EXPLORING THE PEDAGOGICAL CONTENT KNOWLEDGE OF EXPERIENCED GEOGRAPHY TEACHERS

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ABSTRACT

This study examines the nature of experienced Geography teachers' Pedagogical Content Knowledge (PCK) of students' ideas and the role of two key factors, teachers' content knowledge and teachers' epistemological beliefs, in shaping the development and enactment of this knowledge base. Whereas earlier studies in Mathematics and Science education have highlighted the need for teachers to consider students' common alternative conceptions when designing instruction, relatively little is known about this area of Geography teachers' knowledge.

The study employs a mixed method design, including the use of structured questionnaires, drawing tasks and semi-structured interviews, to determine the alternative conceptions of tropical cyclone causes and processes held by 380 Year 9/10 students studying Geography in Sydney schools. This data is used as a basis for examining the PCK of students' ideas held by 17 experienced secondary Geography teachers. Lesson observations, semi-structured interviews and video-stimulated recall sessions are used to investigate the ways in which Geography teachers use their knowledge of students' common alternative conceptions to inform instruction, and to investigate the importance of the teachers' content knowledge and epistemological beliefs in the development and enactment of this knowledge base.

The findings of the study indicate that experienced Geography teachers vary in their depth of knowledge of students' conceptions and that the development and enactment of this knowledge base is influenced by a number of factors or filters (including the teachers' content knowledge and epistemological beliefs). These findings have implications for further research, for curriculum mapping and program development in schools, for teacher professional development and the formulation of policy. A preliminary model of PCK development and enactment is proposed as a framework to guide the future research agenda in this area.

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STATEMENT OF CANDIDATE

I certify that the work in this thesis entitled "Exploring the pedagogical content knowledge of experienced Geography teachers" has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree to any other university or institution other than Macquarie University.

I also certify that the thesis is an original piece of research and it has been written by me. Any help and assistance that I have received in my research work and the preparation of the thesis itself have been appropriately acknowledged.

In addition, I certify that all information sources and literature used are indicated in the thesis.

The research presented in this thesis was approved by Macquarie University Ethics Review Committee, reference number HE22AUG2008-D06018.

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Chapter 1 – Introduction

Since the early 1980s there has been significant interest in the exploring teachers' diverse knowledge domains for planning and teaching (Magnusson, Krajcik & Borko, 1999). Much of this work has built on Shulman's conceptualisation of pedagogical content knowledge (PCK) and its recognition of the importance of *subject-specific knowledge* in effective teaching. According to Shulman (1986, p. 8):

> [PCK] represents the blending of content and pedagogy into an understanding of how particular topics, problems, or issues are organized, represented, and adapted to the diverse interests and abilities of learners, and presented for instruction.

Shulman's conceptualisation highlights the need for teachers to combine their knowledge of content with an understanding of the students they teach. This includes knowledge of students' conceptions, preconceptions and misconceptions in the "most frequently taught topics and lessons" in each subject domain (Shulman, 1986, p. 9). The central importance of this knowledge base has been confirmed by more than 30 years of analysis of students' alternative conceptions and conceptual change in Science, Mathematics and Psychology (see, e.g., Berg & Brouwer, 1991; de Jong & van Driel, 2001; Jones, Carter & Rua, 1999; Kokkotas, Vlachos & Koulaidis, 1998; Morrison & Lederman, 2003; Sequeira, Leite & Duarte, 1993; Smith & Neale, 1989; Zembal-Saul, Starr & Krajcik, 1999). The findings of this research demonstrate that students construct mental models of many of the core concepts in the curriculum prior to formal instruction (Duit, Treagust & Widodo, 2008). While these mental models are often inconsistent with the established views of experts they can serve as important resources for building student understanding if teachers are aware of them and use them effectively during instruction (Larkin, 2012; Smith, diSessa & Roschelle, 1994). Shulman (1986) argues that knowledge of students' alternative conceptions is essential if teachers are to be able to transform content knowledge effectively to promote student learning.

Like researchers in Mathematics and Science, scholars in geographical education have for some time acknowledged the need to first diagnose, then address alternative conceptions through instruction (Dove, 1999; Ghaye & Robinson, 1989; Lambert & Balderstone, 2010; Leat & Chandler, 1996; Lee, 1999). Researchers in this domain have investigated the nature of students' preconceptions in several key content areas and have explored a range of strategies for promoting geographical understanding (see Hutchinson, 2011 for a recent review). The challenge for geographers, however, is that research in this area remains relatively underdeveloped in two main ways. Firstly, there are many topic areas in Geography in which student conceptions are yet to be explored; secondly, researchers have largely overlooked the implications of the work with *students* for research exploring *Geography teachers'* PCK. One consequence of this has been a lack of attention directed to the investigation of Geography teachers' PCK of students' ideas and the factors influencing the development of this knowledge base. Likewise, little is known about the ways in which experienced Geography teachers use their knowledge of students' mental models to shape their thinking about classroom practice. This is in contrast to a relatively rich literature exploring these issues in primary as well as secondary Science and Mathematics (see Section 2.3.2). This literature shows that both in-service and pre-service teachers in primary and secondary Science are themselves frequently unaware of students' naive beliefs, have "inadequate" content knowledge, and are often restricted in their ability to implement appropriate pedagogical strategies to address students' alternative conceptions (see, e.g., Berg & Brouwer, 1991; de Jong & van Driel, 2001; Jones et al., 1999; Kokkotas et al., 1998; Morrison & Lederman, 2003; Sequeira et al., 1993; Smith & Neale, 1989; Zembal-Saul et al., 1999). These studies (mainly in primary Science) indicate that teachers often possess only limited knowledge of student preconceptions in key topic areas and lack the ability to transform content into a form that is "penetrable" for students (Smith & Neale, 1989, p. 3). This is not restricted to novice teachers; research into the practices of 'expert' middle school Science teachers in the United States has revealed that, even when teachers are aware of the nature and importance of students' alternative conceptions, they often do little to either diagnose or address these ideas in the classroom (Morrison & Lederman, 2003).

In contrast to the literature in Science, specific research investigating Geography teachers' knowledge of students' preconceptions and the use of this knowledge to inform pedagogy is scarce. The work of Dove (1996b) and Reinfried (2006a) provides notable exceptions; however, even those studies focus more on the preconceptions of teachers or student teachers than on the teachers' awareness of students' intuitive mental models.

As Mackintosh (1999, p. 71) notes:

> geography should learn from the science alternative framework . . . teachers *need to take into account the children's prior ideas in their choice of concepts to be taught*, the order of their teaching and particularly their choice of learning experiences, with clear purposes for each activity. This necessitates research into both children's learning and the effectiveness and appropriateness of teaching strategies, both in and beyond the classroom. It also requires a bottom-up not top-down, approach. To use that old-fashioned but pertinent expression, we must 'start where the children are at', once we have established this, not at some distance above it, leaving an unbridgeable gap!

1.1 The context of change in geographical education

While there is a gap in our research-based knowledge of Geography teachers' PCK, there is growing awareness at both a national and international scale of the need to develop Geography teachers' knowledge across the range of domains identified by Shulman (1987). This growth in awareness is evidenced through the introduction of policies, regulations and processes to describe and develop the diverse knowledge base of Geography teachers, including their content knowledge, pedagogical knowledge, knowledge of context and PCK. The following four developments in geographical education illustrate the increased focus on the dimensions of Geography teachers' knowledge.

1.1.1 The development of standards for describing accomplished Geography teaching and threshold learning outcomes for Geography graduates

The recently developed *National Professional Standards for Accomplished Teaching of School Geography* (University of Melbourne, AGTA, GTAV & Victoria Institute of Teaching, 2010) and *Learning and Teaching Academic Standards* for bachelor degree graduates with Geography majors (Australian Learning and Teaching Council, 2010) highlight the importance of the knowledge dimensions identified by Shulman (1986) and Grossman (1995). While these documents highlight the importance of a "coherent geographical understanding of trends, processes and impacts" (Australian Learning and Teaching Council, 2010, p. 11) they also emphasise the need for Geography teachers to develop knowledge of their students, the curriculum and pedagogical practices for improving student understanding.

1.1.2 The structuring/restructuring of curriculum around 'core knowledge'

A second key development in geographical education has been the renewed focus on "core knowledge" in the development and revision of national curriculum documents both in Australia and overseas. The process of the curriculum revision in the UK, for example, has focused on the need to determine the core concepts and "unifying ideas" that "all children should be expected to acquire in the course of their schooling" (DfE, 2010, p. 41). This focus on core knowledge is also evident in the Australian context, where *The Australian Curriculum: Geography* has been structured around three core concepts (space, place and environment) and four secondary concepts (interconnection, sustainability, scale and change). Although these developments impact most directly on the design of curriculum materials for students, they also have important implications for the content knowledge and PCK requirements of teachers.

1.1.3 Revised discipline-specific content requirements for teachers (in Australia)

The Australian Institute for Teaching and School Leadership (AITSL) has recently moved to mandate minimum discipline-specific content requirements for teachers in Australia. Changes have also been made to the length of graduate programs (2 years' full-time-equivalent professional studies in education) and the undergraduate content requirements for prospective primary teachers. Teachers of secondary Geography are now required to have a minimum of six units of discipline-specific study in their degree with no more than two units at first year level and at least two units at third year level. There is, however, no requirement for prospective Geography teachers to have an academic major in Geography or a balance of studies in Human and Physical Geography. These changes have implications for the development of Geography teachers' content knowledge, in turn influencing the development of their PCK.

1.1.4 The Productivity Commission's research report on schools' workforce

In 2010, the Australian Government asked the Productivity Commission to examine the issues impacting on the workforces in the early childhood development, schooling and vocational education and training sectors. The report (Productivity Commission, 2012) makes a range of recommendations regarding teacher training and accreditation that have the potential to impact on the development of teachers' knowledge. These recommendations include the use of the *National Professional Standards for Teachers* (including statements dealing with teachers' knowledge of content and how students learn) in teacher appraisal schemes. The Commission recommends that the existing national standards be supplemented with indicators and criteria that can be used as the basis for evaluating teachers' knowledge and skills. In line with this recommendation, the Australian Institute of School Leadership (AITSL) has recently released the *Australian Teacher Performance and Development Framework* which aims to provide annual appraisals of every teacher in every school against national professional teaching standards, including standards related to teachers' content knowledge and knowledge of the students they teach. Key elements of the framework include (1) goal setting by all teachers, (2) access to high quality professional learning, (3) the use of multiple sources of evidence to reflect on and evaluate teacher performance, and (4) an annual review of performance including both verbal and written feedback. As a minimum, teachers will be required to collect data showing their impact on student learning outcomes, information based on direct observation of teaching and evidence of collaboration with colleagues (Australian Institute for Teaching and School Leadership - AITSL, 2012).

The report also makes a number of recommendations regarding the accreditation of pre-service teacher training programs. The Commission is supportive of an evidence-based and outcomes-focused approach to the accreditation of teacher education programs, highlighting the need for training providers to demonstrate that their graduates *actually meet* the graduate standards, including standards related to content knowledge, before they can be accredited and reaccredited.

The above discussion highlights a number of contextual factors with the potential to influence the development of Geography teachers' PCK. Despite this, however, we currently lack research-based understanding of how this knowledge is developed and used by teachers to inform their practice. Of particular concern is the lack of research exploring the nature of

Geography teachers' PCK, especially their knowledge of and work with students' alternative conceptions.

1.2 Situating the study

The preceding discussion highlights the need for further research into the PCK of experienced Geography teachers, especially components relating to teachers' knowledge of the students they teach. It is currently not known, for example, how aware Geography teachers are of students' alternative conceptions in this domain or how they use this information to shape their thinking about classroom instruction. What is known is that expertise is domain-specific (Berliner, 2001) and that researchers need to study teachers' knowledge in domain-specific and topic-specific contexts (Abell, 2008). Targeted, discipline-specific research is therefore required to identify experienced Geography teachers' knowledge of student preconceptions in key topic areas and the way this knowledge is used to inform practice.

1.3 Aim and purpose

This study addresses existing gaps in the literature by investigating experienced Geography teachers' PCK of students' ideas and their use of this knowledge to inform instruction. An important first step in this process involves exploring the conceptual knowledge and depth of understanding of 17 Geography teachers and their students in a key topic area typically featured in Geography curriculum – tropical cyclone causes and processes.

1.4 Research design

Although there is a paucity of literature exploring the PCK of experienced Geography teachers, investigations in Science highlight the need for researchers to focus on a particular topic area in order to explore the content knowledge and PCK of teachers and their students. The topic of tropical cyclone causes and processes, which is found within the NSW Stage 5 Geography Syllabus focus area: *Investigating Australia's Physical Environments (5A1),* has been selected as the context for this study because of the paucity of previous research on alternative conceptions in this area; the likelihood that students would have been exposed in their lives to informal ideas about tropical cyclones; the ease with which the conceptual building blocks of understanding (such as air pressure and evaporation) can be identified; and the existence of research indicating that such concepts present difficulties for many students. Although students attending school in Sydney might not have experienced a tropical cyclone event directly, they are likely to have been exposed to information about tropical cyclones from a range of other sources including news media, the internet and popular culture.

