teachers' individual teaching beliefs and styles (KF 4.3, 4.5, 5.7, 5.15, and 5.23), but mostly because of the different nature of the concepts being presented in each topic (A 6.2).

Body-based experiences were more evident and were used more frequently in the teaching of the Force*s* topic (CS 2) than in the teaching of *the* Materials and their uses topic (CS 1). Christine and Melanie (CS 2) relied upon body-based experiences to provide students access to the abstract key concepts in their unit and incorporated them into most activities as a part of the concept building process. In contrast, the key concepts in Sandra's (CS 1) topic were mostly concrete in nature; visually observable and physically accessible to students and thus the need for embodiment as a way to access the concepts was not required. Instead of relying upon body-based experiences to build conceptual learning as in CS 2, Sandra (CS 1) used body-based experiences as an ancillary representational form to recall, review, enrich, solidify and symbolise (gestures) concepts, which had already been taught through hands-on activities (KF 4.3) and to support discourse interactions and language-based reasoning (A 6.10) (Hackling & Sherriff, 2015).

Despite these differences an important finding emerging from the cross-case analysis is that the body and body-based experiences were important semiotic tools in each case study (particularly evident in the teaching of the CS 2 Force*s* topic) and were embedded in the development of conceptual understandings and the promotion of higher order thinking. They were utilised in three ways: they provided sensations or experiences of phenomena, they were incorporated as active and actual parts of students' thinking and meaning making process and they were utilised by both students and teachers as representational tools symbolising whole or part-concepts which aided students' communication and justification of ideas (Ibrahim-Didi et al., 2017) (Figure 6.12).

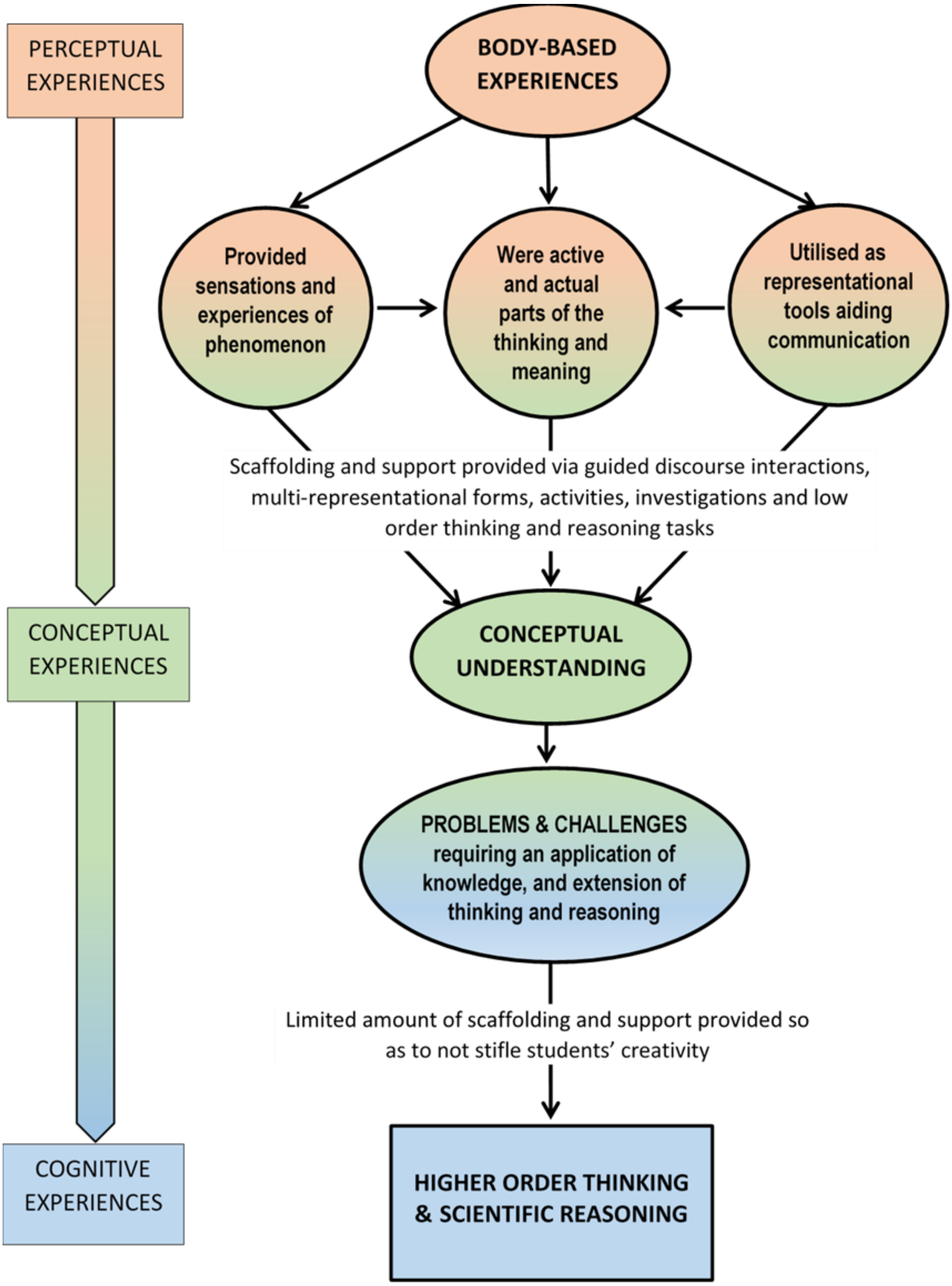



**Figure 6.12: Model of how body-based experiences were integral in the building of conceptual understanding and creating opportunities for higher order thinking and reasoning**

With scaffolding and support at strategic times; for example, in the form of guided discourse interactions, other representational forms, the incorporation of activities, investigations, challenges and problems to solve, Sandra (CS 1), and Christine and Melanie (CS 2) utilised body-based experiences to connect their Year 4 students to complex and abstract concepts (perceptual experiences), to build students' conceptual understandings (conceptual experiences) and to create opportunities for students to think, justify and reason (cognitive experiences) (Figure 6.12).

**Assertion 6.13**
Body-based experiences made strong contributions towards students' conceptual development and higher order thinking and reasoning in both case studies by giving access to complex and abstract concepts; by being active and actual parts of students' meaning making processes and as representative tools for communicating thinking, reasoning and justification of ideas. Teacher guided discourse interactions were essential for interpreting and linking body-based representations with other modes of representations in learning sequences that developed conceptual understandings and extended students thinking and reasoning. This was particularly obvious in CS 2 with Christine and Melanie's frequent use of embodiment due to their belief in kinaesthetic learning and the abstractness of concepts in their Forces topic.

**Pedagogies and strategies discussion**

Sandra (CS 1), and Christine and Melanie (CS 2) planned and employed a range of pedagogies and strategies that worked in unison to scaffold, support and create opportunities for higher order thinking and scientific reasoning, for example: pedagogies and strategies that created an overt thinking and reasoning culture; pedagogies and strategies that taught metacognition and the use of metacognitive skills for thinking and reasoning; discourse-based and body-based pedagogies and strategies; and, the sequencing of learning tasks and representations (Figure 6.13). Pedagogies and strategies that created an overt thinking and reasoning culture brought thinking and reasoning into the open and demonstrated to students that the development of thinking and reasoning was important and an expectation in lessons, alongside conceptual development. Sandra (CS 1), and Christine and Melanie (CS 2) utilised pedagogies and strategies that explicitly taught metacognitive skills and how and when to use metacognitive processes for promoting higher order thinking and reasoning supported students' thinking and reasoning. These pedagogies and strategies built essential life skills and showed students that they were not only responsible for their own thinking and learning, but that they had the power to think critically and creatively, to address challenges and to find solutions to problems.


**Figure 6.13: The combination of pedagogies and strategies used in CS 1 & 2 to scaffold, support and create opportunities for higher order thinking and scientific reasoning**

Discourse-based pedagogies and strategies promoted student talk, thinking aloud, sharing of ideas and collaboration and afforded Sandra (CS 1), and Christine and Melanie (CS 2) opportunities to extend students' thinking and reasoning through their modelling, coaching and scaffolding of dialogic interactions, argumentation; and, in CS 1 the early introduction and development of science terminology to support language-based reasoning (Hackling & Sherriff, 2015). Body-based pedagogies and strategies played a significant part in the development of students' thinking and reasoning. In both case studies they were utilised as tools for meaning making and communicating thinking and reasoning.

In CS 2, body-based experiences were essential for higher order thinking and reasoning as they provided access to the complex and abstract Forces concepts, required by students to think and reason. In addition, in both case studies , the purposeful sequencing of learning and representational tasks scaffolded, supported and created opportunities for higher order thinking and reasoning. The increasing of cognitive difficulty of tasks and fading of support as sequences progressed, built, scaffolded and extended students' conceptual understandings and thinking and reasoning. Opportunities for students to think and reason occurred as they were supported to transfer their thoughts and ideas from one task in the sequence to the next and ultimately during final tasks in learning sequences that involved students generating, constructing and explaining their own representations. Sandra's (CS 1), and Christine and Melanie's (CS 2) pedagogies and strategies resemble many of the strategies outlined in the cognitive apprenticeship model (A. Collins et al., 1989).

**Assertion 6.14**
Sandra's (CS 1), and Christine and Melanie's (CS 2) overall instructional approaches and pedagogies and strategies map directly onto the cognitive apprenticeship model (CAM) (A. Collins et al., 1989). The four major components and sub-components of CAM provide a solid basis on which to formulate, select and sequence pedagogies and strategies that scaffold, support and create opportunities for higher order thinking and scientific reasoning.

Sandra (CS 1), and Christine and Melanie (CS 2) each employed a range of pedagogies and strategies that worked in combination to develop students' thinking and reasoning. As was expected, slight differences in individual teacher instructional styles, overall ability and science experience of student cohorts, topics and their level of abstractness; number of teachers and students in each class and classroom spaces lead to variations in the actual pedagogies and strategies used in the two case studies, but overall the types of pedagogies and strategies implemented throughout each case study were very similar.

Cross-case analysis revealed that the development of higher order thinking and scientific reasoning was a multifaceted process and that combination of six categories of pedagogies and strategies were instrumental in scaffolding, supporting and creating opportunities for thinking and reasoning in the case studies. These included: pedagogies and strategies that promoted a strong and overt thinking and reasoning culture; pedagogies and strategies that promoted metacognition; pedagogies and strategies that sequenced learning tasks of increasing cognitive load alongside conceptual development; discourse-based pedagogies and strategies and body-based experiences.

**Assertion 6.15**
Whilst there were some variations between the two case studies, leading to different pedagogies and strategies being used, there were six categories of pedagogies and strategies used across both case studies that worked together to develop higher order thinking and scientific reasoning. These included pedagogies and strategies that promoted a strong and overt thinking and reasoning culture, metacognition; that sequenced tasks and representations of increasing cognitive load as sequences progressed and as conceptual development increased; discourse-based pedagogies and strategies and body-based experiences.

## Summary

This cross-case analysis chapter identified and discussed in relation to the existing literature and the conceptual framework guiding this study (Figure 6.1), the similarities and differences regarding how Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for higher order thinking and scientific reasoning. The comparison was focused on contextual factors; teacher beliefs; instructional approaches; and, pedagogies and strategies. To conclude this chapter an overview of the main themes emerging from the cross-case analysis, assertions related to these themes and a model summarising each factor and how these factors interrelate will be presented. (Appendix J provides a list of the Assertions drawn from Chapter 6.)

The major themes emerging from the cross-case analysis have been grouped according to whether they relate to contextual factors or teacher/s and students.

*Contextual factors*

- Contextual factors influenced how the teachers scaffolded and supported thinking and reasoning (A 6.1, 6.3 and 6.5).
- A safe and supportive classroom environment was critical for building thinking and reasoning (A 6.2, 6.3, 6.7 and 6.12).

*Teacher/s and students*

- Instructional approaches based on inquiry learning, group work, authentic hands-on activities, lots of talk, language development, collaboration, teacher facilitation and modelling provided a solid basis for pedagogies and strategies that built thinking and reasoning across activities, lessons and the unit (A 6.2 – 6.7 and 6.12).
- Careful planning, facilitation and monitoring by teachers and personal effort by students assisted the development of thinking and reasoning skills (A 6. 11 and 6.14 ).
- Thinking and reasoning developed when shared, talked about and discussed with others and was a priority during lessons alongside the teaching of concepts (A 6.2, 6.3, 6.5, 6.7 and 6.8).
- Simultaneous development of concepts and cognitive skills supported the development of thinking and reasoning as concepts provided context for students to think about and reason with (A 6.2, 6.4, 6.8, 6.10, 6.11, 6.13 – A 6.15).
- Sequenced and multimodal learning tasks implemented across instructional settings and increasing in cognitive complexity as sequences progressed, developed and moved students from lower order thinking and reasoning to higher order thinking and reasoning.(A 6.10 - 6.13)
- Body-based experiences make strong contributions towards students' conceptual development by providing students access to complex and abstract concepts; by being active and actual parts of students' meaning

making processes and as representative tools for communicating thinking, reasoning and justification of ideas (A 6.13).

- Students were given the responsibility for their own thinking and learning (A 6.4, A 6.6 and A 6.9).
- Metacognition, a form of higher order thinking involved in scientific reasoning was taught, scaffolded and supported so that students knew how and when to use it for critical thinking, argumentation, scientific reasoning and problem-solving (A 6.6).
- Opportunities for students to generate and construct their own representations and to apply their knowledge and thinking and reasoning skills to solving authentic problems promoted thinking and reasoning (A 6.4 and A 6.11).
- The cognitive apprenticeship model is a useful framework to base pedagogies and strategies on, to develop thinking and reasoning (A 6.14).

Classrooms are complex environments and how teachers scaffold, support and create opportunities for higher order thinking and scientific reasoning is a complex process dependent upon an intertwining of factors (Hackling, Chen, et al., 2017). The findings of the cross-case analysis have been presented in a model (Figure 6.14), which incorporates the factors discussed in this chapter, their interrelationships and how they contribute to thinking and reasoning.

Taking an overall view of the model (Figure 6.14), by focusing on the position of the summary boxes of each factor and the direction, origin and end points of the arrows, two main findings from the cross-case analysis are represented. Firstly, the development of thinking and reasoning are influenced by the combination of contextual factors (CF), teacher beliefs (TB), instructional approach (IA) and pedagogies and strategies (PS). Secondly, there are interrelationships between these factors. For example, contextual factors and teacher beliefs have a direct influence on teacher instructional approach; and, instructional approach in turn has a direct influence on pedagogies and strategies.

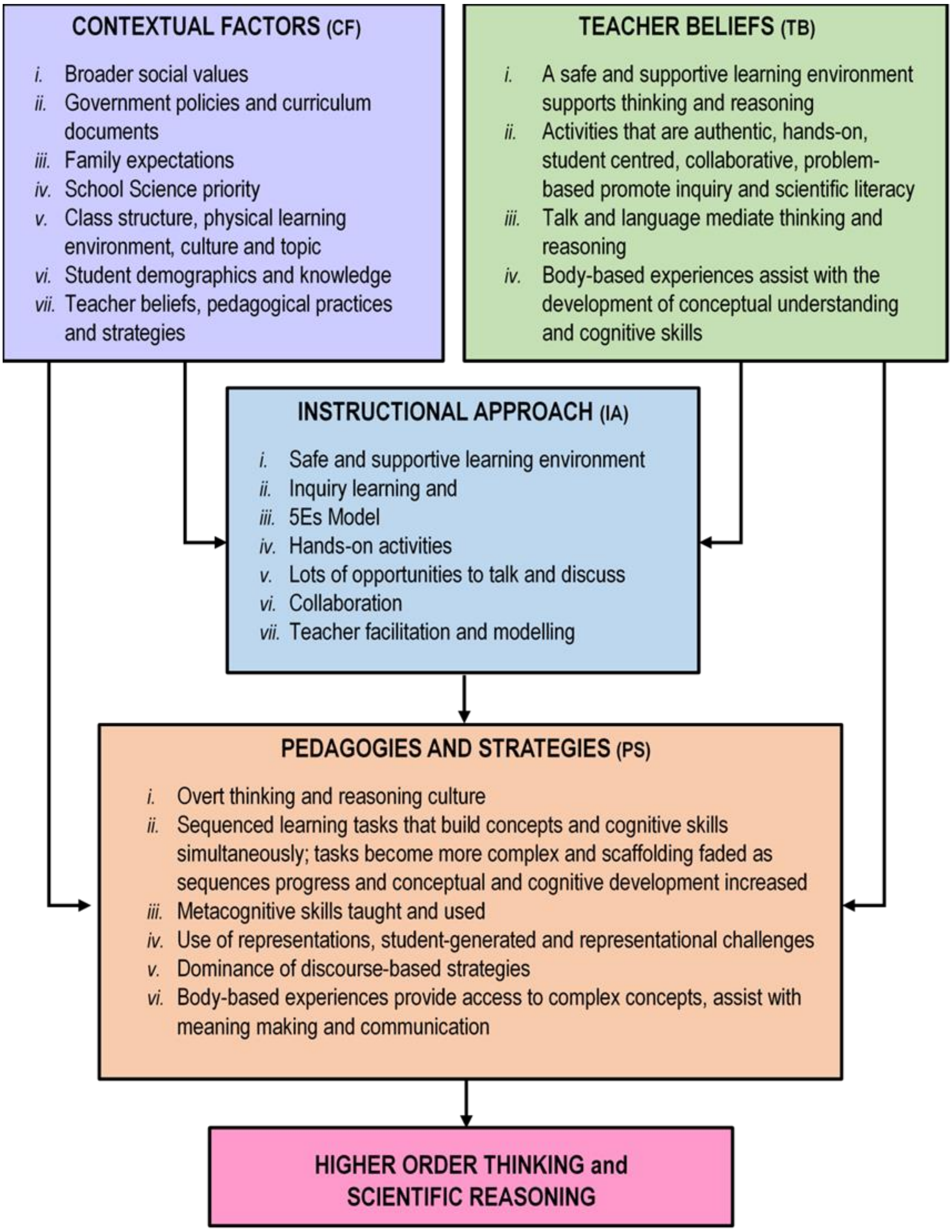



**Figure 6.14: Model identifying the relationships between contextual factors, teacher beliefs, instructional approaches and pedagogies and strategies affecting higher order thinking and scientific reasoning in CS 1 and CS 2**

Alternate pathways of influence are also illustrated in the model, where teacher beliefs and contextual factors have a direct influence on pedagogies and strategies. An example of this is in CS 2, with the contextual factor '. . . topic' (Figure 6.14 – point CF *v*), where the abstract nature of the concepts in the Force*s* topic having a direct influence on Christine and Melanie's (CS 2) pedagogies and strategies, in that many of their pedagogies and strategies included the use of 'body-based experiences' (Figure 6.14 – point PS *vi*).

Taking a more specific view of the parts of the model by focusing on the summaries of the factors within the boxes in Figure 6.14, it is interesting that 'theme threads' can be observed that link or illustrate a relationship between factors (boxes). For example, the six summary points in the *Pedagogies and Strategies* box (Figure 6.14 – points PS *i-vi*), which are central to how Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for higher order thinking and scientific reasoning, have origins that can be traced back to particular teacher instructional approaches, or teacher beliefs or contextual factors or a combination of these. For example, the *Pedagogies and Strategies* Box first summary point (Figure 6.14 – point PD *i*) 'overt thinking and reasoning culture' can be traced back through the *Instructional Approach* first summary point (Figure 6.14 – point IA *i*) 'safe and supportive learning environment', to *Teacher* summary point (Figure 6.14 – point IA *i*) 'safe and supportive learning environment', to *Teacher Belief* summary point one (Figure 6.14 – point TB *i*) 'a safe and supportive learning environment that supports thinking and reasoning' and *Contextual Factor* summary point five (Figure 6.14 – point CF *v*) 'class structure, physical learning environment and culture'.

In reverse this theme thread illustrates that teacher belief, context and instructional approach influenced the strategy of creating an overt thinking and reasoning culture. Another example is a theme thread, which relates to the social nature of learning through interaction with others and the importance of language and talk espoused by the social constructivist, sociocultural and distributed cognition theories (Driver et al., 1994; Smith, 2013; Tytler, 2012), that is , *Pedagogies and Strategies* summary point five (Figure 6.14 – point PS *v*) 'dominance of discourse-based strategies'. This can be traced back to *Instructional Approach* summary points five and six (Figure 6.14

– points *v* & *vi*) 'lots of opportunities to talk and discuss' and 'collaboration' and *Teacher Belief* summary point one (Figure 6.14 – point TB *i*) 'talk and language mediate thinking and reasoning'.

A final example of a theme thread is the tracking back of *Pedagogies and Strategies* summary point six (Figure 6.14 – point PS *vi*) 'body-based experiences provide access to complex concepts, assist with meaning making and communication', which was referred to in the discussion of the second main finding illustrated in Figure 6.14. Its origin can be traced back directly to *Teacher Belief* summary point four (Figure 6.14 – point TB *iv*) 'body-based experiences assist with the development of conceptual understanding and cognitive skills' and *Contextual Factor* summary point five (Figure 6.14 – point CF *v*), which relates to the influence of topic. The other *Pedagogies and Strategies* summary points (Figure 6.14 – points PS *ii-iv*) not mentioned are also the result of theme threads which have origins that can be traced back to instructional approach, teacher beliefs and/ or contextual factors.