To develop an understanding of cyclone causes and processes, both students and teachers require factual and conceptual knowledge of a range of key ideas including evaporation, cloud formation, air pressure and precipitation. These ideas act as threshold concepts (Meyer & Land, 2006) in this topic, enabling students to develop a relational understanding of the links between the various causes and processes.

Evidence from the Science literature suggests that the abstract and intangible nature of these underlying concepts, coupled with exposure to both fictional and scientific ideas about tropical cyclones through popular culture and the media, is likely to provide fertile ground for the development of naive theories and alternative conceptions. The topic of tropical cyclone causes and processes is, therefore, a useful focus for the investigation of PCK because of the likely range of alternative conceptions affecting student understanding in this area. Teacher awareness of these preconceptions and use of this knowledge to inform pedagogy can also be reliably assessed using a variety of qualitative techniques including semi-structured interviews, classroom observations and video-stimulated recall sessions.

The major research questions for this study are the following:

1. To what extent are experienced Geography teachers aware of common alternative conceptions held by students (i.e. What is their PCK of students' ideas)?

2. How do teachers use their existing knowledge of students' conceptions and the data provided by the researcher to inform practice? (i.e. How is PCK of students' ideas enacted in the classroom?)

3. What is the relationship between the teachers' PCK development/enactment and their (a) accuracy and depth of content knowledge and (b) epistemological beliefs about learning and teaching?

To address the above questions it is necessary to investigate:

1. the alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by Year 9/10 Geography *students*

2. the alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by experienced *teachers* of secondary school Geography

3. the depth of understanding of experienced Geography teachers in this topic area

4. the teachers' epistemological beliefs about learning and teaching

5. the intended purpose of the teaching practices employed by these teachers.

1.5 The nature of Geography and philosophical approach of the study

The discipline of Geography, particularly within a school context, adopts a holistic approach and draws on the knowledge and philosophies of the natural sciences, social sciences and humanities. Geography's recent and sustained engagement with different philosophical traditions means that there are a number of competing schools of thought about the nature of geographical knowledge (epistemology) and how this knowledge base should be investigated and conceptualised (Hubbard, Kitchin, Bartley & Fuller, 2002). This study adopts the epistemological position that knowledge is constructed, problematic and continually evolving. In order to facilitate the identification of students' and teachers' alternative conceptions, however, the NSW Geography curriculum, and the scientific understandings upon which it is based, are used as benchmark for defining the expected learning outcomes of students. While it is accepted that there is no single body of universally "correct" geographical knowledge, there is general agreement in the scientific community regarding the causes, processes and impacts of tropical cyclones. The processes and principles used as a reference point in this study are not, therefore, seen as contentious.

1.6 Terminology adopted in this study

A range of terms have been used in the Science literature to describe the intuitive mental models or concept images that students develop prior to formal instruction. They include "children's Science" (Gilbert, Osborne & Fensham, 1982), "alternative conceptions" (Arnaudin & Mintzes, 1985; Dove, 1998a; Lin & Cheng, 2000), "preconceptions" (Gallegos, Jerezano & Flores, 1994), "misconceptions" (Fisher, 1985; Pine, Messer & St. John, 2001) and "alternative frameworks" (Driver & Erickson, 1983). In this thesis the term "preconception" (Ausubel, 1968) is used to refer to students' pre-instructional knowledge as well as their ideas, concepts or theories concerning geographical processes and phenomena that have been constructed as a result of everyday experiences (Reinfried, 2007). The term "alternative conception" is used to denote an understanding that is inconsistent with currently accepted "expert views". Learning that involves the fundamental restructuring of students' pre-instructional ideas is referred to as "conceptual change" (Duit & Treagust, 2003).

1.7 Organisation of the thesis

The thesis is organised into seven chapters:

Chapter 1 describes the context for the study, outlines its purpose and provides an overview of the thesis structure.

Chapter 2 provides a review of the literature in two parts. *Part 1* is an overview of the dimensions of PCK and the educational and political contexts that led to its conceptualisation, followed by a discussion of the research exploring alternative conceptions and their impact on student learning. *Part 2* examines the degree to which PCK has been recognised in both generic and domain-specific teaching standards and models of pedagogy. The extent to which PCK is used to shape experienced teachers' thinking about classroom instruction is determined by an exploration of the research in both Science and geographical education. This review leads to a discussion of the existing gaps in the research and the framing of research questions for the current study.

Chapter 3 presents an overview of the research design, theoretical rationale and methodology. This chapter is organised around the two phases of the study: *Phase 1* was designed to identify the conceptual understandings and alternative conceptions of secondary Geography students. *Phase 2* focused on the teachers' conceptions of tropical cyclones, their PCK of students' ideas and their use of this knowledge to inform instruction.

Chapters 4 to *6* provide an overview of the results and methods of data analysis. The students' content knowledge, depth of understanding and alternative conceptions are presented in *Chapter 4* and that of the teachers in *Chapter 5*. A series of rich case studies is presented in *Chapter 6* to examine teachers' use of PCK to inform instruction. Each chapter integrates the reporting of results with a discussion of the data in light of the literature.

The final chapter provides a summary of the findings of the research as well as the implications for theory, practice and the development of Geography teachers' PCK. The chapter also includes a discussion of the limitations of the study and recommendations for future research.[1]

[1] A number of publications have been generated from this thesis. The details of these papers are provided in Appendix 1.

Chapter 2 - Literature review

2.1 Context

This study investigates the PCK of experienced secondary school Geography teachers and the ways in which this knowledge is used to inform instruction (i.e. the *enactment* of PCK).

This literature review examines research in both Geography and Science education. This is a deliberate choice because of the conceptual overlap between the disciplines. The Royal Geographical Society with the Institute of British Geographers (2009) define Geography as "the study of the earth's landscapes, peoples, places and environments." They add that Geography is "unique in bridging the social sciences (Human Geography) with the natural sciences (Physical Geography)". Scholars in these domains have, however, adopted contrasting approaches to the investigation of teachers' knowledge. Researchers in geographical education, for example, have devoted significant attention to aspects of teachers' PCK, especially strategies for promoting *geographical understanding*. In contrast to the literature available in Science education, however, there has not been the same focus on teachers' knowledge of students' alternative conceptions and the use of this information to shape planning and instruction.

This chapter highlights the need for further research exploring the PCK of Geography teachers by providing a two-stage review of the literature. The first stage provides an overview of the dimensions of PCK and the educational and political contexts that led to its conceptualisation/development. Attention is then given to the component of PCK which includes the development of alternative conceptions and their impact on student learning. Research indicates that teachers' knowledge of this forms an important foundation of effective pedagogy and that this knowledge should be used to inform instruction.

After establishment of the importance of understanding students' common preconceptions as a component of PCK, the second stage of the review examines the degree to which this knowledge has been recognised in professional teaching standards and models of pedagogy. The extent to which PCK is used to shape experienced teachers' thinking about classroom instruction is determined by an exploration of the research in both Science and geographical education. This review leads to a discussion of gaps in the research and the framing of research questions for the current study.

2.1.1 Pedagogical content knowledge

Teacher knowledge has for a long time been an issue of interest in educational research (Dewey, 1904, Scheffler, 1965, Green, 1971 cited by Shulman, 1987). Early research in this area concentrated mainly on content knowledge, general pedagogical knowledge and teachers' knowledge of self, including an awareness of how their values and personal characteristics impact on their teaching (Grossman, 1995). A particular focus of this research was the identification of potential correlational relationships between teachers' knowledge and students' achievement. The findings of this research indicate, however, that teachers' factual understandings about a concept or topic (declarative content knowledge) is not strongly associated with student performance (Good, 1991 cited by Grossman, Wilson & Shulman, 1989; Tambyah, 2007). By the mid-1980s, attempts to professionalise teaching in the United States and elsewhere resulted in a focused effort to identify a specialised knowledge base that was unique to teaching and to investigate the way in which teachers' knowledge and thinking shapes their planning and actions in the classroom (Grossman, 1995). Research by Shulman (1986) and Leinhardt and Smith (1985) demonstrated that there was an important relationship between teachers' knowledge of subject content and their approach to classroom planning and instruction. Shulman's work led him to identify several categories of teacher knowledge: content knowledge, general pedagogical knowledge, curriculum knowledge, knowledge of learners and their characteristics, and knowledge of educational contexts and educational ends (Shulman, 1987). In addition to these knowledge domains, Shulman's research revealed a distinct form of knowledge involving a combination of content and pedagogy that is "uniquely the province of teachers, their own special form of professional understanding" (Shulman, 1987, p. 8).

Shulman referred to this amalgam as pedagogical content knowledge (or PCK), describing it as topic-specific knowledge for teaching a particular subject. According to Shulman (1987, p. 8):

> [PCK] represents a blending of *content* and *pedagogy* into an understanding of how particular topics, problems or issues are organized, represented and adapted to the diverse interests and abilities of learners and presented for instruction. Pedagogical content knowledge is the category most likely to distinguish the understanding of the content specialist from that of the pedagogue.

Shulman and his colleagues later refined their framework to acknowledge the importance of a third knowledge dimension in the formation of PCK. Wilson, Shulman, and Richert (1988) argued that PCK was the product of the transformation and integration of content knowledge, pedagogical knowledge and knowledge of educational contexts. The integration of these three components, it was argued, creates a unique and powerful form of knowledge that is more than the sum of its parts (Abell, 2008; Magnusson et al., 1999). As Shulman (cited by Berry, Loughran & van Driel, 2008) explained:

> just knowing the content well was really important, just knowing general pedagogy was really important and yet when you added the two together, you didn't get the teacher. (p. 1274)

Shulman (1986) maintained that, up until the mid-1980s, research on teaching and, as a consequence, policy development to improve teaching standards tended to ignore the role of content knowledge in effective teaching. This represented a "blind spot" (p. 8) in educational research that Shulman and his colleagues hoped to address through their research into "knowledge growth in teaching" (p. 8). The intention of this initiative was not to denigrate the importance of pedagogical understanding as a component of effective teaching but to promote a better understanding of the interrelationships between content knowledge, pedagogical reasoning and classroom practice. According to Shulman (1986, p. 8):

> mere content knowledge is likely to be as useless pedagogically as content-free skill. But to blend properly the two aspects of a teacher's capacities requires that we pay as much attention to the content as we have recently devoted to the elements of teaching process.

The concept of PCK provided a framework for examining the relationships between subject content knowledge, pedagogy and context, and has stimulated more than three decades of research into these links in Science education (Grossman, 1995). Since the mid-1980s, academics in Science education have been at the forefront of research into PCK.

Shulman (1986) defined PCK as "expert content-knowledge of subject matter and curricular knowledge linked to effective teaching strategies within a content area" (p. 9). His initial conceptualisation of PCK consisted of two components, (a) knowledge of multiple methods for representing and organising subject content to make it comprehensible to students and (b) knowledge of what makes the learning of particular content easy or difficult for students. The first component comprised an awareness of relevant analogies, illustrations, examples, and explanations, together with knowledge of specific strategies and activities for promoting student understanding in the subject domain. Shulman's concept of PCK acknowledged that "depth, quality and flexibility" of content knowledge were required in teaching, as well as an ability to create "powerful representations and reflections" on that knowledge (Shulman, 1999, p. xi). Other researchers, including Calderhead and Miller (1983), Elbaz (1983) and Feinman-Nemster and Buchmann (1985), have also highlighted the importance of making content knowledge "penetrable" for students by translating it into knowledge appropriate for teaching.

Shulman (1986) noted that in order for these representations to be translated into successful strategies for "reorganising the understanding of learners" (pp. 9–10), teachers need to be informed by knowledge of what makes the learning of particular content easy or difficult for students. Consequently, he identified students' common conceptions and preconceptions in key topic areas as the second important component of PCK. According to Shulman (1986), an understanding of the alternative conceptions that students develop prior to formal instruction and the instructional conditions necessary for overcoming these beliefs should be "at the heart of our definition of needed pedagogical knowledge" (p. 10). Knowledge of students' alternative conceptions (or PCK of students' ideas) is foundational for the development of strategies and representations for addressing students' common areas of misunderstanding. Equally, this knowledge is important for the development of valid and reliable assessments to diagnose and address learning problems in schools.

Over the past 25 years, Shulman and his colleagues have modified their conception of the domains of teacher knowledge and the nature and components of PCK. Other researchers investigating the nature of teachers' knowledge have also elaborated upon Shulman's original framework. One such example is the work of Magnusson, Borke, and Krajcik (1999). Building on the work of Shulman (1986, 1987), Grossman (1990) and Tamir (1988), Magnusson et al. (1999) provide a revised model of the components of PCK for Science teaching. This model unpacks PCK into five areas of teacher knowledge and beliefs, adding the following three elements to Shulman's original conceptualisation: teachers' orientation to teaching Science, knowledge of Science curricula and knowledge of assessment of Science literacy. Park and Oliver (2008) expanded the model further by adding teacher efficacy as "an affective affiliate of PCK" (p. 261) and by highlighting the importance of reflection in the integration and development of PCK components. Figure 2.1 (adapted from Park & Oliver, 2008) shows the components of PCK as they relate to the knowledge base of Geography teachers.