In conclusion, Figure 6.14 is a useful framework and model that provides insight into the complexity of interacting factors: teacher beliefs, contextual factors, instructional approach and pedagogies, that were at play during both case studies and how they contributed to the scaffolding, support and creation of opportunities for thinking and reasoning. This chapter identified and discussed similarities and differences between how exemplary teachers Sandra (CS 1) and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for higher order thinking and scientific reasoning. From the cross-cases analysis themes emerged, from which assertions were created. These assertions will now form the basis for conclusions, answers to the research questions and implications for future teacher practice, teacher professional learning and for further research in the final chapter.

| **Assertion 6.16** |
|---|
| In these two case studies the scaffolding, support and creation of opportunities for higher order thinking and scientific reasoning was a complex multifaceted process influenced by the combination of teacher beliefs, contextual factors surrounding each case study, inquiry based instructional approaches and a repertoire of pedagogies and strategies (A 6.16). |

# Chapter 7: CONCLUSION AND IMPLICATIONS

## Introduction

The aim of this study was to investigate how exemplary teachers develop higher order thinking and scientific reasoning in primary science. The study investigated how exemplary Year 4 primary teachers in two Western Australian metropolitan primary school classes scaffolded, supported and created opportunities for thinking and reasoning during the teaching of a physical science topic. The chapter will be divided into three sections, Conclusions, Implications and a Final Note to conclude the study.

## Conclusions

In this section the assertions created in Chapter 6 will be used to answer the three subsidiary research questions. A summary of these responses will then be used to answer the overall research question, *How does the teacher scaffold, support and create opportunities for higher order thinking and scientific reasoning?.*

#### Research subsidiary question 1

**What beliefs do teachers hold about scaffolding and supporting higher order thinking and scientific reasoning?**

Sandra (CS 1), and Christine and Melanie (CS 2) held similar beliefs regarding the teaching of science, which framed opportunities for students to engage in thinking and reasoning (A 6.1 and A 6.7). Their shared beliefs related to the importance of developing students' scientific literacy through hands-on, authentic, problem-based collaborative inquiry learning investigation tasks and activities; that talk and language mediate thinking, learning and reasoning; that body-based experiences and a variety of modalities assist with conceptual and cognitive development; and, the importance of providing a safe and supportive learning culture and environment (A 6.2).

Slight variations in Sandra’s (CS 1) and Christine and Melanie’s (CS 2) beliefs due to individual interests and the topic being taught affected their focus, instructional approach (A 6.7) and how they implemented pedagogies and strategies (A 6.2). Sandra’s (CS 1) belief in talk and language (A 6.12) and Christine and Melanie’s (CS 2) belief in kinaesthetic learning (A 6.13) as ways of mediating thinking and reasoning (A 6.2) were related to the nature of the concepts in the Materials and their uses (CS 1) and Force*s* (CS 2) topics they taught.

**Research subsidiary question 2**

**What pedagogical practices do teachers employ and how do they scaffold, support and create opportunities for higher order thinking and scientific reasoning?**

Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for thinking and reasoning through the combination of instructional approaches and a range of pedagogies and strategies (A 6.8). Their similar instructional approaches included: the provision of a safe and supportive classroom learning environment; hands-on inquiry supported by the 5Es instructional model; and, facilitation as a way of instruction with lots of talk and collaboration (A 6.8).

Sandra’s (CS 1), and Christine and Melanie’s (CS 2) pedagogical practice of maintaining a safe and supportive learning environment throughout their units was critical for the promotion of talk, collaboration and for students to feel safe and confident to share their ideas, support their opinions with reasons, take risks in speaking their minds; question, debate, critique and be critiqued; to argue, change their minds and use evidence to support conclusions (A 6.3).

Sandra (CS 1), and Christine and Melanie (CS 2) facilitated students’ thinking, reasoning and conceptual development through the use of the 5Es model and by monitoring, scaffolding, supporting, guiding, modelling and responding to students’ ideas rather than simply delivering information. Students in both case studies were given the responsibility for their own thinking and learning through hands-on student-focused activity-based investigations and problem solving activities that engendered exploration, problem solving and creativity (A 6.4).

In both case studies talk and collaboration played key roles in stimulating and extending students' thinking and reasoning. Students were given many opportunities to talk and discuss their ideas throughout the unit. Due to contextual differences between the case studies relating to class size and classroom settings, the orchestration of these opportunities differed between the two case studies. In CS 1 much of the talk and collaboration occurred during small group work and class discussions. In CS 2; with the class size double that of CS 1 and the classroom being a large communal space devoid of furniture, Christine and Melanie (CS 2) favoured whole class discussions interspersed with many quick think-pair-share sessions to maximise talk and collaboration opportunities (A 6.5). Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches worked in combination as a foundation for their pedagogies and strategies employed to scaffold, support and create opportunities for higher order thinking and reasoning (A 6.8).

There were six categories of pedagogies and strategies used across both case studies that worked together to develop thinking and reasoning. These included pedagogies and strategies that promoted a strong and overt thinking and reasoning culture; metacognition; sequencing of tasks and representations that progressively increased cognitive load; discourse-based pedagogies; and, and body-based experiences (A 6.15).

In both case studies a strong overt thinking and reasoning culture played an integral role in the development of students' thinking and reasoning skills by promoting thinking and reasoning as an important outcome of lessons alongside the development of conceptual understanding. It placed the responsibility for thinking and reasoning on the student and provided an environment and platform that encouraged students to think deeply, to question, to verbally share their thoughts to co-construct arguments with others and to justify their claims with reasons. Speaking about, highlighting, modelling, discussing, prompting, scaffolding and extending thinking and reasoning continually during lessons also heightened students' awareness of the importance of these skills for their education and as necessary life skills (A 6.9).

Metacognition featured prominently in each case study and was a crucial component in the development of high order thinking and reasoning. Sandra (CS 1), and Christine and Melanie (CS 2) taught, supported and guided the development and application of students' metacognitive knowledge of tasks and metacognitive strategies such as reflective thinking, monitoring and self-regulation through the use of informal pedagogies and strategies such as thinking-out-loud; sharing of thinking processes; teacher prompts and questions; teacher modelling and the showcasing of expert students' thinking processes; and, formal pedagogies and strategies such as Hot seat, Fish bowl, Learning train, Sticky note fact graph, WILF and TIB and Big picture question (A 6.6).

Sandra (CS 1), and Christine and Melanie (CS 2) sequenced learning tasks to build conceptual understanding and to scaffold and support the development of thinking and reasoning skills. The building of conceptual understanding in learning tasks was integral to the development of students' thinking and reasoning skills, which was demonstrated in that all learning tasks had a conceptual and cognitive component. The expectation for students to think and reason independently increased as tasks along the learning sequences became cognitively more demanding moving from lower order thinking and reasoning tasks in the beginning of the sequences to higher order thinking and scientific reasoning tasks at the end of the sequences. In the beginning of learning sequences students were highly scaffolded and supported but as students became more proficient conceptually and cognitively the support and scaffolding was reduced or faded (A 6.10).

Representations were important in Sandra's (CS 1), and Christine and Melanie's (CS 2) scaffolding and support of conceptual development and creation of opportunities for higher order thinking and scientific reasoning. Sequences of representations of increasing cognitive demand; the combination of teacher and student generated representations; modelling of representation construction and how representing ideas can be used to extend thinking and reasoning; together with teacher-student negotiations regarding students' planning, construction, interpretation, explanation and evaluation of students' constructed representations provided opportunities for thinking and reasoning such as problem solving and critical and creative thinking throughout both case study units. Final assessment tasks, which required students to construct their own representations were the ultimate cognitively challenging task in both units and created the greatest opportunity for higher order thinking and reasoning in both case studies (A 6.11).

Discourse-based pedagogies in both case studies; encouraged thinking aloud, reflective thinking, language-based reasoning (particularly in CS 1 due to Sandra's belief in giving students the language to reason), and scaffolded, supported and created opportunities for higher order thinking and reasoning. Facilitated by safe learning environments, dialogic interactions between teacher and students and between students; having students come to a consensus; modelling, coaching and scaffolding the steps involved in argumentation; challenged, shaped, extended students' individual and collaborative thinking and reasoning from lower order thinking and reasoning to higher order thinking and more complex reasoning such as critical and creative thinking (A 6.12).

Body-based experiences made strong contributions towards students' conceptual development and higher order thinking and reasoning in both case studies by giving access to complex and abstract concepts; by being active and actual parts of students' meaning making processes and as representation tools for communicating thinking, reasoning and justification of ideas. Teacher guided discourse interactions were essential for interpreting and linking body-based representations with other modes of representations in learning sequences that developed conceptual understandings and extended students thinking and reasoning. This was particularly obvious in CS 2 with Christine and Melanie's frequent use of embodiment due to their belief in kinaesthetic learning and the abstractness of concepts in their Forces topic (A 6.13).

Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches and pedagogies and strategies mapped directly onto the cognitive apprenticeship model (A. Collins et al., 1989). Consistent with their pedagogical practices, the four components of the model listed below, provide a solid basis for an instructional model on which to formulate, select and sequence pedagogies and strategies that scaffold, support and create opportunities for higher order thinking and scientific reasoning.

1. Methods – ways for promoting expertise (modelling and explaining, coaching, scaffolding and fading, articulation, reflection and exploration)
2. Sequencing – ways of ordering learning activities (increasing complexity, increasing diversity and global before local)
3. Sociology – social characteristics of learning environments (situated learning, community of practice, intrinsic motivation and exploiting cooperation)
4. Content – types of knowledge required for expertise (domain knowledge, heuristic knowledge, control strategies and learning strategies) (A 6.15).

The following research question relates to contextual factors that facilitate or constrain opportunities for thinking and reasoning.

**Research subsidiary question 3**

**What contextual factors such as classroom culture and student demographics facilitate and constrain the opportunities for higher order thinking and scientific reasoning?**

Contextual factors influenced Sandra's (CS 1), and Christine and Melanie's (CS 2) choice of pedagogies and strategies, the starting points for developing students' cognitive development and how they scaffolded, supported and created opportunities for thinking and reasoning. In addition to the broader social factors; school contextual factors including the priority given to science, the physical and social environment of the classroom, student demographics and prior knowledge; teachers' beliefs, pedagogical practices and the topic being taught framed the opportunities for students to engage with higher order thinking and reasoning in this study (A 6.1).

Sandra (CS 1), and Christine and Melanie (CS 2) were very aware of contextual factors. They pre-empted potentially constraining contextual factors such as class size and physical classroom environment and made adjustments to their teaching and the social and physical classroom environments. Opportunities for thinking and reasoning were facilitated through their positive, safe, social and physical learning environments that supported hands-on activities and collaboration; by adjusting levels of scaffolding and support to cater for different student demographic backgrounds, abilities, knowledge, experience, confidence levels and where students were at with their cognitive development (A 6.3); by encouraging collaboration by providing opportunities for individual students to input their ideas and receive feedback in group situations no matter the size of the class; and, using authentic examples and activities as well as multimodal teaching practices to provide students' across all learning styles and abilities access to cognitively challenging concepts (A 6.1b).

Conclusions formulated from the three subsidiary questions will now be summarised to formulate a response for the overall research question, *How does the teacher scaffold, support and create opportunities for higher order thinking and scientific reasoning?.*

**Overall research question summary**

**How does the teacher scaffold, support and create opportunities for higher order thinking and scientific reasoning?**

The emphasis of the overall research question is on 'how' Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for higher order thinking and scientific reasoning. This was a complex multifaceted process influenced by the combination of teacher beliefs, the contextual factors surrounding each case study and their choice of instructional approaches and pedagogies and strategies (A 6.16).

Sandra (CS 1), and Christine and Melanie (CS 2) as exemplary teachers of science, were key to the development of their students' thinking and reasoning. Additional to their exemplary teaching skills, they had a passion for science and science teaching and actively worked and committed planning time and class time towards developing students' scientific literacy of which thinking and reasoning are components. They had an understanding of the content, science processes and inquiry skills required in the teaching of their physical science units which were fundamental in the development of thinking and reasoning; they used a collection of inquiry based instructional approaches and drew upon a variety of pedagogies and strategies to scaffold, support and create opportunities for higher order thinking and scientific reasoning.

Sandra's (CS 1) and Christine and Melanie's (CS 2) awareness of contextual factors influenced their choice of instructional approaches and selection of pedagogies and strategies. Contextual factors such as classroom space, class size and variation in student abilities were changed, worked around or worked with to support collaboration and the sharing of ideas and pedagogies and strategies were adjusted so that contextual factors did not constrain opportunities for thinking, reasoning and learning. Sandra's (CS 1) and Christine and Melanie's (CS 2) instructional approaches reflected their beliefs and were important for the stability, rigor and foundation of their pedagogies and strategies. They included the promotion of a safe and supportive learning environment, inquiry learning and the use of the 5Es inquiry model, hands-on activities, lots of opportunities to talk, discussion and collaboration, teacher facilitation and modelling. Students in both case studies were given responsibility for their own learning journey (A 6.4, A 6.6 and A 6.9) and were expected to put some personal effort into developing their thinking and reasoning (A 6.11 and A 6.15).

Sandra (CS 1), and Christine and Melanie (CS 2) scaffolded, supported and created opportunities for thinking and reasoning through their overt thinking and reasoning cultures, their sequencing of learning tasks and representations, their use of discourse-based and body-based experiences and strategies. All of these pedagogies worked together to scaffold, support and created opportunities for higher order thinking and scientific reasoning.

In short, Sandra (CS 1), and Christine and Melanie (CS 2) were exemplary teachers of science; they were 'experts' in higher order thinking and scientific reasoning; they knew what higher order thinking and reasoning looked like in the context of their topics and for the age group of their students; they were committed to teaching thinking and reasoning alongside content learning; and, they had the knowledge, instructional approaches and employed pedagogies and strategies to model, share and develop these skills in their students.

## Implications

In this section implications for teacher practice, teacher professional learning and future research will be outlined.

### Implications for practice

The research has shown that there are a number of key focus areas for scaffolding, supporting and creating opportunities for higher order thinking and scientific reasoning. First, the teacher needs to gain an understanding of what higher order thinking and reasoning is and what it looks like in the classroom context and for the age of their students; and, to have the science content knowledge and pedagogical content knowledge relating to their topic (Shulman, 1986) to support the development of thinking and reasoning.

Second, thinking and reasoning needs to be an important learning outcome for each lesson, consciously planned for and taught simultaneously with concepts across the unit of work, all of which take time. Building upon the foundation of a safe and supportive classroom culture, there needs to be a strong overt thinking and reasoning culture where awareness and the importance of thinking and reasoning is constantly in the foreground of lessons.

Third, the research has shown that the instructional approach (Anderson, 2002) based on inquiry supports the development of thinking and reasoning and that the cognitive apprenticeship model (A. Collins et al., 1989) is a useful framework to consider for developing instructional approaches and pedagogies and strategies that scaffold, support and create opportunities for higher order thinking and scientific reasoning.

Finally, the research has shown that a combination of pedagogical practices based on discourse interactions, the building of thinking and reasoning through sequences of learning and representational tasks, metacognition and body-based experiences effectively scaffold, support and create opportunities for higher order thinking and scientific reasoning.

**Implications for teacher professional learning**

Two implications for professional development are proposed. The first is broad and suggests the use of video for pre-service training and professional development and the second is more specific and relates to constructing increasingly cognitive demanding representations to scaffold, support and create opportunities for thinking and reasoning.

Sandra's (CS 1), and Christine and Melanie's (CS 2) quality pedagogical practices captured on video and in interviews demonstrated their understanding and confidence in teaching, developing and assessing higher order thinking and scientific reasoning. Many pre-service and in-service teachers; however, are not so clear about what higher order thinking and scientific reasoning mean, look like and do not feel prepared to teach or assess it (Schulz & Fitz Patrick, 2016). Using authentic classroom videos for pre-service and professional learning sessions could effectively inform teachers' understanding of higher order thinking and scientific reasoning. Viewing real life video of exemplary practice such as Sandra's (CS 1), and Christine and Melanie's (CS 2) would stimulate discussion, facilitate joint analysis and cause both pre-service and practicing teachers to reflect, review and in some cases upgrade their practice (Marsh & Mitchell, 2014).

Some of the pedagogies and strategies demonstrated by Sandra (CS 1), and Christine and Melanie (CS 2) in this research are quite complex for pre-service teacher education and would be better addressed as professional learning topics once teachers have settled into teaching. For example, the research has shown that the use of representations of increasing cognitive challenge is an effective pedagogy for scaffolding, supporting and creating opportunities of higher order thinking and scientific reasoning. This finding is an extension to the research already in existence on the affordance of multiple representations and representation construction for higher order thinking and scientific reasoning (Hackling et al., 2012; Tang et al., 2014; Treagust et al., 2017; Tytler, Murcia, et al., 2017; Tytler, Prain, Hubber, & Waldrip, 2013).

The research revealed that the combined effect of four factors on dimensions relating to who generates the representation (teacher -> student), the level of thinking expected (low -> high), level of scaffolding provided (low -> high) and the openness of the representational challenge (teacher directed -> open) determine the cognitive challenge of representations (refer to Figures 6.9 and 6.10). Teachers could be guided in professional learning sessions to use these factors to identify and construct sequences of increasing cognitively challenging representational challenges to scaffold and support higher order thinking and scientific reasoning.

**Implications for research**

Given that this was a small exploratory study into how teachers scaffold, support and create opportunities for higher order thinking and scientific reasoning, the generalisability of the findings is limited. However, the findings from these exemplary primary science teachers may be transferable to teachers who work within similar contexts; and, if the research was replicated with a greater number of case studies in a range of different settings the transferability of the findings may increase.

As fostering students' STEM skills such as higher order thinking and reasoning skills is considered an important educational goal for *all* students, which was recently reiterated in a statement made by the Premier of Western Australia Mr Mark McGowan (Government of Western Australia, 2019), of particular interest to the Researcher would be to extend this research and to conduct further research into non-mainstream classes, such as educational support classes where students are low-achieving due to learning difficulties or disabilities and to examine whether there are any similarities or differences in how the teacher/s scaffold, support and create opportunities for thinking and reasoning. The Researcher has had first-hand experience with students in a Year 3 - 5 education support class in a metropolitan school in Western Australia who engaged in the trial of the STEM Learning Project Module *Every bird needs a home (*http://stemlearning.org.au/). A number of those students despite their intellectual, social and emotional limitations, engaged in critical and creative thinking (Mildenhall, Cowie, & Sherriff, 2019). The findings of Zohar and Dori (2003) suggest that the net gain of low achievers can be significantly higher than for high achievers. It would be interesting to see whether the instructional approaches identified in this doctoral study can be applied to an educational support setting.

## Final Note

Teaching higher order thinking and scientific reasoning is part of the current drive for improving students' 21st century STEM skills and to support the future workforce and future economies (Government of Western Australia, 2019; Husin et al., 2016; Scott, 2015). As Australian students haven't appeared to have improved in these areas in international tests such as TIMSS over the last 10 years (Thomson, Wernert, et al., 2017), it is important for teachers and tertiary educators to take an inventory of their understanding of higher order thinking and scientific reasoning and to look at their current pedagogies and strategies to see if there could be improvement.

Pre-service and practicing teachers need to understand what higher order thinking and scientific reasoning are and what they look like in their classrooms. This study showcased how three exemplary Year 4 primary teachers scaffolded, supported and created opportunities for higher order thinking and scientific reasoning during the teaching of a physical science topic. The research has demonstrated that teacher beliefs, contextual factors, instructional approach and a combination of pedagogies and strategies has influenced the scaffolding, support and creation of opportunities for higher order thinking and scientific reasoning.

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# APPENDICES

## Appendix A: Summary linking the research questions with the data source, researcher involvement in data collection and analysis tools