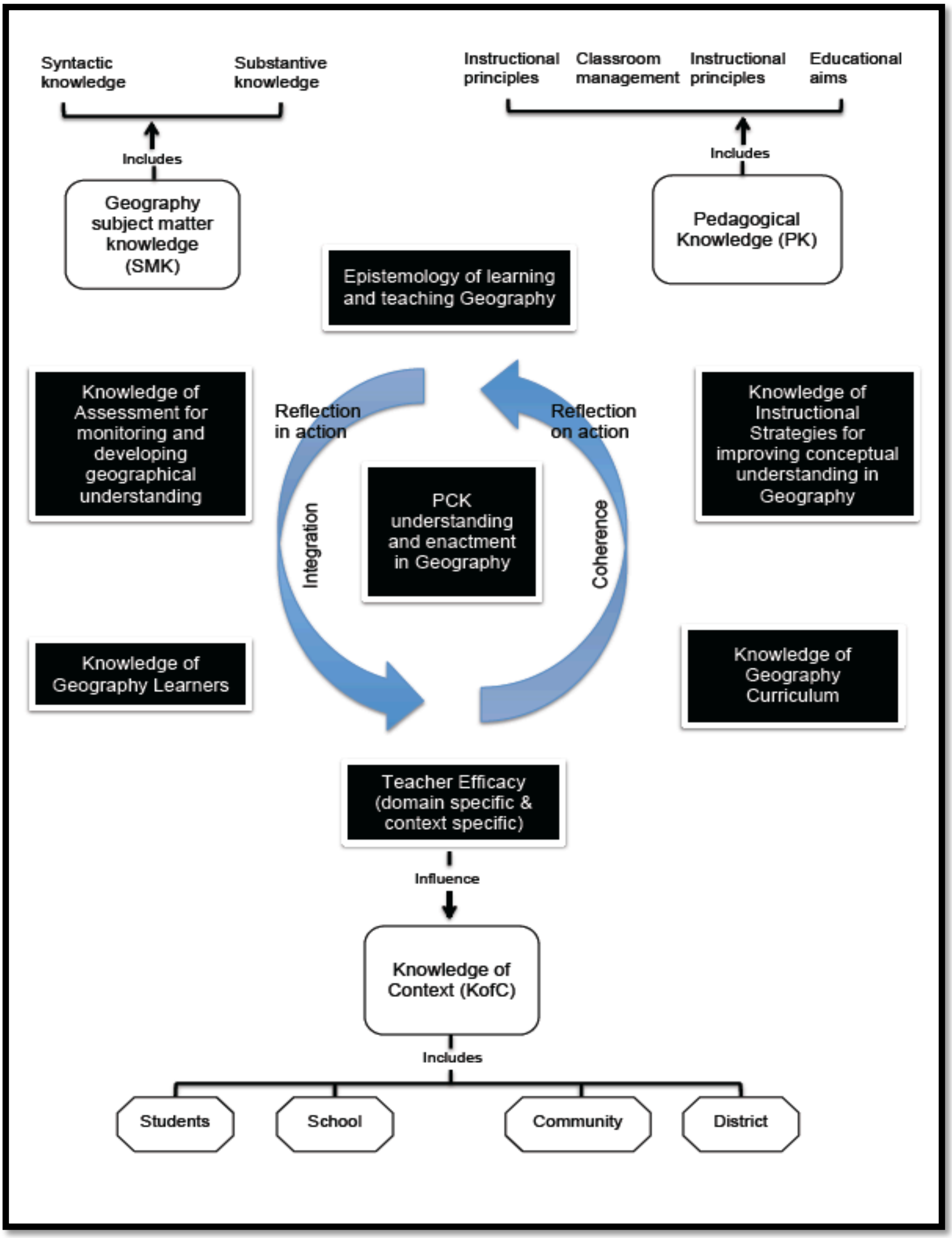


Figure 2.1 Model of PCK for Geography teaching (adapted from Park & Oliver, 2008)

The pre-eminence of teachers' PCK, in particular, knowledge of students' preconceptions, in the facilitation of learning has been supported by research findings in cognitive psychology as well as by conceptual change studies in Science, Mathematics and Psychology (Taylor & Kowalski, 2004; Vosniadou, Vamvakoussi & Skopeliti, 2008). Bruner (1960), for example, argued that effective learning involves connecting what is known with what is new. These findings are reinforced by the results of experimental research conducted in the 1980s and 1990s. This research indicated that learning is best facilitated when there is a "goodness of fit" between students' existing understandings and new information and skills presented through instruction (Anderson, 2004). For teachers to create this goodness of fit, they require an understanding of students' common preconceptions.

Research conducted by Park and Oliver (2008) in Chemistry education found that teachers' understandings of students' preconceptions appeared to be a primary factor shaping the development of PCK. They observed that it was only when teachers:

> grasp[ed] their students' cognitive and affective status with regard to the learning of a particular topic [that] they [could] apply pedagogically adjusted procedures in order to facilitate learning. (p. 279)

The authors argue that a teacher's capacity to "read" students is essential to their PCK development because students' conceptions can only be used to inform teaching practices when teachers are "aware of their significance" (p. 279). If we accept that knowledge is the result of constructivist activity (a common theoretical assumption) then we must also acknowledge the need to ground pedagogy in a detailed knowledge of students' existing conceptions, including those both consistent and inconsistent with the current views of experts in particular subject domains.

Shulman (1987) maintained that PCK deserves particular attention in research because, unlike the other categories of teacher knowledge identified in the literature (see e.g. Grossman, 1990), PCK represents a distinctive body of knowledge that is unique to the teaching profession. Research also demonstrates that there is a relationship between teachers' PCK and their approach to classroom instruction (Grossman et al., 1989; Hashweh, 1996a; Ingvarson & Kleinhenz, 2006; Smith & Neale, 1989), as well as how and what their students learn (Magnusson et al., 1999).

Given the central importance of students' preconceptions as a component of PCK, the following review focuses specifically on elements of PCK related to students' preconceptions, teachers' awareness of these beliefs and the use of this knowledge to inform instruction. This is not the place to provide a detailed account of the other areas of PCK identified in Figure 2.1, including the extensive literature exploring the nature of conceptual development and strategies for promoting conceptual change (Adley & Shayer, 1994; Baird & Mitchell, 1986; Basca & Grotzer, 2001; Biemans, Deel & Simons, 2001; Chi, Slotta & De, 1994; Chinn & Brewer, 1993; Clement, 2008; Driver, 1989; Posner, Strike, Hewson & Gertzog, 1982; Thagard, 1992). A useful recent review of the conceptual change research in Science and its implications for the development of relational and meaningful learning in Geography (with particular reference to sustainability education) is provided by Harrison and Purnell (2012).

The intention here is to provide an overview of the nature and characteristics of alternative conceptions in order to highlight the central importance of teacher knowledge in this area. The importance of this knowledge is further investigated through an analysis of the recognition of PCK in teaching standards and general pedagogical models. The literature in Science and Geography is then reviewed to determine the state of current knowledge about Geography teachers' PCK of students' ideas and the use of this knowledge to inform classroom practice.

2.1.2 The nature and development of alternative conceptions

Shulman's conceptualisation of PCK highlights the need for teachers to understand the nature of students' common preconceptions and alternative conceptions in all key topic areas they teach. To better understand the need for this awareness it is important to briefly examine the development and characteristics of alternative conceptions as well as their role in student learning.

Research conducted over the past three decades, across a range of subject domains, has provided both teachers and academics with valuable insights regarding the nature of the knowledge construction process. Studies in Mathematics, Science and Psychology, for example, confirm that students construct their own understandings of "how the world works" prior to formal instruction (Duit et al., 2008; Henriques, 2000) that they generate "naive theories" or views of phenomena in an attempt to make sense of their everyday experiences (Bransford, Vye, Stevens, Kuhl, Schwartz, Bell, Meltzoff, Barron, Pea, Reeves, Roschelle &

Sabelli, 2006; Clough & Driver, 1986; Greca & Moreira, 2000). These "intuitive understandings" are stored in mental structures (known as schemas or mental models), and are often substantially different from the ideas to be taught and from the established views of experts in particular subject domains (Driver, 1989).

Research conducted by Driver, Squires, Ruchworth, and Wood-Robinson (1994) suggests that alternative conceptions of natural phenomena are widely held among students and that they are neither idiosyncratic nor culturally dependent. These theorised views of the world represent more than a simple accumulation of facts which may or may not be correct. Students' constructed mental models act as a lens through which they interpret and decode information in order to construct meaning. There is therefore an important distinction between inadequate or incorrect background knowledge on the one hand and alternative conceptions on the other. An understanding of this distinction is vital if we are to develop appropriate pedagogical responses to build student understanding. The conceptual change literature has traditionally viewed students' alternative conceptions as barriers to the development of deep understanding (Posner et al., 1982; Smith & Neale, 1989). More recently, Smith (1994) and Larkin (2012) have emphasised the important role of alternative conceptions in the learning process. Larkin (2012, p. 6) argues that students' mental models should be viewed as resources for instruction that can be used by both teachers and students to "foster deeper and more meaningful learning."

Alternative conceptions arise from prior learning in the classroom as well as learning generated through everyday experiences. According to constructivist theory, students build new knowledge and understandings based on their existing knowledge and perceptions (Driver, 1981; Vosniadou et al., 2008). The interaction between old and new ideas can at times result in an understanding of the world that is incomplete and theoretically incorrect, despite appearing to be functional, plausible and evidence-based to the learner (Reinfried, 2006a). Vosnaidou et al. (2008, p. 4) maintain that students' intuitive views of the world are "not fragmented observations but form a coherent whole [or] framework theory." These theories are constructed from learners' "interpretations of . . . common everyday experiences in the context of lay culture" (p. 15) and are used by learners to make predictions and to provide explanations of phenomena. Other researchers hold different views about the coherence of learners' knowledge structures. Di Sessa (2008), for example, describes students' "naive ideas" as "diverse, fragmented and displaying limited integration or coherence." According to this view, students' knowledge can be more accurately described as an “ecology of quasi-independent elements” (Ozdemir & Clark, 2007, p. 351) rather than a coherent theory. Despite these differences in perspective, the knowledge-as-theory and knowledge-as-elements perspectives agree that students’ intuitive knowledge (1) is strongly influenced by everyday experiences, (2) influences their formal learning, and (3) is resistant to change because it is continually reinforced and confirmed by everyday experience (Ozdemir & Clark, 2007).

Dove (1998b, 1999) and Reinfried (2004) cite a number of possible sources of alternative conceptions in Science and Geography, including the use of everyday language in domain-specific contexts, changing definitions, the oversimplification of concepts, overlapping similar concepts, rote learning, students’ preconceptions from private world experiences, stereotyping and incorrect information in textbooks, myths and inadequate prerequisite knowledge. Lee (1999) highlights the importance of the discourses or voices that children encounter in social and cultural contexts and the role they play in shaping students’ beliefs. He argues that students make meaning from various information sources, including family, teachers, school, friends and the media. When examining the possible origins of students’ conceptions in both Science and Geography it is important to remember the role of social interaction in the process of knowledge construction. Common sayings such as “the dew is falling”, “the force be with you” and “shut the door to keep the cold out” can provide students with overly simplified and incorrect analogies about the operation of physical processes, resulting in the reinforcement of alternative conceptions (Driver et al., 1994).

Research conducted across a range of subject domains (but mainly Science) over the past three decades has highlighted the complex, context-dependent and sometimes contradictory nature of alternative conceptions. Individuals process ideas via a rich selection of episodic knowledge, metaphors, interpretive frameworks, emotions, values and aesthetics. They often use a “cocktail of conceptions” to construct their explanations and can simultaneously hold contrasting (and conflicting) conceptions of the same phenomena (Greca & Moreira, 2000; Reinfried, 2006a). One result of this is that students often form mental models of phenomena that are both inconsistent with accepted “expert” views and incompatible with each other. The challenges of identifying alternative conceptions are further exacerbated by the continually evolving nature of students’ ideas. Mental models continue to be enlarged and improved as new information is incorporated within them (Reinfried, 2006a). Students rely less on their intuitive conceptions as they get older and are exposed to increasingly complex scientific explanations of physical phenomena (Arnold, Sarge & Worrall, 1995). According to Arnold et al. (1995), students progress through a range of "intermediate" or "transitional" notions before they acquire conceptions that are consistent with current expert thinking. It is important for teachers to have an understanding of these common alternative conceptions, the way in which they change over time, and strategies for helping students articulate, compare, analyse, evaluate and where necessary restructure these ideas. These are all important elements of Shulman's conception of PCK.