**Overarching research question**:
*How does the teacher scaffold, support and create opportunities for higher order thinking and scientific reasoning?*

| **Subsidiary research questions** | **Data source** | **Second-hand data** | **Researcher involvement with the collection of data** | **Data analysis tools to be utilised in the proposed study** |
|---|---|---|---|---|
| 1. What *beliefs* do teachers hold about scaffolding, and supporting higher order thinking and scientific reasoning? | i. EQUALPRIME (EQ) CS (CS) 1 & 2 video footage.<br>ii. EQ CS 1 & 2 Pre – study teacher interviews.<br>iii. EQ CS 1 & 2 Pre- and post-lesson interviews.<br>iv. A semi-structured interview will collect additional teacher information relevant to the research questions from each teacher in the study.<br>v. A post analysis video stimulated interview will be conducted with each teacher to verify the Researcher's interpretations. | ✓<br>✓<br>✓ | i. Video footage – the Researcher was a camera operator for each EQUALPRIME CS.<br>ii. Pre- and post- study interviews<br>• Pre-study interview – not involved<br>• Post-study interview – provided the interviewer with examples of emergent themes and video clips to prompt teacher discussion.<br>iii. Pre- and post-lesson interviews were conducted by the Researcher.<br>• Pre-lesson interview- teacher asked about lesson aims and practical information to assist with filming.<br>• Post-lesson interview - teachers were asked to identify and discuss | Multimodal transcripts, micro-ethnographic analysis of video, mapping and participant checking. |

| | | | | |
|---|---|---|---|---|
| | | | where they thought the quality learning occurred during the lesson.<br>iv. The Researcher will conduct a semi-structured interview with each teacher prior to commencing fine grade analysis.<br>v. The Researcher will conduct a post analysis video stimulated interview with each teacher once assertions have been drawn from their respective cases data and prior to recording of CS findings. . | |
| 2. What *pedagogical practices* do teachers employ and how do they scaffold, support and create opportunities for higher order thinking and scientific reasoning? | i. EQ CS 1 & 2 video footage.<br>ii. EQ CS 1 & 2 Pre – study teacher interviews.<br>iii. EQ CS 1 & 2 Pre- and post-lesson interviews.<br>iv. A semi-structured interview will collect additional teacher information relevant to the research questions from each of the teachers in the study.<br>v. A post analysis video stimulated interview will be conducted with each teacher to verify the Researcher's interpretations.<br>vi. EQUALPRIME CS 1 & 2 observational field notes. | ✓<br>✓<br>✓ | i. As above.<br>ii. Observational field notes – the Researcher as the camera operator took notes during each videoed lesson, highlighting interesting events and changes in classroom activity. | Multimodal transcripts, micro-ethnographic analysis of video, mapping, representations of key themes and patterns emerging from the data, participant checking. |

| | | | | |
|---|---|---|---|---|
| | | ✓ | | |
| 3. What *contextual factors* such as classroom culture and student demographics facilitate and constrain opportunities for higher order thinking and scientific reasoning? | i. EQ CS 1 & 2 video footage.<br>ii. EQ CS 1 & 2 Pre – study teacher interviews.<br>iii. EQ CS 1 & 2 Pre- and post-lesson interviews.<br>iv. A semi-structured interview will collect additional teacher information relevant to the research questions from each of the teachers in the study.<br>v. A post analysis video stimulated interview will be conducted with each teacher to verify the Researcher's interpretations.<br>vi. EQ CS 1 & 2 observational field notes | ✓<br>✓<br>✓<br>✓ | i. As above. | Mapping the following within and across studies:<br>teacher pedagogical supports, scaffolds teacher beliefs, knowledge, contextual factors such as classroom culture and student demographics, and cross-case analysis |

**Appendix B: Overview of Sandra's lessons; identifying, aims, concepts and processes incorporated into each lesson**

| LESSON | 5E PHASE | TITLE | AIMS | CONCEPTS | PROCESSES |
|---|---|---|---|---|---|
| 1 | ENGAGE | Frank's fish n chips | Introduction to the topic using the dilemmas in the concept cartoon "Frank's fish n chips" and the classroom curtain dilemma. | Different materials have different properties. This makes them suitable for some uses and not for others. | Concept cartoon<br>Drag and drop word bank IWB<br>Ideas pad in pairs on laptop<br>Sharing ideas in small group<br>Written and verbal justification of thinking<br>Fish bowl sharing activity<br>Homework project |
| 2 | EXPLORE | Unfair class relay | Review of fair testing and the use of an investigation planner to design an investigation to test their theories to solve Frank's fish n chip dilemma. | What makes an investigation fair?<br>Different materials have different properties. | Unfair class relay<br>Class discussion<br>Individual written quiz<br>Peer traffic light assessment<br>Homework project modelled<br>HW planner reviewed by a peer<br>Whole class discussion of classroom curtain |
| 3 | | Soak, leak or repel | Explore the absorbency of different of materials and to understand how the properties of materials determine their use. | Some materials are better at absorbing water than others | Reviewed class blog regarding HW<br>Class discussion<br>Group investigation<br>Teacher guided use of investigation planner<br>Introduction of scientific terms beaker, pipette<br>Class discussion on findings. |
| 4 | | Snap, tear or stretch | Explore the tensile strength of materials, plan and conduct a fair test, | Some materials have a higher tensile strength than others. | Handling, describing and naming materials<br>Class discussion<br>Group investigation<br>Teacher modelled set-up and use of investigation planner. |

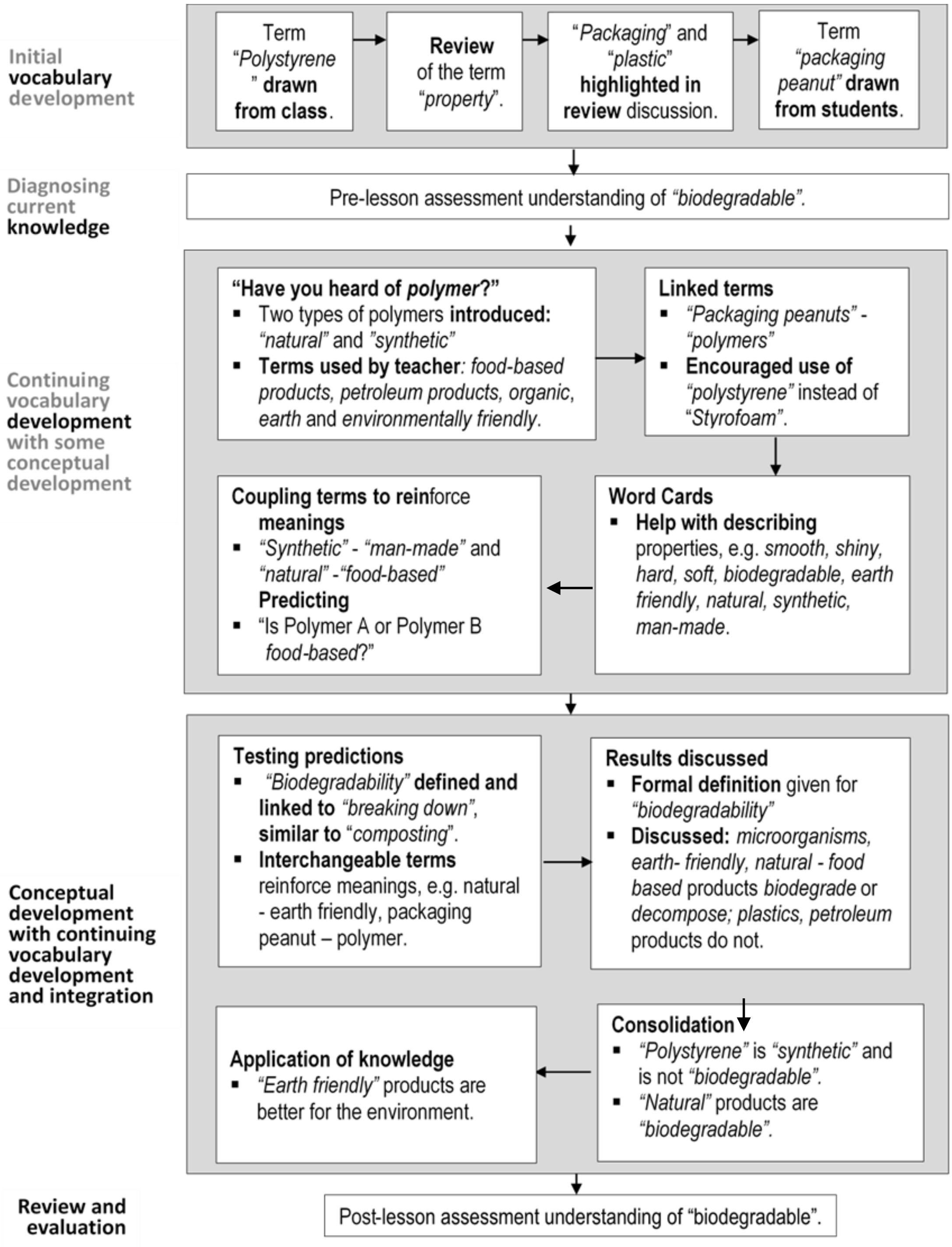
| | | | | | |
|---|---|---|---|---|---|
| | | | record results in a table and interpret findings. | | Individuals record findings and conclusions |
| 5 | | Two types of packaging peanuts | Explore the differences in biodegradability between man-made and natural polymers. | 'Natural' products are more biodegradable than synthetically made products. | Reviewed concept word wall<br>Drag and drop word sort<br>Class discussion<br>'Stick it' note wall graph<br>Teacher instruction<br>Group investigation<br>Class discussion<br>Revisited 'Stick it' note wall graph<br>Fish bowl sharing activity<br>Class discussion |
| 6 | EXPLAIN | Puzzling with plastics | Predict, plan and conduct an investigation relating to the biodegradability of polymers. Make connections between biodegradability as a property of materials and real life issues concerning the environment. | Some materials if not managed can lead to pollution. | Class discussion and review<br>Video clip<br>Class discussion<br>Small group pair share reading facts<br>Individual writing<br>Class discussion<br>Teacher-led whole class discussion<br>Class predicted planned & set-up fair test<br>Hot-seat interviews |

**Appendix C: Types and number of instructional setting changes each lesson over the Materials unit (CS 1) (Chapter 4)**

| **Sandra's Materials unit (CS 1)** | | | | | | |
|---|---|---|---|---|---|---|
| Lesson | 5E Phase | Class instructional settings each lesson | | | | Number of instructional setting changes per lesson |
| | | Individual student activity (ISA) | Paired activity (PA) | Small group activity (SGA) | Whole class activity (WCA) | |
| 1 | Engage | 0 | 2 | 1 | 3 | 6 |
| | | | | | | |
| 2 | Explore | 1 | 0 | 1 | 3 | 5 |
| 3 | Explore | 0 | 0 | 1 | 3 | 4 |
| 4 | Explore | 1 | 0 | 2 | 3 | 6 |
| 5 | Explore | 1 | 0 | 4 | 5 | 10 |
| | | | | | | |
| 6 | Explain | 1 | 0 | 4 | 5 | 10 |
| | | | | | | |
| 7 | Elaborate | 2 | 2 | 1 | 5 | 10 |
| 8 | Elaborate | 0 | 0 | 1 | 2 | 3 |
| | | | | | | |
| 9 | Evaluate | 1 | 0 | 1 | 2 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| TOTAL over the unit | 7 (12%) | 4 (6%) | 20 (28%) | 31 (54%) | 58 |
| Average number of changes per lesson over the unit | | | | | 6.5 |