The research findings detailed above should be of significant interest to geographers given the vital role of students' ideas in the construction of new knowledge (Reinfried, 2006a). The identification of student preconceptions and the exploration of these ideas through instruction are important steps in the development of deep understanding (Duit & Treagust, 2003). Research consistently shows that pedagogy informed by knowledge of students' existing ideas is more efficient in promoting conceptual change than traditional methods of instruction (Boyes & Stanisstreet, 1991; Duit & Treagust, 2003; Duit et al., 2008; Marques & Thompson, 1997). As Larkin (2012) notes, students' intuitive conceptions should be viewed as the "raw material for classroom learning" to be "refined, revised, bridged and built upon by both teachers and students alike" (p. 6).

The ability to develop "deep understanding" is a characteristic of accomplished practice recognised in most models of effective pedagogy. This understanding, as demonstrated by the above research, is a product of learners continuing to reconstruct their existing conceptions. To support this process teachers require an awareness of students' preconceptions, including those both consistent and inconsistent with current expert views. Equally important is the recognition of teachers' PCK of students' ideas in general pedagogical frameworks and in statements of professional standards for highly accomplished teaching.

2.2 Recognition of PCK in general pedagogical frameworks and professional teaching standards

The aspects of PCK that focus on students' prior understandings, teachers' ways of organising subject knowledge and use of appropriate subject-specific strategies to promote student understanding are well represented in Australia's National Professional Standards for Teachers (Australian Institute for Teaching and School Leadership - AITSL, 2011). They are also represented in general pedagogical frameworks such as the NSW Quality Teaching Framework (Professional Support and Curriculum Directorate, 2003).

What has been missing, until recently, from these documents is recognition of the need for teachers to diagnose and address common student alternative conceptions. Although there is reference, for instance, to the importance of building on students' prior knowledge and understanding students' backgrounds and experiences in a generic sense, recognition of the importance of students' alternative conceptions for subsequent learning has been largely absent. The absence of key aspects of PCK in state and territory teaching standards appeared to have been addressed in early 2010 with the release of the *Draft National Professional Standards for Teachers*. Under Standard 2, "know the content and how to teach it", the document stated that highly accomplished teachers will:

> Know and utilise current research on effective pedagogical content knowledge to identify and address difficulties their students may encounter and know how to share this with colleagues. (AEEYSOC National Standards Expert Working Group, 2010, p. 17)

This statement, however, was re-worded during the consultation process. The final National Professional Standards statements (Australian Institute for Teaching and School Leadership - AITSL, 2011) do not make reference to PCK or the need for teachers to develop awareness of common student preconceptions. These aspects of teachers' knowledge have, however, been better represented in statements of professional standards in disciplines such as Science, where the tradition of research in PCK has been strong.

2.2.1 Recognition of PCK in the professional standards for accomplished Science teaching

At a subject-specific level it is not surprising that disciplines with a research tradition focused on the importance of conceptual change are those that make references to students' preconceptions in their professional teaching standards.

The National Professional Standards for Highly Accomplished Teachers of Science (Australian Science Teachers Association, 2002), for example, provide specific recognition of the importance of knowing both the content of Science and the common conceptions and explanations of scientific phenomena that students construct prior to formal instruction.

> Highly accomplished teachers of science not only know their subject matter deeply; they know how to help others develop deeper understanding of that subject matter. Highly accomplished teachers have a rich bank of pedagogical content knowledge that allows them to make subject matter comprehensible to students. This expertise enables them to transform their content knowledge into a form that is understood by their students. It enables them to choose the analogies, examples or applications of a concept or skill that make the content accessible and interesting to a given group of students . . .
>
> They know that all learning builds on previous experiences and mental constructs and that they must find a way of relating and meshing these constructs and experiences with those which are being introduced to their students. In teaching science, highly accomplished teachers are aware of the conceptions and explanations of science phenomena that students are likely to hold at different stages of development. They know how to explore, review and, where necessary, challenge these conceptions, through specifically designed learning experiences. (p. 13)

These standards indicate that PCK is not only an important element of a Science teacher's professional knowledge but also a key indicator of accomplished teaching practice in this domain. This recognition is largely a function of the long history of research exploring teachers' knowledge in Science. The following review examines the existing literature on PCK in this domain, with a particular focus on teachers' knowledge of students' alternative conceptions and methods for addressing these ideas through instruction. This serves as a model for examining research on PCK in the related discipline of Geography.

2.3 PCK research in Science

2.3.1 Overview of the literature

Shulman's (1986, 1987) suggestion that teachers needed strong PCK to develop student understanding has resulted in a comprehensive range of studies exploring the PCK of pre-service and in-service primary and secondary Science teachers (Loughran, Mulhall & Berry, 2008). Although the literature in this area lacks coherence (Abell, 2007) it can be roughly organised according to the components of PCK identified by Magnusson et al. (1999). There are distinct areas of research, focusing on:

1. Teachers' orientations towards Science instruction (Anderson & Smith, 1987; Hollon, Roth & Anderson, 1991; Smith & Neale, 1989)
2. Science teachers' knowledge of Science learners (Berg & Brouwer, 1991; Halim & Meerah, 2002; Morrison & Lederman, 2003); curriculum goals, programs and materials (McIntosh & Zeidler, 2006); subject-specific and topic-specific instructional strategies (de Jong & van Driel, 2001; Geddis, Onslow, Beynon & Oesch, 1993; Halim & Meerah, 2002; Hashweh, 1996b); and Science assessment (Champagne, Gunstone & Klopfer, 1985; Morrison & Lederman, 2003; Pine et al., 2001).

Additional areas of research address the nature and development of both pre-service and in-service Science teachers' PCK and the development of teacher education programs to help build teachers' knowledge in this area (Jones et al., 1999; Smith & Neale, 1989; Sperandeo-Mineo, Fazio & Tarantino, 2006; Van Driel & De Jong, 2001; Veal, Tippins & Bell, 1999). Improved understanding of the nature of teachers' knowledge gained through longitudinal studies in Science classrooms has also enabled researchers to develop systems for capturing and describing the development of PCK in this domain (Berry et al., 2008). One example includes the development of "pedagogical and professional-experience repertoires" (PaP-eRs) by Loughran, Milroy, Berry, Gunstone, and Mulhall (2001), a framework for mapping the PCK of Science teachers.

The findings of extensive research exploring the elements of PCK in Science have been summarised in publications including *The Handbook of Research in Science Education* (Abell & Lederman, 2007), *Examining pedagogical content knowledge: The construct and its implications for teacher education* (Gess-Newsome & Lederman, 1999) and special issues of key Science journals including the *International Journal of Science Education* (e.g. Vol. 30 No. 10, 2008).

This review specifically focuses on a core element of Shulman's original conceptualisation of PCK: research investigating teachers' knowledge of Science learners, in particular their awareness of students' common alternative conceptions (PCK of students' ideas). There is a significant body of research in Science demonstrating that instruction is most effective when it is informed by an understanding of the common alternative conceptions that students hold in specific topic areas (Park & Oliver, 2008). It is argued that with this knowledge, teachers are in a better position to be able to make sense of students' actions and beliefs and to develop strategies for addressing these ideas through instruction (Magnusson et al., 1999).

The review is divided into two parts. The first section examines the literature on pre- and in-service primary and secondary teachers' PCK of students' ideas in Science, the instructional strategies they use and the likely effectiveness of these approaches. The second section looks at two key factors influencing teachers' awareness of students' ideas in this domain, namely their subject content knowledge and beliefs about knowledge and learning. This component of the review also considers the link between teachers' beliefs, their awareness of students' ideas, and the potential effectiveness of the pedagogical approaches they adopt in their classrooms. The purpose here is to highlight a number of recurring themes about Science teachers' knowledge of students' preconceptions (or PCK of students' ideas) that warrant further investigation in a geographical context.

2.3.2 Teachers' PCK of students' alternative Science conceptions

There is a body of literature in Science education examining novice and experienced primary and secondary teachers' understandings of "children's Science" (Berg & Brouwer, 1991; de Jong & van Driel, 2001; Jones et al., 1999; Kokkotas et al., 1998; Morrison & Lederman, 2003; Sequeira et al., 1993; Smith & Neale, 1989; Zembal-Saul et al., 1999). These studies highlight a number of common trends in the PCK development of Science teachers. The trends include (1) an overall lack of awareness of students' conceptions, (2) general rather than specific knowledge of students' difficulties, (3) a narrow knowledge of specific alternative conceptions, and (4) resistance to the development of PCK.

(1) An overall lack of awareness of students' alternative conceptions

Despite their training in this area, both novice and experienced Science teachers often lack an awareness of students' common alternative conceptions (Smith & Neale, 1989). Research with both primary and secondary teachers has revealed a "striking lack of attention to children's ideas, predictions [and] explanations" (Smith & Neale, 1989, p. 12), an insensitivity to students' viewpoints (Osborne, Bell & Gilbert, 1983); and a lack of awareness of the potential for alternative conceptions to interfere with science learning (Hollon & Anderson, 1987). Experienced teachers of primary and secondary Science are often "shocked", "surprised" and "intrigued" when made aware of the alternative conceptions held by some of their students (Jones et al., 1999, p. 554). Teachers often respond by either ignoring the students' ideas or assuming that these conceptions can be easily changed through instruction, for example, teacher exposition (Hollon & Anderson, 1987).

(2) General rather than specific knowledge of students' Science conceptions

While teachers may possess some awareness of the common alternative conceptions held by their students, they generally lack the more specific and detailed PCK required to effectively address these ideas in instruction (Magnusson et al., 1999; Morrison & Lederman, 2003; Watts & Zylbersztajn, 1981). Morrison and Lederman (2003), for example, in their detailed analysis of four exemplary secondary Science teachers, found that all the participants were able to identify concepts within the curriculum that students "seemed to have trouble with" (p. 863) however only one (a teacher with more than 34 years teaching experience) was able to identify a comprehensive list of specific preconceptions. Teachers with less experience provided examples demonstrating student confusion between terms (e.g. atomic number and mass number) rather than alternative conceptions.

(3) A narrow knowledge of specific alternative conceptions in Science

Where teachers do possess detailed and specific knowledge of students' preconceptions, it is often restricted to a narrow range of concepts or topics. Watts and Zylbersztajn (1981), for example, in their study of the PCK of senior Science teachers, found that the participants were aware of the distribution of students' responses in some areas of the topic they were teaching (forces) but were unable to provide accurate predictions for students' responses beyond this. Berg and Brouwer's (1991) study with a larger sample of 20 Canadian Physics teachers produced similar results. Their findings indicated that although the teachers as a group had a comprehensive knowledge of students' alternative conceptions of force and gravity, individual teachers were rarely able to identify more than a few of these ideas. Similar results have been found with pre-service teachers of Physics (Halim & Meerah, 2002), Chemistry (de Jong & van Driel, 2001) and primary Science (Kokkotas et al., 1998).

(4) Resistance to change

Evidence suggests that the issue of inadequate PCK is not only widespread but also deep-seated and resistant to change. Low awareness of common student preconceptions persists despite efforts in pre-service teacher education to inform prospective teachers of the importance of these ideas. Sequeira et al. (1993), in their study of Portuguese primary and secondary teachers' attitudes towards alternative conceptions, found a disconnection between the content of pre-service teacher education courses and the level of awareness of teachers. Although 80% of professors described the nature of alternative conceptions in their courses and presented pre-service teachers with strategies for addressing these ideas, more than half of the secondary Science teachers in the study stated they had not heard of alternative conceptions before.

The four points outlined above summarise the research findings regarding teachers' PCK of students' ideas in Science. This knowledge is needed if teachers are to develop strategies for addressing students' ideas during instruction. Research exploring the potential effectiveness of existing classroom practice for addressing alternative conceptions is reviewed in the following section.

2.3.3 Teachers' perceptions of the value of students' ideas

Larkin (2012) explored 14 pre-service teachers' views of the value and role of eliciting student's ideas during science instruction. He identified five different "orientations" towards student's ideas, including the view that these ideas were (1) evidence of content coverage, (2) blockages to understanding, (3) tools to prime students' activity and interest, (4) elements of a positive classroom environment, or (5) raw materials for learning. Larkin argues that these diverse orientations are a product of the mixed messages pre-service teachers receive from teacher educators and from the Science education literature. He suggests that viewing students' alternative conceptions as barriers to learning is inconsistent with the principles of constructivism and that teacher educators should emphasise the importance of students' conceptions as "the raw materials out of which theories and models are built and revised in the minds of learners" (p. 29). These ideas will be revisited in Chapters 6 and 7.

2.3.4 Science teachers' awareness of evidence-based conceptual change strategies

The literature on teachers' use of instructional strategies in Science suggests that the pedagogical approaches employed by many novice and experienced Science teachers in both primary and secondary schools are unlikely to be effective in addressing students' alternative conceptions and that the strategies adopted often result in the development of further misconceptions (Halim & Meerah, 2002; Kokkotas et al., 1998; Sequeira et al., 1993; Smith & Neale, 1989).

In a study of 10 primary school teachers, Smith and Neale (1989) found that, with one exception, the participating teachers had little knowledge of effective strategies for addressing students' alternative conceptions. The teachers were found to employ largely didactic (question–response-evaluation format) or discovery-oriented teaching styles. They rarely probed or challenged students' ideas or planned for discrepant events that might help to elicit or contradict students' alternative conceptions. Even when teachers considered these strategies to be important, their lack of familiarity and flexibility with the content of this domain meant that they struggled to generate useful activities and representations. When students communicated misunderstandings during these lessons, teachers responded either by providing the correct answers or by ignoring students' responses and moving on with the next part of the lesson. This focus on the "correct answers" (p. 13) meant that little effort was made to diagnose or clarify the reasoning behind students' responses. Smith and Neale noted that even after a 4-week summer intervention course focused on strategies for addressing alternative conceptions, participants still "forgot to probe" (p. 15) for explanations and lacked adequate metaphors and analogies for promoting conceptual change. Sequeira et al. (1993) found a similar lack of pedagogical knowledge among 375 primary teachers. Half of the participants in that study believed that teaching strategies should lead directly to the targeted concept and that instruction should avoid the errors commonly made by students. Teacher-centred procedures that aimed to demonstrate to students that their ideas were "wrong" (p. 848) were also popular among the participants. Sequeira et al. (1993) concluded that, contrary to the recommendation of the syllabus, most 5th/6th grade teachers did not use activities to systematically diagnose or address learners' alternative conceptions in their teaching.

The primary school teachers in Berg and Brouwer's (1991) study were also unfamiliar with the strategies for conceptual change outlined in the literature. These teachers used activities that were likely to be only partly effective in creating conceptual change. Expository approaches, where the "correct conception" is presented directly to students, were most popular among participants. To a lesser extent, teachers also indicated the use of demonstrations (20%), analogies (17.8%), and questioning (8.9%) in their classrooms. Few teachers using questioning and discussion as a teaching strategy, indicating that they would direct their instruction at students' alternative conceptions. Students were generally not asked to predict outcomes or to transfer understanding.

The extent to which teachers consider students' ideas in their lesson planning, classroom discourse and assessment has also been explored in recent studies with pre-service Science teachers. Windschitl, Thompson and Braaten (2011) monitored the beliefs and practice of 14 pre-service teachers and developed a three level rubric to describe their approach to working with students' ideas. From least to most sophisticated, the rubric outlines the following pedagogical approaches:

(1) Monitoring, checking and re-teaching ideas – teachers in this category began instruction with no knowledge of students' ideas. Their pedagogical approach focuses on the dissemination of correct information, and assessment (whole class conversations and one-on-one tutoring) is used to "check for nominal understanding" (p. 1357).

(2) Eliciting students' initial understandings – the teacher elicits students' initial hypotheses, questions, or conceptual frameworks about a scientific phenomenon but does not use this information to shape subsequent instruction.

(3) References students' ideas and adapts instruction – within and across lessons the teacher uses students' current conceptions of science ideas to reshape the direction of classroom conversations. This involves teachers either engineering productive classroom conversations or consciously reshaping the students' line of thinking across multiple lessons.

2.4 Factors affecting Science teachers' awareness of student preconceptions and choice of instructional approach.

The literature points to a number of factors that might help to explain Science teachers' low level of awareness of common student preconceptions. These factors include the teachers' subject content knowledge in this domain and their beliefs about knowledge and learning.

2.4.1 Teachers' subject content knowledge

It is well acknowledged among researchers in Science education that teachers require knowledge of the prevalent alternative conceptions that students hold in key areas of the curriculum if they are to develop effective instructional strategies for the promotion of conceptual change and improved student understanding in this domain (Baimba, 1992; Berg & Brouwer, 1991; Morrison & Lederman, 2003; Smith & Neale, 1989; Van Driel, Verloop & De Vos, 1998). As Shymansky et al. (1993) explain, it is the role of the teacher to:

> help students examine the naive theories and invalid ideas that characterize their own science and entertain the ideas reflected in scientists' science. To do this the teacher must possess an in-depth understanding of both the scientist and the student. (p.741)

More than 30 years of PCK research in Science indicates that teachers' awareness of and ability to diagnose alternative conceptions is related to the depth of their subject content knowledge. A number of researchers have noted, for example, that it is unlikely that teachers will be able to recognise, diagnose and address students' alternative conceptions if they themselves possess similar incorrect and imprecise mental models (Dahl, Anderson & Libarkin, 2005; Hoz, Tomer & Tamir, 1990; Schoon, 1995; Smith & Neale, 1989).

According to Reinfried (2006a),

> To correctly diagnose students' preconceptions, teachers themselves should be aware of their own mental models and should have an adequate comprehension of relevant concepts that are scientifically accepted. (p. 42)

The identification of teachers' alternative conceptions has been a productive area of research in Science education. The alternative conceptions of primary and secondary pre- and in-service teachers in a range of topic areas have been studied by researchers across the globe. This has included studies in the United States (Atwood & Atwood, 1996; Dahl et al., 2005; King, 2000; Schoon, 1995; Schoon, 1992), the United Kingdom (Boyes, Chambers & Stanistreet, 1995; Dove, 1996a, 1996b; Summers, Palacio, Kruger, Lenton, Mant, McNeil & Pendlington, 1992), India (Banerjee, 1991), Italy (Sperandeo-Mineo et al., 2006), Canada (Berg & Brouwer, 1991), Malaysia (Halim & Meerah, 2002), Israel (Trumper & Gorsky, 1996) and Australia (Webb, 1992).

A review of the research in this area provided by Dahl et al. (2005) and Abell (2007) indicates that both pre-service and in-service primary and secondary school teachers hold a range of alternative conceptions of the Science concepts they are responsible for teaching. Teachers often form synthetic conceptions or mental models (Vosniadou et al., 2008) by combining accepted scientific conceptions with non-scientific beliefs generated from personal experiences. These conceptions often mirror the ideas of their students. Orion and Ault (2007), in their review of the research exploring Earth Science teachers' content knowledge, concluded that "earth science education in many countries is trapped in a cycle of ineffective instruction and inadequate learning – with preconceptions and misconceptions dominating learning" (p. 662).

The Science content knowledge of primary school teachers has been recognised by a number of researchers as a key area of concern. Osborne, Gilbert and Bell (1983), pioneers in this area of Science research, noted in their observations that much of what is taught in the name of Science in primary schools is "frequently a mixture of the teacher's own views (which may be largely children's Science) and textbook quotations of scientists' science, or curricular science" (p. 11). These conclusions are supported by more recent studies indicating that the Science content knowledge of primary teachers in some topic areas is "fragmented" (Smith & Neale, 1989, p. 8) and that their explanations contain alternative conceptions similar to those commonly held by students (Atwood & Atwood, 1996; Kokkotas et al., 1998; Schoon, 1995; Smith & Neale, 1989).

The problem of inadequate content knowledge is also an issue identified in research with pre-service and in-service secondary teachers (Barba & Rubba, 1992; Hashweh, 1987; Hoz et al., 1990; Sperandeo-Mineo et al., 2006). In their examination of the knowledge of seven Biology and six Geography teachers, Hoz et al. (1990) concluded that:

> The disciplinary knowledge held by the teachers [was] partial and [did] not measure up to the criteria established by discipline experts. (p. 978)

Hoz et al. (1990) maintained that the results of their study demonstrated that the teachers of both subjects:

> knew relatively little of their discipline when evaluated by the dimensions of validity, correspondence, salience, and quality of groups. (p. 982)

The authors concluded that these teachers are "probably unaware of their missing or deficit knowledge and hence are prone to misteach their students" (p. 982). This view is shared by other researchers who maintain that teachers lack awareness of student alternative conceptions that they themselves hold and as a consequence are unable to address these ideas through instruction (Atwood & Atwood, 1996; Berg & Brouwer, 1991; Halim & Meerah, 2002; Hashweh, 1987; Smith & Neale, 1989).

The literature includes a number of studies highlighting the potential impact of inadequate content knowledge and limited awareness of students' ideas on classroom practice and learning outcomes. Researchers have noted that limited PCK can result in the selective teaching of syllabus content and skills in order to avoid known areas of difficulty (Smith & Neale, 1989; Tambyah, 2007, 2008); a tendency to ignore students' incorrect responses, be more "lenient" towards them or mark them as "correct" (Kokkotas et al., 1998, p. 298); the adoption of pedagogical approaches that fail to acknowledge students' ideas (Smith & Neale, 1989); and the development of activities and representations that reinforce alternative conceptions (Halim & Meerah, 2002; Kokkotas et al., 1998; Sequeira et al., 1993).

In their investigation of the PCK requirements for teaching the topics of heat, energy and temperature, Magnusson, Borko and Krajik (1994) provided an illustration of the potential impact of inadequate content knowledge and limited awareness of students' ideas on classroom practice and student learning outcomes. The results suggest that a lack of knowledge of students' common preconceptions can have a detrimental impact on student achievement. One of the major differences in the views of teachers in this study was the belief expressed by some participants that common reasoning errors, for example, "small volumes lose greater energy than large volumes" (p. 13) were unlikely to be made by students. This is in contrast to the findings of Magnusson (1991, cited by Magnusson et al., 1994) suggesting that approximately 30 per cent of students are likely to make this error based on their underlying beliefs about energy and temperature. The assessment of students' knowledge at the end of the project revealed that "only teachers who thought that particular errors were *un*common *had* students who exhibited those reasoning errors *after* instruction in the topic" (Magnusson et al., 1999, p. 107, emphasis added). It stands to reason that teachers who lack knowledge of typical student errors and preconceptions are unlikely to consider it necessary to develop assessment strategies for diagnosing these ideas. Furthermore, having identified alternative conceptions in students' responses, teachers with limited PCK are unlikely to recognise the need to probe these ideas further or develop strategies for addressing them (Magnusson et al., 1999).

2.4.2 The role of teaching orientations and epistemological beliefs

The work of Pinnigar (1989) provides further clues that may help to explain Science teachers' lack of awareness of common student preconceptions. Pinnigar examined 12 Science teachers with different levels of Science experience and investigated their developing knowledge of the students they taught. Teachers were interviewed at key times during a semester and asked to describe the nature and characteristics of their current Science class and the way this influenced planning and pedagogy. The results provide an indication of the types of knowledge teachers gather about students as they observe and interact with classes on a daily basis. In their interview responses, teachers focused on student engagement, effort, cooperation and ability when describing the students they taught and their goals for planning instruction. Little mention was made of students' preconceptions or the need to diagnose and address these ideas through instruction. The low priority assigned to student preconceptions in descriptions of classroom practice and instructional goals may help to explain the teachers' lack of familiarity with common alternative conceptions in key areas of the curriculum.

Another key factor contributing to teachers' low awareness of students' ideas is their orientation to teaching Science. These orientations, summarised by Magnusson, Krajcik, and Borko (1999), include teachers' epistemological views (beliefs about the nature of knowledge and knowing) as well as their related beliefs about learning and teaching. There is a considerable body of research exploring teachers' subject-specific orientations in Science and their impacts on classroom practice (Akerson, Flick & Lederman, 2000; Anderson & Smith, 1987; Duit, Widodo & Wodzinski, 2007; Hashweh, 1996a, 1996b; Henze, van Driel & Verloop, 2007). This literature, which is not reviewed in detail here, shows that teachers' beliefs about knowledge and learning influence their sensitivity towards students' views and their willingness to consider students' preconceptions. Unless teachers hold constructivist views, it is unlikely that they will consider alternative conceptions in their teaching practice. Research conducted by Hashweh (1996a) with 35 secondary Science teachers revealed that teachers with constructivist views were more likely than those with empiricist beliefs to detect students' alternative conceptions during instruction and use evidence-based conceptual change strategies to address these beliefs.

Recent studies support these findings. Duit, Widodo and Wodzinski (2007), for example, used in-depth interviews to explore the epistemological beliefs about teaching and learning held by 13 German Physics teachers. Their study also involved the videotaping and coding of lessons to investigate the relationship between teachers' epistemological beliefs and actual classroom practices. Data from the in-depth interviews revealed that the teachers were generally unaware of the key principles of constructivist theory and the main findings of conceptual change research. Two general orientations of instruction were inferred from the teachers' responses: (1) an instructional orientation – focused on the transmission of Physics content; (2) a constructivist orientation – focused on supporting students to construct understanding. The instructional orientation dominated both the beliefs and classroom practices of the teachers in that study. The authors noted that while the comments of the teachers contained some "intuitive constructivist aspects" many of the teachers held transmissionist views of learning and teaching. These teachers characterised themselves as "mediators of facts and information" (p. 209) and were unaware of the nature and importance of students' conceptions. Their major concerns were the concepts and topics to be taught rather than the capabilities and difficulties of the students.

As Duit, Widodo and Wodzinski (2007) note:

> Most teachers' views of teaching and learning science are . . . quite far from constructivist ideas. Furthermore, most teachers are not informed about publications addressing constructivist views. This also holds for publications written for teachers in teachers' journals. It is even true for publications in which the role of pre-instructional (alternative) conceptions . . . are discussed. (p. 213)

The study also highlighted important links between teachers' epistemological beliefs and their instructional practices. While a broad range of teaching strategies were used by the participants, teacher-dominated methods prevailed. The researchers also noted that the participants made infrequent use of conceptual change strategies proposed in the literature (particularly analogies and strategies for promoting cognitive conflict). Although the students were asked, for example, about their prior learning during lessons, the questioning was not specific enough to detect individual underlying beliefs. After exploring students' prior knowledge the teachers were often unsure what to do with this information. As a consequence, many of the students' ideas were not explored further.