**Appendix D: Integration of language and conceptual threads in L 5 (Hackling & Sherriff, 2015, p. 18)**



## Appendix E: Sandra's Lesson 5 Plan

| Lesson 5 SCIENCE: Chemical Sciences/Inquiry Skills/ Use and Influence of Science |
|---|
| Teacher: Sandra (pseudonym) Science Education Assistant: Mrs T (pseudonym) |
| **AIM**: Students explore differences between man-made and natural polymers, explore and classify properties of materials and conduct an investigation using fair testing procedures.<br>**SKILLS & BEHAVIOURS**: Students make scientific observations of the behaviour of polymers<br>**OUTCOMES**: Students investigate the environmental impacts of degradable and non-degradable polymers, make predictions and record observations. Students will provide reasoning for their ideas relating to the best uses of the polymers investigated. |

| TIME 9.30am | ACTIVITY: Biodegradability | Explore |
|---|---|---|
| Introduction/Engage<br>15 mins | **IWB** word sort and concept classifying activity. Words will then be added to the word/concept wall at a later date. Success Criteria will be discussed and students will be asked to participate in a sticky bars *FACT.* This will be revisited at the end of the lesson. | Science Journals<br><br>Handouts<br>Planners<br>Sticky notes |
| Explore<br>30 mins | Students are to discuss: *What are some of the characteristics? Similarities? Differences?* Students will be given cards and will need to match the properties and uses with the packing peanuts. Introduce new vocabulary. . . .biodegradable, polymer, corn starch, synthetic, natural. Before we begin the investigation, I will share a PowerPoint on the IWB with the students and introduce the investigation question and direct the student's focus onto the 'property' we will be investigating.<br><br>**Investigation**: Students are in their investigation teams. Team roles will be reiterated and the manager is responsible for setting up their equipment**.** Fair testing procedures will be reviewed. We will plan the investigation together as a whole class on the IWB. Mrs T & I will then move from group to group ensuring fair testing procedures are being considered.<br><br>Students will conduct their investigations, recording their observations on the templates provided. Prompts: How does each type of peanut behave in water? Do any of the peanuts dissolve in water? If so, what happens to these peanuts as they dissolve? How fast did they dissolve? | Participation Pies<br>IWB word-sort<br><br>***Investigations***<br>badges<br>3 beakers<br>Tongs<br>Packing -peanuts<br>Warm water |
| Explain<br>10 mins | Would it be practical to replace all the polystyrene used for polystyrene cups and picnic plates with the corn starch material used in some packing peanuts? Why or why not?<br><br>Why is it necessary to develop materials with biodegradability?<br>Show students the PP of the gyre in the Pacific Ocean. | |
| Elaborate<br>10 mins | From the activity, you saw that corn starch packing peanuts break down easily when water was added to them. How is this beneficial to the environment? Corn starch has come a long way from when it was first developed and it may be possible to develop more useful and environmentally friendly corn starch products in the future. | Water daily to mimic weather conditions and review week 10. |
| Evaluate<br>15mins | **Fishbowl sharing activity.** How did today's lesson help you better understand the properties of materials? Can you articulate your understandings relating to how the properties of materials influence their use? What are your thoughts on biodegradability as property of a material, how important is this property?<br><br>We will discuss any talking points. Teams will be given containers of dirt to place two of their 'peanuts'. They will be responsible for making a hypothesis and justifying their ideas using scientific reasoning (hopefully based on the evidence of this lesson!) and recording their observations over time. | |
| | *Reflection: Repeat Sticky Bars FACT* | |

## Appendix F: Overview of Sandra's Lesson 4 and Lesson 5

| Lesson | **Lesson 4** | **Lesson 5** |
|---|---|---|
| 5E phase | EXPLORE | EXPLORE |
| Title | Stretch, tear or snap | Natural vs. synthetic packaging peanuts |
| Aims | To explore the tensile strength of materials.<br>To plan and conduct a fair test, record results in a table and interpret findings. | To explore the differences between man-made and natural polymers.<br>To classify properties of materials.<br>To conduct an investigation using fair testing procedures. |
| Concepts | Some materials have a higher tensile strength than others. | 'Naturally' made products can be more biodegradable than synthetically made products. |
| Brief overview of lesson | • *Whole class discussion*. Students described the feeling of different materials, term fibres introduced. Students named materials based on observable properties and possible uses. *Teacher introduced the term tensile strength.*<br>• *Teacher modelled the procedure for small group investigation* - Tensile Strength – Snap, stretch or tear, set-up and recording of observations.<br>• *Small group investigation* - Students made predictions and started to fill out investigation planner. Discussed their predictions, tested, observed, and recorded findings.<br>• Teacher scaffolded *small group discussion* and analysis of results. Conclusions made.<br>• *Whole class discussion* on the applications and uses of various materials that have high tensile strength. | • *Whole class* -Teacher *reviewed* of previously introduced *terminology and concepts* on concept/ word wall.<br>• *Reviewed* using IWB drag and drop word sort various properties and uses of selected materials.<br>• Terminology discussed – natural and synthetic.<br>• 'Stick it' note graph to ascertain student understanding of *biodegradable*.<br>• Teacher PowerPoint presentation on polymers.<br>• *Small group investigation* - Which packaging peanut is natural? *Whole class discussion* of results.<br>• *Teacher-led whole class discussion* on biodegradability, *Revisited 'stick it'* note wall graph. Fish bowl *sharing activity*<br>• *Whole class review and discussion* on practical applications of natural and synthetic products. |

**Appendix G: Summary of Key Findings drawn from Chapter 4**

Key Finding 4.1

Sandra worked in a school with an above average ICSEA rating and taught a Year 4 class she had previously taught in Year 3. These students demonstrated above average literacy and numeracy skills on NAPLAN assessments in the previous year.

Key Finding 4.2

Sandra was not trained as a science specialist in her pre-service education. She developed an interest in science education in her first two years of teaching and increased her science knowledge through attending professional development sessions. In her role as the school's science coordinator she supports other teachers with teaching science.

Key Finding 4.3

Sandra believes that science inquiry can be the vehicle for all learning and that by linking authentic and problem solving activities to real world situations. She believes strongly in hands-on learning and that talk and discussion should feature prominently in lessons. She also believes it is important to give students the vocabulary and language to question, discuss ideas and reason in science.

Key Finding 4.4

Sandra believes in creating a positive supportive classroom environment that supports collaboration and deeper learning which occurs by going beyond merely sharing ideas with peers but by providing reasons, analysing and critiquing others' ideas.

Key Finding 4.5

Sandra believes in the merits of multimodal instruction and the value of incorporating strategies such as chanting, song, movement and lots of talking to assist students with their consolidation of thinking, retrieval of past learning and application of knowledge to new situations.

Key Finding 4.6

Sandra believes that her teaching is characterised by a large proportion of small group work. However, she believes that each instructional setting is important and provides particular affordances for the development of higher order thinking and science reasoning.

Key Finding 4.7

Sandra modified a Primary Connections unit on materials and utilised the 5Es constructivist approach to focus on an authentic question of significance to her class which involved investigating the properties of materials. The question, What type of material would be best for our classroom curtain? became an important vehicle for linking learning and reviewing of concepts across lessons, promoting thinking and formulated the basis for assessment in the final lesson.

Key Finding 4.8

Sandra set up her classroom and planned lessons to facilitate small group work and whole class activities and discussions. Students sat in groups at tables for the majority of the time and came together to sit on the carpet at the front of the room for receiving instructions and to review previous lesson's concepts.

Key Finding 4.9

Sandra set up the topic by introducing the problem (Lesson 1) that they needed a classroom curtain. Lessons were taught through inquiry. She sequenced activities and lessons and scaffolded learning (concepts and skills), using investigation planners to guide inquiry and to be a written representation of students thinking and learning; and, by building and adding upon learning from one lesson to the next until the students had acquired the knowledge and skills required to choose and justify a suitable material for making their classroom curtain (in the final lesson). Teacher scaffolding and the use of the formalised investigation planners was decreased, and the openness of the investigations were increased, as the unit progressed. As students' understanding and skill level increased Sandra's level of support was decreased.

Key Finding 4.10

Sandra utilised a classroom problem relating to the topic as the vehicle for learning. Her planning, organisation and sequencing of lessons was purposeful and involved building and equipping students with the conceptual understandings and skills to find a solution to the problem.

Key Finding 4.11

Sandra utilised different instructional settings to pace and progress learning, to cater for individual learning styles and as a strategy to support and scaffold higher order thinking and scientific reasoning. She orchestrated and sequenced talk opportunities for students to formulate and represent their thinking and learning verbally.

Key Finding 4.12

Language development is a significant factor in Sandra's teaching and is evidence of her belief that access to relevant science language and vocabulary is necessary to connect and build science ideas and to reason in science.

- Sandra developed and incorporated vocabulary and scientific language with conceptual development in a five step process: selecting and diagnosing understanding of key science terms; probing, drawing out and highlighting general and key vocabulary, introducing new and unfamiliar terms with initial concept development, focusing on conceptual development with continual vocabulary development and integration, and reviewing and evaluating understandings.

- Sandra incorporated visual (e.g. Sticky note fact graph, word/concept wall, interactive word sort, word cards) and verbal representations of coupling, repetition, touch, and embodiment (e.g. gestures), teacher modelling and continual reinforcement across lessons for new science terms.

Key Finding 4.13

Sandra promoted a culture of self-regulation in her classroom highlighting to students that each student is on their own learning journey. Using the Learning train metaphor she asked students to monitor their level of engagement in the learning and to ask for help when they were disengaged or needed help with understanding.

Key Finding 4.14

The Sticky note fact graph strategy was employed by Sandra as a pre- and post-lesson assessment and diagnostic tool and develops students' metacognitive skills. It was a visual and graphical representation of students' thinking and learning and provided a representational stimulus for students' to improve their thinking and learning across the lesson on biodegradability.

Key Finding 4.15

WILF and TIB statements indicated to students the instructional intentions and expectations for the lesson and related how the learning is important for everyday living. On a deeper cognitive level they also functioned as metacognitive scaffolds to foster higher order thinking, reasoning and learning.

- WILF (What I am looking for) function as signposts for student learning and set a level of conceptual learning for students to work towards.
- TIB (This is because…) model the higher order skill of applying knowledge to real life situations and the process of justifying ideas with reasoning.

Key Finding 4.16

The use of and unpacking of new or unfamiliar science terminology in WILF and TIB statements indicated the importance Sandra placed on the development of science language for conceptual learning and science reasoning.

Key Finding 4.17

'Because' was used by Sandra as a syntactical scaffold or prompt to encourage students to justify unsupported claims and promote higher order thinking and reasoning. The frequency of its use together with other prompts such as "Tell me why" created a culture or expectation within Science lessons to always provide reasons or evidence for claims.

Key Finding 4.18

Sandra taught, modelled and reinforced metacognitive strategies and practices to support and scaffold students' reasoning, argumentation, metacognitive awareness and self-regulation. Strategies such as the Learning train, Sticky note fact graph, WILF and TIB statements and the use of 'because' as a syntactical scaffold or prompt assisted students to monitor, understand and progress their learning and to develop higher order thinking and reasoning skills.

Key Finding 4.19

Thinking is an intimate and important part of Sandra's classroom learning culture. She frequently spoke about thinking; shared her own thinking and thought processes, and prompted and encouraged students to do likewise. Sandra incorporated a variety of strategies and practices into her lessons (e.g. thinking-out-loud, questioning, critique, Fish bowl and Hot seat) to enable students to 'safely' and comfortably access, identify, share and extend their thoughts and thought processes as they co-constructed arguments and understanding with others.