Having constructivist beliefs, however, does not guarantee that teachers will understand the nature of alternative conceptions or employ effective strategies to diagnose and address these ideas. Hashweh (1996b) found that only a small proportion of 91 teachers held constructivist views of learning (25%) and an even smaller proportion acknowledged that students' pre-instructional beliefs could at times be inconsistent with current scientific thinking. It is possible, therefore, to hold a generally constructivist view of learning without having an understanding of the nature and importance of alternative conceptions.

In an observational study of four experienced Science teachers, Morrison and Lederman (2003) found further evidence of the lack of alignment between teachers' beliefs and their classroom practice. All four teachers in that study noted the importance of diagnosing students' preconceptions, however few of them used formal assessment tools (e.g. concept maps or pre-tests) to diagnose students' beliefs during their lessons. Although many of the teachers claimed to use questioning as a diagnostic tool, Morrison and Lederman found that most questions asked during the observation lessons focused on simple factual recall and that few attempts were made to assess students' depth of understanding. Only one of the teachers used probing questions to explore students' ideas, and there was little evidence of the use of students' pre-instructional ideas to inform practice. The feedback provided for class tests and quizzes was limited to the indication of correct and incorrect responses. This was also the case when students provided responses suggesting that they might hold alternative conceptions of key concepts in the topic area. Morrison and Lederman noted that while some of the strategies used by the teachers had the potential to elicit students' conceptions (e.g. student presentations), the teachers did not generally use the activities for that purpose.

2.4.3 The role of professional development and reflective practice in the development of Science teachers' PCK of students' ideas

De Jong and van Driel's (2001) study of the pedagogical content concerns of six pre-service Chemistry teachers demonstrates that professional development interventions and reflective practice can play a role in improving teachers' awareness of students' conceptions. De Jong and van Driel (2001) found that before teaching, pre-service teachers had either no idea or a "vague idea" (p. 273) of the difficulties students were likely to encounter and that these concerns were communicated in relatively short statements. During lessons, the teachers faced greater challenges than they initially expected and these experiences enabled them to provide more detailed descriptions of likely student difficulties. Other studies conducted in a variety of contexts have also demonstrated the value of professional development initiatives and reflective practice in improving the PCK of primary and secondary in-service and pre-service Science teachers (Jones et al., 1999; Loughran et al., 2008; Shymansky et al., 1993; Sperandeo-Mineo et al., 2006; Wang, 2004; Zembal-Saul et al., 1999). The findings of these studies demonstrate that although PCK can be improved and enhanced, teachers' beliefs about knowledge and learning are often deep-seated and resistant to change.

2.4.4 Conclusion – the impact of PCK on classroom practice in Science

The review of the Science-related literature highlights the important link between PCK and accomplished teaching in this domain. Teachers' PCK, including their knowledge of students' common preconceptions, can have a significant impact on classroom practice.

As Smith and Neale (1989) concluded from their study:

> Teachers' knowledge of the content, their translation of that content into appropriate and flexible usage in lessons, their knowledge of children's likely preconceptions to be encountered in lessons and of effective teaching strategies for addressing them, and especially their beliefs about the nature of science teaching, all proved to be critical components in the changes they were able to make in their teaching. (p. 17)

The PCK-related research in Science is particularly relevant to this study for two reasons. Firstly, the discipline knowledge of Geography relies on an understanding of many of the same concepts as Science (e.g. air pressure and evaporation). Secondly, there is a long-established and well-developed research base on teachers knowledge of students' Science conceptions that serves as a model for similar research in Geography.

The following section examines the recognition of PCK (including teachers' knowledge of students' preconceptions) in statements of professional standards for accomplished Geography teaching. This is followed by a review of the literature investigating the PCK of both novice and experienced Geography teachers and the factors affecting this knowledge development. The purpose of this review is to highlight areas of PCK that warrant further investigation in this domain and to frame the questions for the current study.

2.5 The literature in Geography

2.5.1 Overview of the literature in geographical education

While there has been a considerable body of work on some aspects of PCK in Geography, this research has focused largely on instructional strategies for improving geographical understanding and holistic studies of teachers' knowledge and expertise (Brooks, 2006; Gudmundsdottir & Shulman, 1987; Martin, 2008).

The gap in the Geography research, however, relates to the second component of PCK identified by Shulman, namely teachers' knowledge of students' common alternative conceptions and their use of this knowledge to inform instruction (PCK of students' ideas). While considerable research has focused on students' alternative conceptions in Physical

Geography and the Earth Sciences (see Orion and Ault, 2007 for a recent review) there is a paucity of research examining Geography teachers' awareness of these common student beliefs and their use of this knowledge to inform instruction.

The review of the Geography literature that follows is divided into seven sections:

1. Recognition of PCK in the Professional Standards for Highly Accomplished Geography teachers
2. Holistic studies of PCK development and subject expertise in Geography
3. Teachers' PCK of strategies for promoting geographical understanding
4. Acknowledgement of students' "private geographies" by humanistic geographers
5. Investigations of children's world views and ethno-geographies
6. Research exploring students' alternative conceptions in Geography
7. Factors affecting the development of Geography teachers' PCK of students' ideas

2.5.2 Recognition of PCK in the Professional Standards for Highly Accomplished Geography teachers

All professional standards reflect the research base or discourse of their discipline. The Science standards (as noted in Section 2.2.1) draw heavily on the Science research literature of the 1980s and 90s and hence use language such as "conceptions" and "mental constructs". In contrast, the recently developed *Professional Standards for Accomplished Teaching of School Geography* (University of Melbourne et al., 2010) uses language consistent with recent research in geographical education (particularly the literature exploring children's geographies). As a consequence, the Geography standards adopt a different view of students' "diverse and developing understandings" and include references to terms such as "personal geographies" and "identities from the local community". In contrast to the research exploring students' conceptions in Science, the study of personal or ethno-geographies (Martin, 2008) focuses on valuing the "awareness, knowledge and understanding developed [by children] through their personal experiences" (Catling, 2011, p. 16) rather than identifying and addressing alternative conceptions.

The Professional Standards for Accomplished Teaching of School Geography acknowledge the following aspects of PCK in their descriptions of accomplished Geography teachers.

Accomplished teachers of Geography:

- encourage students to recognise their *personal geographies* and to use these *lived experiences* as an entry point to understanding the complexities of the contemporary world, seen through events and issues arising at personal, local, national and global scales (Standard 3.5);
- creatively link their sophisticated understandings with the *diverse and developing understanding of the student* (Standard 4.1);
- bring an enriched understanding of students to the classroom because of their particular sensibility to students' diverse communities. They are alert to the spaces and places students occupy so that they can incorporate *students' personal geographies* into learning sequences, drawing clear connections with *students' prior knowledge and identities* from the local community and beyond (Standard 4.2);
- have current and extensive understanding of geographical education processes including *pedagogical content knowledge*. They select, adapt and create field specific and general teaching approaches and resources to support deep understanding of place, space and environments and they justify their choices about planning and teaching (Standard 6.1);
- employ diagnostic assessment to inform their own teaching and student understanding (Standard 7.6).

(*Professional Standards for Accomplished Teaching of School Geography*, 2010 – Emphasis added).

Although these standards acknowledge the importance of PCK and the need for Geography teachers to work with students' "diverse and developing understandings", research in geographical education has not traditionally focused on teachers' knowledge of students' common preconceptions. As McNamara (1991) notes:

> The majority of empirical studies [of teachers' knowledge] have been in the fields of mathematics and science. A small number have looked at English, language, and social studies, but geography and history are hardly represented, and there seems to be no work in art, drama or music. There is also a narrow focus upon age range with the vast majority of studies concentrating upon teaching in the primary (elementary) years. (p. 122)

The following section provides a review of the research exploring Geography teachers' PCK. This review highlights existing gaps in the literature and is used to frame the focus of the current study.

2.5.3 Studies exploring the PCK of experienced Social Studies/Geography teachers

Although the construct of PCK has not received the same attention in geographical education as it has in Science, a number of studies have explored the holistic development of Geography teachers' PCK. The findings of these studies are outlined below.

Gudmundsdottir and Shulman (1987) examined the PCK of one novice (first year) and one "veteran" Social Studies (History) teacher (37 years' experience) using interviews and classroom observations. The study focused on the ability of the teachers to *transform content knowledge into useful representations* for teaching. The researchers were interested in exploring the way in which expert teachers know their subject matter and their ability to do "things in the classroom that the novice teacher can not do" (p. 59). The participants differed in their length of teaching experience however both were subject specialists with high levels of content knowledge. Data from the interviews and classroom observations highlighted significant differences in the PCK of these teachers. The veteran teacher (Harry) had a clear point of view about the content and was aware of the core concepts that students need to master (and their common misunderstandings). Harry had developed a sophisticated approach to segmenting and structuring the curriculum and was aware of the advantages and disadvantages of different instructional approaches. Gudmundsdottir and Shulman describe this teacher as having a superb story-telling technique and ability to facilitate discussions. Harry was aware of the most effective strategies and representations for teaching particular concepts and was flexible in his teaching approach. According to Gudmundsdottir and Shulman, Harry's well-developed PCK enabled him to see the links between key concepts in the topic area and their significance within the wider curriculum.

In contrast, the novice social studies teacher (Chris) focused on short-term survival. He had only limited ideas about organising and segmenting the content and was unable to identify the critical concepts in the topic. Chris also struggled to visualise links between the individual concepts and related ideas in other areas of the curriculum and did not "see the connections or development from one unit to another" (p. 67). He also lacked a diversity of strategies and representations for building student understanding. Chris often used videos or other resources to "compensate for his own lack of representations" (p. 68). His priority was to get safely from one lesson to the next by minimising the chances of "trouble" in his classroom.

Gudmundsdottir and Shulman (1987) argued that the major difference between these teachers was their level of PCK. They argued that this knowledge base enabled Harry to see the "larger picture" (p. 69) and select teaching strategies that were best suited to the concepts being taught. Harry also had a broader repertoire of teaching strategies and representations to select from, which enabled him to be more flexible in his approach. Gudmundsdottir and Shulman maintained that "visualising larger and larger units in terms of curriculum is an important element in a growing pedagogical content knowledge" (p. 67). They concluded that teacher educators need to focus on the development of pre-service teachers' PCK in addition to knowledge of content and general teaching methods. According to Gudundsdottir and Shulman (1987), teachers should be encouraged to think about the subject matter of the curriculum in terms of the appropriate pedagogy for developing understanding. They argued that pre-service teachers need to be aware of the process they have to undertake to make their content knowledge "available for students" (p. 69). It is important to note that while these researchers examined many elements of PCK, the study did not explicitly address the teachers' knowledge of students' common beliefs or alternative conceptions.

Several studies have sought to capture the development of PCK as Geography teachers move from pre-service to in-service teaching (Cheng, 2003; Martin, 2008; Reitano, 2004). In her study of the developing knowledge bases of primary school teachers, Martin (2005, 2008) investigated the pedagogical knowledge and PCK of 79 pre-service primary Geography teachers studying a one-year Post Graduate Certificate in Education (PGCE) course at a UK university. Her research explored the factors affecting the development of these knowledge bases including the students' evolving conceptions of and beliefs about Geography. As a component of that study, four students were observed and interviewed once during their PGCE course then again after 6-7 months of employment as full-time teachers. The results are reported in two detailed case studies providing an account of the teachers' developing knowledge bases over time.

Over the 12 months of the study, changes were noted in the teachers' priorities and knowledge of teaching and learning strategies. With experience, the participants were better able to link content knowledge and knowledge of pedagogy to improve student understanding. In the initial interviews/observations, the focus of many of the teachers centred around classroom management issues, engaging students and implementing generic teaching strategies (e.g. to improve literacy skills). After employment as full-time primary teachers for 6-7 months, aspects of the participants' knowledge and practice began to change. The teachers provided expanded opportunities for students to develop their "own meanings" (p. 25) during class and made greater use of authentic tasks recognising the students' existing geographical knowledge and life experiences. The teachers were better able to identify appropriate ways of representing geographical knowledge and were more selective in their use of resources to achieve specific learning objectives. With experience, each of the participants was able to access a greater range of resources to improve their pedagogical knowledge.

The PCK development of novice social science teachers has also been investigated in the context of secondary schools. Reitano (2004), for example, investigated the general knowledge growth and PCK of ten novice social science teachers (Studies of Society and Environment, History, Senior Geography) over their final year of study and their first year as practising teachers. Using concept mapping tasks and video-stimulated recall interviews, Reitano tracked the development of the students' knowledge of general pedagogy; content; learners and learning; the curriculum; educational contexts; educational ends, goals, and values; and PCK over a 2-year period. As a component of the concept mapping task students were asked to identify the "features of effective social science teaching" (p. 65). Students' transcripts (from the VSR interviews) and concept maps were then coded according to Shulman's knowledge bases of teaching.