Key Finding 4.20

The Fish bowl and Hot seat strategies modelled and allowed students to refine their higher order thinking and reasoning skills by providing a verbal, visual and in a sense bodily representation of students collaboratively presenting high quality arguments and coming to a consensus. The success of the Fish bowl and Hot seat strategies in Sandra's class is due to the positive and safe learning culture and environment established in the class.

Key Finding 4.21

Sandra fostered and sustained student talk and discussion to afford students 'talk time', 'sharing time' and 'thinking time' for the co-construction of knowledge. Her contribution to conversations were minimal and were mainly to sustain student talk, guide the exploration of ideas and for assessment and diagnosis. Sandra's open questions, non-evaluative and neutral responses and mirroring or repeating of key phrases from students' responses are characteristic of her approach.

Key Finding 4.22

Sandra's use of neutral, open ended prompts and questions indicating her interest in students' ideas guided students to verbalise and extend their thinking and to make connections between their experiences, new ideas and concepts.

Key Finding 4.23

In small group situations Sandra promoted the development of higher order thinking, scientific reasoning and argumentation by encouraging students to critique, compare, modify and to come to a consensus with their ideas.

Key Finding 4.24

Sandra's teaching style is very flexible. In the small group situation she took on a range of interactive roles depending on her diagnosis of where students were at in their learning. She may play onlooker, silent observer, facilitator, peer learner, model, instructor and devil's advocate. Each role puts the students in-charge of their own learning.

Key Finding 4.25

Disagreement was a vibrant, acceptable and successful tool in Sandra's class. It was used for creating situations in small group discussions, where students' ideas and thoughts are challenged and extended; and, science reasoning, higher level thinking and argumentation skills are developed. Established and maintained 'ground rules' ensure that all students felt safe and supported in sharing their ideas.

Key Finding 4.26

In the small group setting Sandra utilised strategies (which are built upon whole class strategies and practices) to draw out and develop students' higher level thinking and science reasoning by:

- fostering and sustaining student talk, discussion, thinking-out-loud and verbal reasoning,
- representing a dichotomy of ideas to increase student exchanges
- monitoring and assessing students' learning and identifying areas where support is needed and,
- scaffolding, supporting and providing opportunities for development of quality discourse, higher order thinking and scientific reasoning skills.

## Appendix H: Types and number of instructional setting changes each lesson over the *Forces* unit (CS 2) (Chapter 5)

| Christine and Melanie's Forces unit (CS 2) | | | | | | |
|---|---|---|---|---|---|---|
| Lesson | 5 E Phase | Class instructional settings | | | | Number of instructional setting changes per lesson |
| | | Individual student activity (ISA) | Paired activity (PA) | Small group activity (SGA) | Whole class activity (WCA) | |
| 1 | Engage | 2 | 3 | 0 | 4 | 9 |
| | | | | | | |
| 2 | Explore/Explain | 2 | 5 | 1 | 9 | 17 |
| 3 | Explore/Explain | 3 | 3 | 1 | 8 | 15 |
| 4 | Explore/Explain | 3 | 7 | 0 | 11 | 21 |
| 5 | Explore/Explain | 5 | 3 | 2 | 11 | 21 |
| | | | | | | |
| 6 | Elaborate | 3 | 6 | 4 | 11 | 24 |
| 7 | Elaborate | 2 | 3 | 1 | 7 | 13 |
| | | | | | | |
| 8 | Evaluate | 1 | 1 | 1 | 3 | 6 |

| TOTAL over the unit | 21 (16%) | 31 (25%) | 10 (8%) | 64 (51%) | 126 |
|---|---|---|---|---|---|
| Average number of changes per lesson over the unit | | | | | 16 |

**Appendix I: Summary of Key Findings drawn from Chapter 5**

Key Finding 5.1

Christine and Melanie co-taught their combined Year 4 Science classes. They were not trained as specialist Science teachers. Christine's interest in science led to her completing a minor in Science for her undergraduate degree. She took on the role of Junior School Science Coordinator and managed the teaching of the curriculum across year levels, supported teachers with professional development and resourced and coordinated whole school science activities and community projects. Melanie enjoyed teaching Science and looked forward to becoming more involved in College science initiatives.

Key Finding 5.2

Christine and Melanie co-taught their Year 4 classes for Science in a private junior boarding school for girls with an above average ICSEA rating. Their students demonstrated above average literacy skills on NAPLAN assessments; developed computer literacy, confidence in speaking in front of others, advanced general and science knowledge and vocabularies for their age; and, an awareness of contemporary science issues.

Key Finding 5.3

Established 'ground rules' in both case studies provided a safe and supportive classroom culture that promoted thinking, thinking-out-loud, asking questions, reasoning and justification was already established in Christine and Melanie's combined class. Talking, sharing, discussing and working collaboratively provided an environment where students could build conceptual understanding and develop thinking and reasoning skills.

Key Finding 5.4

The physical organisation of the classroom environment facilitated physical and intellectual interactions between students. By being in close proximity with peers and resources, students were able to talk, share, question, discuss, test and refine ideas together.

Key Finding 5.5

Christine and Melanie believe that the development of scientific literacy is the major purpose of primary science education and that the development of students' reasoning and thinking are essential to this. They believe in hands-on student centred activity-based inquiry learning using authentic examples and find the Primary Connections 5Es model a useful instructional approach.

Key Finding 5.6

Christine and Melanie favoured facilitation rather than direct instruction and believed in a constructivist sociocultural approach to teaching and learning science;

that learning is built upon prior knowledge and that individual learning takes place in a social context across all instructional settings, allowing students to jointly create understanding through sharing testing and refining ideas. Talk, questioning, discussion and verbalising reasons (using 'because') are important verbal forms of communication in the teaching and learning Science. Lessons were structured for collaboration and discussion. The majority of class time was spent in whole class activity and 85% of lesson time across the topic was spent in instructional settings which enabled students to talk, discuss and work collaboratively.

Key Finding 5.7

Christine and Melanie believe that the verbal mode is an important and central mode of instruction but that Science is best taught through multiple modes and representations. They believe strongly in kinaesthetic learning and that students need to be physically involved in their learning especially when dealing with abstract concepts. They frequently use embodiment in teaching Science and all of their other subjects.

Key Finding 5.8

Christine and Melanie believe in a literacy focus in Science lessons and that each lesson needs to contain some form of literacy task. Vocabulary development supports communication of ideas and is a focus in their lessons. ICT is useful for introducing, reviewing and showcasing ideas and activities that are not available in the classroom.

Key Finding 5.9

Christine and Melanie based their Forces unit on the trial version of the Australian Curriculum: Science. They drew ideas from the Primary Connections: Smooth moves unit and other sources, modifying them to suit their students and classroom environment. Christine and Melanie were guided by the Primary Connections 5Es constructivist teaching and learning model when planning and teaching.

Key Finding 5.10

Christine and Melanie established and sustained a thinking, questioning and reasoning classroom culture. They modelled this culture with their general and science talk (use of 'because') and introduced the thinking and questioning emphasis in Lessons 1. Students were expected to think and question during lessons and to justify claims with reasons.

Key Finding 5.11

Lessons were sequenced and structured to cumulatively build conceptual understanding. Push and pull forces were used as the foundational concepts for all of the Force concepts being taught during the unit.

Key Finding 5.12

As conceptual understanding increased, the expectation for thinking and reasoning increased and scaffolding decreased. Lessons 1 – 5 focused on building conceptual understanding, in Lessons 6 and 7 students applied understanding to solve problems and in Lesson 8 students used their knowledge and innovation and creativity skills to make a game on Forces.

Key Finding 5.13

Christine and Melanie used instructional settings and setting changes as a strategy to scaffold and support students' thinking, reasoning and learning within lessons. Christine and Melanie used a sequence of steps using different instructional settings, sometimes multiple times within an activity to scaffold students through activities and tasks. The whole class setting was used in between the other instructional settings for instructions, whole class discussions and for coming to a consensus.

Key finding 5.14

Christine and Melanie co-taught their combined class and took turns being lead teacher. The support teacher moved around the class and between groups monitoring and informally assessing where students were at and gave students in need, support and guidance. Christine and Melanie use of instructional settings and changing of instructional settings within lessons created opportunities for higher order thinking and reasoning. The number of setting changes correlated with the amount of support and scaffolding afforded to students.

Key Finding 5.15

Multiple multimodal learning activities and representations incrementally built the conceptual story and developed students' thinking and reasoning skills as the sequence progressed. The use of multiple multimodal representations catered for diverse abilities and learning styles. Different representations and re-representations enabled students to review, refine, reinforce, demonstrate, apply understandings to new situations and increase thinking and reasoning skills.

Key Finding 5.16

The Big picture question task provided students with a framework and process to build and grow and deepen their thinking and learning as the unit progressed. The question "Why do things move?" was chosen as it required students to investigate and think deeply and encouraged students to question and to search for answers. The Big picture question sheet was a tangible way of monitoring students' thinking, learning and understanding.

Key Finding 5.17

The Big picture question was a three phased metacognitive and representational tool that scaffolded students' thinking, reasoning and ownership of cognitive development across the unit. Students represented their thinking and reasoning in written word, written questions, diagrams, connecting lines and verbal discussion.

- First thinking enabled students to access prior learning, to ask questions about what they wanted to know more about and provided a starting point for teaching and learning.
- Second thinking allowed students to see how far they had come in their thinking and learning, which of their questions they had found answers for and the ones that still needed answering. It also indicated to Christine and Melanie how students were progressing at the half-way point of the topic.
- Third thinking which was also used an assessment item, allowed both the student and Christine and Melanie to see the depth of knowledge and understanding that each student had gained over the topic.

Key Finding 5.18

The Big picture question task supported students' thinking, reasoning and learning across the unit and was also a tangible way for Christine and Melanie to monitor and assess students' work.

Key Finding 5.19

Christine and Melanie utilised partner work and talk during the Big picture question task and multiple other times each lesson across the unit. The verbal sharing of personal ideas with a partner, provided students with a process and forum to learn from others and to access, process, review and extend their conceptual learning, thinking and reasoning. Partner work was used for introducing, building and reviewing concepts, for emphasising and signposting salient points; and, for pacing, guiding, focusing and assessing students' thinking and learning. The Think-pair-share and See-saw strategies were formalised types of partner work frequently used by Christine and Melanie in their teaching.

Key Finding 5.20

Reporting back on someone else's thoughts was a prominent strategy in Christine and Melanie's teaching. Reporting back was a verbal representational challenge that enabled students to review their prior knowledge, to ask themselves questions, to learn from others and to extend their thinking. Through sharing and reporting activities students developed listening, memorising, thinking, processing and communication skills; all of which are important for higher order thinking and reasoning.

Key Finding 5.21

Investigation planners were used as graphical organisers and a metacognitive scaffold for the process of inquiry. Investigation planners together with Christine and Melanie's reminders helped students to internalise the thinking steps required when approaching an investigation. Formulating hypotheses' and deciding whether then were accepted or rejected required reasoning. Teacher scaffolding and the use of the formalised investigation planners was decreased, and the openness of the investigations were increased, as the unit progressed.

Key Finding 5.22

Christine and Melanie used a variety of question types to scaffold and support student's thinking and reasoning skills. Teacher initiated prompts, questions and comments like "Because…?""Why?", "Tell me more.", "What is another way?", "What did you think about . . .?" and "What did your partner think about . . .?" teased out students' ideas and thoughts particularly during investigations which assisted with justification of ideas and the formulation of arguments.

Key Finding 5.23

A feature of Christine and Melanie's teaching was their use of embodiment. Christine and Melanie's lessons were highly embodied and each lesson had some form of embodiment incorporated into it. Embodied representations were used to engage students and provide a platform for conceptual development and a basis for thinking and reasoning.

Key Finding 5.24

Christine and Melanie used embodiment and embodied experiences to: introduce, engage with, explore, review, build, reinforce, link to real life situations, consolidate, represent conceptual knowledge and ideas and apply their knowledge of concepts. They were also used to: render abstract and difficult concepts accessible to students of all abilities, as a catalyst for remembering conceptual understanding and for solving problems, to promote and assist with communication and sharing of ideas, and as semiotic tools to link facets of concepts for meaning making.

Key Finding 5.25

Christine and Melanie's prompting, modelling, referring back to previous embodied experiences and guiding of students to interpret, translate and transfer their feelings, thoughts and what they learnt from embodied experiences to other representational and re-representational challenges, engaged students in more complex thinking and reasoning.

Key Finding 5.26

Complex representational and re-representational tasks were used by Christine and Melanie to create opportunities for students to think and reason. They challenged students to formulate explanations and solutions to problems and required a higher level of thinking and reasoning from students. Continual monitoring, modelling of diagrams, verbal prompts in the form of instructions, hints, questions, and gestures were used in the scaffolding and supporting of these tasks.

Key Finding 5.27

Representational activities and re-representational challenges, were sequenced, supported by metacognitive and verbal scaffolds and underpinned by a safe, positive, thinking and collaborative classroom and learning culture, to build and create opportunities for higher order thinking and scientific reasoning.

Key Finding 5.28

Embodiment and embodied experiences were foundational in building conceptual development, conceptual development provided the context for representational activities and lower level thinking and reasoning and re-representational challenges created the opportunities for students to be engaged in higher order thinking and scientific reasoning.

**Appendix J: Summary of Assertions drawn from Chapter 6**

Assertion 6.1

Contextual factors influenced Sandra's (CS 1), and Christine and Melanie's (CS 2) choice of pedagogies and strategies. In addition to the broader social factors; school contextual factors including the priority given to science, the physical and social environment of the classroom, student demographics and prior knowledge; teachers' beliefs and pedagogical practices and the topic being taught framed the opportunities for students to engage with higher order thinking and reasoning.

Assertion 6.2

Sandra (CS 1), and Christine and Melanie (CS 2) held similar beliefs regarding scaffolding, supporting and creating opportunities for higher order thinking and reasoning, but they had a slightly different focus. Their shared beliefs related to the importance of scaffolding the development of scientific literacy through hands-on authentic problem-based collaborative inquiry learning tasks, investigations and activities; that talk and language mediate thinking, learning and reasoning; that body-based experiences assist with conceptual and cognitive development and the importance of providing a safe and supportive learning culture and environment.

The difference between the nature of the Materials and their uses concepts (CS 1) and Forces concepts (CS 2) may explain Sandra's (CS 1) belief in and the emphasis on talk and language as mediators of thinking and reasoning; and, Christine and Melanie's (CS 2) belief and emphasis on body-based experiences as mediators of thinking and reasoning.

Assertion 6.3

Sandra's (CS 1), and Christine and Melanie's (CS 2) pedagogical practice of maintaining a safe and supportive learning environment throughout their units was critical for the promotion of talk, collaboration, hands-on inquiry and for students to feel safe and confident to share their ideas, support their opinions with reasons, take risks in speaking their minds; question, debate, critique and be critiqued; to argue, change their minds and use evidence to support conclusions.

Initial levels of student confidence differed between the two case study classes due to contextual differences relating to students' prior knowledge, vocabularies, awareness of contemporary science issues and amount of exposure students had previously with sharing ideas and the process of argumentation. These factors influenced Sandra's (CS 1), and Christine and Melanie's (CS 2) choice of pedagogies and strategies, starting points for cognitive development and how they scaffolded and supported higher order thinking and scientific reasoning.

Assertion 6.4

Sandra (CS 1), and Christine and Melanie (CS 2) facilitated students' thinking, reasoning and conceptual development through the use of the 5Es model and by monitoring, scaffolding, supporting, guiding, modelling and responding to students' ideas rather than simply delivering information. Students in both case studies were given the responsibility for their own thinking and learning through hands-on inquiry, student-focused activity-based investigations and problem solving activities that engendered exploration, problem solving and creativity.

Assertion 6.5

In both case studies talk and collaboration played key roles in stimulating and extending students' thinking and reasoning. Students were given many opportunities to talk and discuss their ideas throughout the unit. Due to contextual differences between the case studies relating to class size and classroom settings, the orchestration of these opportunities differed between the two case studies. In CS 1 much of the talk and collaboration occurred during small group work and class discussions. In CS 2; with the class size double that of CS 1 and the classroom being a large communal space devoid of furniture, Christine and Melanie (CS 2) favoured whole class discussions interspersed with many quick think-pair-share sessions to maximise talk and collaboration opportunities.

Assertion 6.6

Metacognition featured prominently in each case study and was a crucial component in the development of high order thinking and reasoning. Sandra (CS 1), and Christine and Melanie (CS 2) taught, supported and guided the development and application of students' metacognitive knowledge to tasks and metacognitive strategies such as reflective thinking, monitoring and self-regulation through the use of informal pedagogies and strategies such as thinking-out-loud; sharing of thinking processes; teacher prompts and questions; teacher modelling and the showcasing of expert students' thinking processes; and, formal pedagogies and strategies such as Hot seat, Fish bowl, Learning train, Sticky note fact graph, WILF and TIB and Big picture question.

Assertion 6.7

Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches reflected their beliefs and closely aligned with the characteristics of inquiry teaching and learning, which engages students in evidence finding, interpretation and critical and logical reasoning and therefore enhances higher order thinking and scientific reasoning.

Assertion 6.8

Facets common to Sandra's (CS 1), and Christine and Melanie's (CS 2) instructional approaches, namely: the provision of a safe and supportive classroom learning environment; hands-on inquiry supported by the 5Es instructional model; facilitation as a way of instruction and lots of talk and collaboration, worked in combination and at different levels of influence, as a foundation for pedagogies and strategies employed to scaffold, support and create opportunities for higher order thinking and reasoning.

Assertion 6.9

In both case studies a strong overt thinking and reasoning culture played an integral role in the development of students' thinking and reasoning skills by promoting thinking and reasoning as an important outcome of lessons alongside the development of conceptual understanding. It placed the responsibility for thinking and reasoning on the student and provided an environment and platform that encouraged students to think deeply, to question, to verbally share their thoughts to co-construct arguments with others and to justify their claims with reasons. Speaking about, highlighting, modelling, discussing, prompting, scaffolding and extending thinking and reasoning continually during lessons also heightened students' awareness of the importance of these skills for their education and as necessary life skills.

Assertion 6.10

Sandra (CS 1), and Christine and Melanie (CS 2) sequenced learning tasks to build conceptual understanding and to scaffold and support the development of thinking and reasoning.  The building of conceptual understanding in learning tasks was integral, which was demonstrated in that all learning tasks had a conceptual and cognitive component. The expectation for students to think and reason independently increased as tasks along the learning sequences became cognitively more demanding moving from lower order thinking and reasoning tasks in the beginning of the sequences to higher order thinking and scientific reasoning tasks at the end of the sequences. In the beginning of learning sequences students were highly scaffolded and supported but as students became more proficient conceptually and cognitively the support and scaffolding was proportionally reduced or faded.

Assertion 6.11

The use of representations were important for conceptual development and the scaffolding, support and creation of opportunities for thinking and reasoning in both case studies. The sequencing of representational tasks of increasing cognitive demand, the combination of teacher and student generated representational tasks, the modelling and practice of representation construction; together with, teacher-student negotiations regarding the planning, construction, interpretation, explanation and evaluation of students' constructed representations provided opportunities for the development of thinking and reasoning. Final assessment tasks, which involved students representing and constructing their own representations were the ultimate cognitively challenging task in both units and created the greatest opportunity for higher order thinking and reasoning in both case studies.

Assertion 6.12

Discourse-based pedagogies and strategies in both case studies; encouraged thinking aloud, reflective thinking, language-based reasoning (particularly in CS 1 due to Sandra's belief in giving students the language to reason), and scaffolded, supported and created opportunities for higher order thinking and reasoning. Facilitated by safe learning environments, dialogic interactions between teacher and students and between students; having students come to a consensus; modelling, coaching and scaffolding of the steps involved in argumentation; challenged, shaped, extended students' individual and collaborative thinking and reasoning from lower order thinking and reasoning to higher order thinking and more complex reasoning such as critical and creative thinking.

Assertion 6.13

Body-based experiences made strong contributions towards students' conceptual development and higher order thinking and reasoning in both case studies by giving access to complex and abstract concepts; by being active and actual parts of students' meaning making processes and as representative tools for communicating thinking, reasoning and justification of ideas. Teacher guided discourse interactions were essential for interpreting and linking body-based representations with other modes of representations in learning sequences that developed conceptual understandings and extended students thinking and reasoning. This was particularly obvious in CS 2 with Christine and Melanie's frequent use of embodiment due to their belief in kinaesthetic learning and the abstractness of concepts in their Forces topic.

Assertion 6.14

Sandra's (CS 1), and Christine and Melanie's (CS 2) overall instructional approaches and pedagogies and strategies map directly onto the cognitive apprenticeship model (CAM) (A. Collins et al., 1989). The four major components and sub-components of CAM provide a solid basis on which to formulate, select and sequence pedagogies and strategies that scaffold, support and create opportunities for higher order thinking and scientific reasoning.

Assertion 6.15

Whilst there were some variations between the two case studies, leading to different pedagogies and strategies being used, there were six categories of pedagogies and strategies used across both case studies that worked together to develop higher order thinking and scientific reasoning. These included pedagogies and strategies that promoted a strong and overt thinking and reasoning culture, metacognition; that sequenced tasks and representations of increasing cognitive load as sequences progressed and as conceptual development increased; discourse-based pedagogies and strategies and body-based experiences.