Consistent with the findings of Martin (2005, 2008), Reitano's findings indicated that teachers focused more on the importance of "knowing the learner" after they had gained some experience in schools. By the end of the study, almost all of the teachers viewed knowledge of learners and learning as an important dimension of effective social science teaching. This category included the teachers' knowledge of students' individual differences, learning abilities, personal backgrounds, relationships with other students, prior knowledge and interests. It is important to note, however, that the study did not focus on the teachers' PCK of students' ideas. This element of PCK was not specifically coded and described in the data analysis process.

The findings of Reitano (2004), and Martin (2005, 2008) are consistent with the work of Cheng (2003) with pre-service and early career Geography teachers in Hong Kong. Throughout their pre-service training and first year of teaching, the three teachers in this study became increasingly aware of the importance of learners and the need for appropriate pedagogy to facilitate learning. The teachers' conceptions of PCK also developed from the simple transmission of text to the formulation of structured ideas appropriate for the promotion of pupil understanding, and the integration of content and method.

It is important to note that a number of current researchers in geographical education have been critical of the usefulness of PCK as a construct for understanding the knowledge base and practice of Geography teachers. In particular, several of the contributors to the recent book *Geography Education and the Future* (Butt, 2011) have argued for a different conceptualisation of teachers' knowledge. Firth (2011), for example, using the work of Segall (2004), applies the perspective of critical pedagogy and cultural studies to re-examine PCK. In another chapter, Brooks (2011) argues that the concept of PCK is limiting because, among other things, it fails to recognise the dynamic and constructed nature of geographical knowledge.

Although the work of Shulman has been challenged this does not dismiss the value of PCK as a theoretical framework for exploring the knowledge base of Geography teachers. As noted in the introduction to this thesis, the discipline of Geography, particularly within a school context, draws on a range of philosophies including those derived from the natural sciences, social sciences and humanities. This thesis does not adopt the assumption that knowledge is fixed and unproblematic. The history of Science demonstrates that concepts, laws, and theories accepted at any point in time eventually evolve and are replaced by new ideas (Arabatzis & Kindi, 2008). In the context of this thesis, knowledge in both the social and natural sciences is seen as socially constructed, contested, and continually evolving. To facilitate the exploration of teachers' and students' knowledge, however, this research uses the curriculum, and the science upon which it is based, as a benchmark for examining teachers' and students' ideas. While the school curriculum aims to promote critical thinking (including a recognition of multiple knowledges and perspectives), in practice, these documents adopt a realist approach – where there are defined concepts, processes and principles that students need to understand.

2.5.4 Investigation of the links between "subject expertise" and the teaching of Geography

As well as exploring specific aspects of PCK, researchers in geographical education have also looked more broadly at the links between Geography teachers' "subject expertise" (Brooks, 2006) and their classroom practice. Brooks (2006, 2010), for example, examines the subject expertise of Geography teachers in a broad, holistic sense. Her research explores the ways in which Geography teachers' subject knowledge, passions, experiences, and values influence their classroom practice. This involves the analysis of "expert" or "experienced" teachers' narratives about their "relationship with geography" as well as their accounts of "how and why they decided to teach geography" (Brooks, 2006, p. 356). Brooks uses the teachers' accounts of their motivations for teaching Geography and the factors influencing their teaching to gain an understanding of their practice.

Although Brooks does not focus on teachers' PCK of students' ideas or alternative conceptions in her research, she does highlight the need for teachers to "understand the concepts that underpin knowledge in their field, alongside engaging with what their students know about the subject, their experience of it and how they make sense of this experience" (Brooks, 2011, p. 177). Drawing on the work of Dewey (1972 [1897]) and Wineberg and Wilson (1991), Brooks (2011) argues that teachers can build a bridge between "the sophisticated understanding of the teacher and the developing understanding of the student" (p. 175) by "psychologizing subject matter" (p. 174) or helping students make sense of past experiences. Brooks argues that, to "psychologize" the curriculum, teachers need to move beyond the content of the curriculum to consider "its epistemological assumptions, what the children's experience of the subject would be, any misconceptions they may have of it and also public perceptions that may be relevant" (p. 176).

The subject expertise of Geography teachers has also been investigated by Lambert (2002) and Walford (2001), who examined whether in-service and pre-service Geography teachers' viewed themselves as "possessing expertise as geographers (and attach particular value to this)" or whether they saw themselves as teachers of *children* "through the medium of Geography" (Lambert, 2002, p. 358). Lambert's study included excerpts from "research conversations" with 12 present and former masters degree students currently working as Geography teachers. These excerpts highlight the important links between content knowledge, expertise and PCK development in this domain. As one teacher noted:

> To be an expert, or at least convincing and knowledgeable, geographer is "imperative" because it provides a platform for teaching which is confident, flexible, responsive (to pupils' questions), lively, topical, resourceful (not textbook bound) and able to raise interest of pupils through open-ended debate. Specialist subject knowledge enables teachers to control and regulate discussion, where necessary, with disciplinary expertise . . .
>
> Geographical subject expertise essentially refers to an "approach" rather than a list of contents. You need "background" to help explain, see the significance of what pupils do or do not know or understand, and "to help make pennies drop." Pupils know if you do not have this background. (Lambert, 2002, p. 264)

Lambert also recognised the important link between teachers' subject content knowledge in Geography and their ability to work with students' ideas. In support of this view he cited Aubrey (1994, p. 5) who noted, in the context of primary education, "where subject knowledge is richer, deeper and better integrated it is more likely that the teachers will be confident and more open to children's ideas, contributions."

2.5.5 Teachers' PCK of strategies for promoting geographical understanding

Considerable research in geographical education has focused on certain aspects of PCK, especially those concerning strategies for promoting geographical understanding. Hutchinson (2011) provides a recent review of the range of skills-based approaches available for advancing student learning in this domain. These include strategies for improving spatial cognition (Golledge, 1997), enquiry learning approaches (Roberts, 2003), concept mapping (Ghaye & Robinson, 1989), student discussion and debate (Leat & Lin, 2003), using graphics to improve geographical understanding (Gerber, 2000), open questioning (Leat, 1997), debriefing (Kriewaldt, 2006; Leat, 1997), mental model-building (Reinfried, 2006a), guided problem-solving approaches for enhancing reasoning skills and active cognitive processing (Reinfried, Aeschbacher & Rottermann, 2012), strategies for improving metacognition (Kriewaldt, 2006), language and learning approaches (Slater, 1989), approaches for enhancing student writing (Write it Right project, 1996), and encouraging students to explain themselves (Leat & Lin, 2003). Initiatives such as "Thinking through Geography" engage students in a combination of the above activities (Leat, 1997).

The work of Leat and Lin (2003) provides insights regarding the PCK of accomplished Geography teachers. This research involved the use of student interview data to identify the roles that teachers perform during "Thinking through Geography" lessons to encourage metacognition and the transfer of critical thinking skills. Although that study did not aim to directly investigate the knowledge base of Geography teachers, several of the roles identified, such as "providing heuristics and alternative representations" (p. 393), align with Shulman's (1986) dimensions of PCK. The difference from the current study, however, is that its data were derived from students rather than directly from teachers' knowledge, beliefs and practices. Other thinking skills approaches for developing student understanding in Geography have been summarised by Fogarty (2006) and Ashworth (2002).

It has been argued by Leat (1997, 1999), Reinfried (2004, 2006a) and others that teachers of Geography need to enhance their PCK by assessing their own subject content knowledge, gaining an awareness of the common alternative conceptions held by students and a knowledge of strategies that can be used to assess students' preconceptions and create opportunities for cognitive conflict. An important contribution of the above strategies for developing geographical understanding is their capacity to assist teachers to identify common student alternative conceptions during instruction. All these approaches provide important opportunities for the diagnostic and formative assessment of students' beliefs. Research conducted by Mid-continent Research for Education and Learning (2005) with 62 secondary Geography teachers indicates strong links between teachers' PCK of instructional strategies and improvements in student learning outcomes as measured by the National Assessment of Educational Progress (NAEP) in the United States.

2.5.6 Acknowledgement of students' "private geographies" by humanistic geographers

For students to be able to account for spatial patterns and explain interactions between humans and the environment, an understanding of physical processes and concepts is essential. Developing this understanding involves acknowledgment of student preconceptions.

The significance of preconceptions in the development of conceptual understanding is not new to geographers. Humanistic geographers in the late 1970s recognised that there were two distinct bodies of knowledge in Geography: private geographies and academic or school geographies (Fien, 1983; Tuan, 1976). Private geographies are defined as the largely unconscious parts of actions and identities (memories, values and skills) that allow individuals to make sense and operate effectively within the environment. Academic or school geographies, on the other hand, consist of "shared public meanings" (Fien, 1983, p. 47) and are more systematic and disciplined. Humanistic geographers argue that private geographies can be restructured, refined, extended and enriched through contact with the concepts and methods of academic Geography. Like the physical and cognitive scientists, humanistic geographers stress the importance of grounding curriculum construction in an understanding of students' world views. This continues to be the message of recent research exploring the subject expertise of Geography teachers (Brooks, 2006; Catling & Martin, 2011; Martin, 2008). As noted above, Brooks (2006, 2010), for example, highlights the importance of teachers combining knowledge of Geography with an understanding of students, including their prior and current knowledge and experiences.

It is important to note that the humanist tradition in Geography has not resulted in urgency by geographers to identify students' common alternative conceptions and methods for addressing them through instruction. With the exception of a surge in research activity in the 1990s (Platten, 1995; Scoffham, 1998; Wiegand, 1993) most research into children's ideas in physical Geography has been conducted by academics from outside the domain (mainly in Science education) (Mackintosh, 1999).

2.5.7 Wider work on children's everyday (ethno)geographies

In addition to Brooks' work, there is a related area of research in geographical education exploring children's understandings of, and interactions with, the world (Biddulph, 2011; Catling, 2005, 2011; Reynolds, 2004; Robertson & Gerber, 2000). This literature, which is not reviewed in detail here, is largely concerned with the role of imagination, perception, interpretation and visualisation in the construction of children's understandings of phenomena in the real world. As Catling and Martin (2011) note, "*children's geographies* recognise that children's experiences, views and understandings of the local and wider world are not the same as those of adults but are no less valid to recognise, investigate, appreciate and value" (p. 325). These studies investigate a range of themes, including children's construction of identity (Robertson & Gerber, 2000), their perceptions of place and space (Freeman & Tranter, 2011; Harwood & McShane, 1996; Scoffham, 2004; van der Schee, 2000), and their attitudes, opinions and behaviour towards the environment (Lee, 2000). For the most part, this literature focuses on the importance of understanding the "content of students' experiences" and their perceptions/world views so that this knowledge can be used to plan curriculum, "trigger" motivation and improve student learning outcomes (Robertson & Gerber, 2000, p. 365). Although these studies acknowledge the importance of eliciting children's understandings and building on their informal geographical experiences, they do not specifically focus on the diagnosis of alternative conceptions through instruction or the building of teachers' PCK in this area. This literature is of general relevance to the current study because it highlights the importance of subjective emotional experiences as well as the role of the media in the shaping of students' perceptions (Reynolds, 2004) and the need for teachers to be aware of students' world views (Robertson & Gerber, 2000). This literature also reminds us that students develop sophisticated conceptual understandings prior to formal instruction and that this knowledge is "a point from which deeper conceptual understanding can be developed" (Martin, 2008, p. 36).

2.5.8 Children's spatial cognition and behaviour

Building on research in psychology (see e.g., Piaget & Inhelder, 1967; Seigel & White, 1975; Tollman, 1948), geographers have also explored both children's and adults' developing conceptions of place and space (i.e. their spatial comprehension and environmental cognition). Golledge (1999) provides a comprehensive review of this literature which includes studies of children's place recognition, the development of cognitive maps (internal spatial representations), way finding behaviour (navigation and the role of cognitive maps in this process) and layout comprehension. Recent research in this area includes the work of Schmeinck (2009) and Schmeinck and Thurston (2007) examining primary students' mental maps of the world and the factors affecting the ability of students to develop these representations. These studies highlight the sophisticated mental models held by many 10-year-olds and the importance of children's interests, school experiences, cartographic competencies, exposure to media and travel experiences in the development of these conceptions. Contributors to the recent book *Children and their Environments* (2006) have also examined children's conceptions of scale (Bell, 2006), visual-spatial reasoning skills, way finding processes (Cornell & Hill, 2006) and understanding of environmental representations (Plester, Blades & Spencer, 2006).

While the literature on spatial cognition and cognitive mapping explores "distortions" and errors in individuals' cognitive maps (Couclelis, Golledge, Gale & Tobler, 1987) it does not explicitly seek to identify "alternative conceptions" or to build the knowledge base of teachers in this area. The emphasis of this literature is on the psychology underpinning individual spatial behaviour.

2.5.9 Research drawing on the Science tradition: exploring students' alternative conceptions in Geography

Over the past two decades, taking inspiration from the vast and expanding literature in Science, researchers in Geography have renewed their call for increased attention to the role of alternative conceptions in the construction of geographical understanding (Dove, 1999; Dove, Everett & Preece, 1999; Mackintosh, 1999). A comprehensive bibliography of research exploring students' conceptions, everyday ideas and conceptual change in Geography and the Earth Sciences has been compiled by Reinfried and Schuler (2009). Dove (1998b) and Nelson (1992) also provide detailed reviews of the literature exploring students' alternative conceptions in Science and the implications of this research for teaching and learning Geography.

The research in geographical education outlined above has expanded our knowledge of students' alternative conceptions in this domain. Students' beliefs regarding a number of key concepts have been investigated, including weathering and erosion (Dove, 1997a), perceptions of nature (Mortari, 1997), rivers (Dove, Everett & Preece, 2000), tropical storms (Belknap, 2003), hurricane causes and processes (Lee, 1999), the water cycle (Ben-zvi-Assarf & Orion, 2005; Wilson & Goodwin, 1981), the greenhouse effect (Rajeev, Fox & Mangelky, 1997; Reinfried et al., 2012), ozone depletion and acid rain (Dove, 1996b), rainforests (Dove, 2012), groundwater (Dickerson, Callahan, Van Sickle & Hay, 2005; Reinfried, 2006a), waste management (Palmer, 1993; Palmer, 1995), the environmental impact of motor vehicles (Batterham, Stanisstreet & Boyes, 1996); earth and space (Schoon, 1992), the locations of continents, states and the size of oceans (Francek, Nelson, Aron & Bisard, 1993). While not specifically focusing on the identification of alternative conceptions, researchers have also investigated children's acquisition of geographical knowledge about countries (Barrett, Lyons & Bourchier-Sutton, 2006).

Researchers in environmental education have also devoted attention to the study of students' conceptions. Academics in this field have investigated students' and pre-service teachers' conceptions of the environment (Johnson & Fensham, 1987; Robertson, 1993), sustainability (Walshe, 2008), ecologically sustainable development (Summers, Corney & Childs, 2004), conservation and pollution (Johnson & Fensham, 1987). The literature in this area also acknowledges the importance of teachers' depth of content knowledge (Firth & Winter, 2007) and understanding of students' pre-instructional conceptions (Robertson, 1993; Walshe, 2008). As Robertson (1993) notes:

> learners commence educational programs with prior beliefs and values relating to the programme curriculum . . . these commitments must be made explicit for meaningful learning to occur . . . It is crucial for environmental educators to take these conceptualisations into account, for, as Evernden (1993, p. 35) contends, "how we act toward the non-human is a consequence of our beliefs about how we should act and what we are acting on." (p. 97)

Despite the growth in research exploring students' alternative conceptions in this domain, there remains a lot that we do not know about teachers' knowledge of students' ideas in Geography (a key component of PCK) and their use of this knowledge to inform instruction. There is, however, a related body of research exploring Geography teachers' content knowledge and beliefs regarding learning and teaching. These factors are of relevance to the current study because they are they are likely to impact on the development of PCK, especially the willingness of teachers to diagnose and where necessary address students' alternative conceptions.

2.6 Factors affecting the development of Geography teachers' PCK

2.6.1 The content knowledge and preconceptions of pre-service and in-service Geography teachers

While not the focus of this study, the research exploring Geography teachers' content knowledge and alternative conceptions is reported here because of its links with PCK development (see Section 2.4.1). Lambert and Balderstone (2010) argue that Geography teachers need content knowledge that is not only worthwhile and relevant but accurate, up-to-date and applicable. As noted in Section 2.4.1, teachers without this knowledge are unlikely to be able to recognise, identify and address alternative conceptions during instruction (Reinfried, 2006a). In contrast to the research in Science, however, significantly less attention has been devoted to the examination of Geography teachers' substantive content knowledge and alternative conceptions. The work of Reinfried (2004, 2006a, 2006b, 2007, 2009) and Dove (1996b) is an exception here.

Reinfried (2006a) studied the subject content knowledge and preconceptions of 30 German undergraduate teacher education students completing either a minor or major in Geography. She found that more than 75% of these student teachers held conceptions of groundwater that were either unclear or incorrect, based on simple, "common sense" views. Reinfried argued that teachers need adequate subject content knowledge and an awareness of their own mental models before they can diagnose and address students' alternative conceptions. In order to enhance the PCK of the participating teachers, an intervention based on the mental model-building strategy (Taylor, Barker & Jones, 2003) was employed. This intervention enabled pre-service teachers to experience conceptual change first-hand, reduce their alternative conceptions and refine their mental models of abstract concepts. The mental model-building strategy is based on the premise that a learner's mental models can be modified through the use of simplified miniatures or enlargements of scientifically accepted models of a concept. Reinfried's findings suggest a link between Geography teachers' mental models of key concepts and processes (subject content knowledge) and their ability to identify and address students' alternative conceptions through instruction (PCK).

Dove (1996b, 1997b) explored the content knowledge and alternative conceptions of undergraduate students and pre-service primary teachers in the UK. This research suggested that undergraduate students held a range of alternative conceptions about environmental issues including the greenhouse effect, ozone depletion and acid rain. Dove (1996b) concluded that a teacher's knowledge of common "misconceptions" is vital for building understanding:

> Lecturers need to discover what the misconceptions [of students] are before the topics are taught, to avoid students trying to attach new knowledge to existing false ideas. Lecturers need to engage in dialogue with their students to find out reasons for the misconceptions and how best such ideas might be displaced. Students could be encouraged to devise a lesson which explained a concept in a novel way. Student teachers need to be aware that children hold misconceptions about a range of scientific concepts (Driver et al., 1994). During their teaching practice placements students could be encouraged to conduct their own research into misconceptions about environmental issues with the children they teach. This

> would reinforce the importance of starting from the knowledge the child has, rather than what the student teacher wishes the pupil to know. (p. 99)

With the exception of Dove and Reinfried, researchers in geographical education have focused on aspects of teachers' knowledge other than their awareness of alternative conceptions. This work has examined Geography teachers' subject expertise (Brooks, 2006; Lambert, 2002), the "gaps" in teachers' knowledge, and their depth of understanding (Hoz et al., 1990; Rynne & Lambert, 1997).

Yavetz, Goldman, and Pe're (2009) found that teachers of environmental education in Israeli schools (K-10) had low levels of environmental literacy and that this was evidenced in the low levels of environmental literacy among school students. Likewise, Cutter-Mackenzie and Tilbury (2002), in two studies exploring the PCK of final-year pre-service primary teachers, found that these teachers lacked "ecological literacy" and that their knowledge of the facts, principles and foundational concepts in environmental education was limited. In their analysis the authors note:

> At least three quarters of the interviewed student teachers acknowledged that they lacked significant knowledge of environmental education and environmental concepts. They displayed general, simplistic views when asked to define and conceptualise environmental education in a pedagogical framework. Comments tended to lack substantive content and terminology associated with the environmental education process. (Cutter-Mackenzie & Tilbury, 2002, p. 28)

The pre-service teachers in that study were mainly concerned with the development of students' attitudes and values towards the environment and were dismissive of the importance of substantive (content) knowledge:

> the majority of the surveyed participants disagreed that teachers needed a thorough knowledge of environmental education concepts, approaches and theories in order to practise environmental education at the primary school level. (Cutter-Mackenzie & Tilbury, 2002, p. 29)

Hoz et al. (1990) used concept maps to examine the conceptual subject matter knowledge and pedagogical knowledge of six Geography teachers. The researchers looked at the discipline validity (correctness) of the links included in the concept maps and the abundance of these links. The study also explored whether the teachers' knowledge base was related to their length of classroom experience. The findings suggest that the disciplinary and pedagogic knowledge of the teachers was unsatisfactory. The two types of knowledge did not improve with experience and the latter slightly deteriorated. The authors concluded that these teachers were "probably unaware of their missing or deficit knowledge and hence … prone to misteach their students" (Hoz et al., 1990, p. 982). The study did not, however, report data related to teachers' alternative conceptions.

Although these studies do not focus explicitly on the identification of alternative conceptions, they do have implications for the development of PCK. Teachers without sound, relational content knowledge are unlikely to recognise their students' alternative conceptions and develop strategies for addressing these ideas.

Research in primary contexts reveals that many teachers at this level also lack the subject-specific knowledge and confidence to teach geographical concepts (Martin, 2005; Schoon, 1995; Tambyah, 2008). In research exploring the knowledge base of 220 primary pre-service teachers in Queensland (Australia), Tambyah (2008) concluded that many students lacked "subject matter expertise" (p. 55) in the social sciences and drew on knowledge gained from personal experience to inform their teaching rather than understandings derived from formal disciplinary studies. She noted that:

> primary student-teachers struggle with subject-specific knowledge, possibly because they may have neither a disciplinary background in the social sciences nor do they attach importance to conceptual understanding as the basis of their teaching in SOSE [Studies of Society and Environment]. (Tambyah, 2008, p. 56)

In contrast to these findings, Martin (2005), in her study of primary pre-service teachers in the UK, found that student teachers tended to "discount life experiences as a valuable source of geographical knowledge" (p. 366).

One possible explanation for the lack of subject matter expertise among teachers is the limited Geography training received by pre-service primary teachers in the UK (Catling, 2006) and the United States (Gilsbach, 1997 cited by Tambyah, 2006). A second contributing factor identified by Rynne and Lambert (1997) is the lack of alignment between the undergraduate experiences of pre-service Geography teachers in the UK and the teaching demands of the school Geography curriculum. In their study of 54 Post Graduate Certificate in Education (PGCE) students, Rynne and Lambert found that many pre-service teachers felt they would require additional resources and support to competently teach some Geography topics in schools (e.g. meteorology and climatology). This support was needed because of a "mismatch" (p. 75) between the topics studied by these students in their undergraduate degrees and the content of the curriculum they were required to teach.

2.6.2 The role of teaching orientations and epistemological beliefs

As noted in Section 2.4.2, teachers' beliefs about knowledge and learning (their epistemological views) influence their sensitivity towards students' beliefs and their willingness to diagnose and address these ideas during instruction (Duit et al., 2007). While there are few studies exploring the links between Geography teachers' epistemologies and their knowledge of students' alternative conceptions, several researchers have investigated the relationship between Geography teachers' conceptions of learning and teaching and their general PCK development. Cheng (2003), for example, explored the conceptions of learning and teaching held by three secondary school Geography teachers as they moved from pre-service teacher training to full-time employment. The three teachers in this study exhibited seven conceptions of teaching, ranging from the simple transmission of text through to the development of structured ideas appropriate to pupil understanding, and the integration of content and method. Cheng found that the participants' beliefs developed from a view of teaching as the superficial presentation of content through to an awareness of the role of learners and the need for appropriate pedagogy to facilitate learning. A range of factors influencing teachers' conceptions of teaching and learning and PCK development were also identified. These factors include the teachers' own past learning, their theoretical expectations and practical concerns, their views of pupils and their beliefs regarding the importance of disciplinary knowledge.

Leat (1999) also identified important links between Geography teachers' beliefs about learning and teaching and their willingness to employ constructivist approaches in their classrooms. He reported that many pre-service and experienced teachers held beliefs regarding teaching (e.g. the transmission of content for examinations), their students' abilities (e.g. students are incapable of engaging in metacognitive activities), and their own knowledge and skills, that prevented them from successfully employing constructivist thinking skills programs in their classrooms. These beliefs made it difficult for the teachers to see the value of engaging students in group work, class discussions, debriefing sessions and reflection tasks focused on building metacognitive skills. Leat concluded that teachers may have to overcome these entrenched habits and beliefs before they can successfully implement constructivist teaching approaches in their classrooms.

2.6.3 Conclusion

Researchers in geographical education have for some time acknowledged the importance of students' conceptions in the learning process and the need for Geography teachers to develop an awareness of these beliefs (Fien, 1983; Tuan, 1976). The importance of Geography teachers' PCK has been recognised in *The Professional Standards for Accomplished Teaching of School Geography* (University of Melbourne et al., 2010) and there is an established literature exploring children's ethno-geographies and alternative conceptions as well as Geography teachers' content knowledge, epistemological beliefs, general PCK development, expertise and strategies for promoting geographical understanding.

In contrast to the literature in Science education, however, we know very little about teachers' level of awareness of common student preconceptions. Likewise, little is known about the ways in which teachers use these ideas to help students develop a deep understanding of geographical processes and phenomenon. What we do know is that expertise is domain-specific (Berliner, 2001) and that the skills of accomplished Geography teachers cannot be simply inferred from the literature in Science, Psychology and Mathematics. Targeted research is required to explore these aspects of Geography teachers' knowledge and practice. The following research questions are therefore the focus of this thesis:

1. To what extent are experienced Geography teachers aware of common alternative conceptions held by students (i.e. What is their PCK of students' ideas)?

2. How do teachers use their existing knowledge of students' conceptions and the data provided by the researcher to inform practice? (i.e. How is PCK of students' ideas enacted in the classroom?)

3. What is the relationship between the teachers' PCK development/enactment and their (a) accuracy and depth of content knowledge and (b) epistemological beliefs about learning and teaching?

In order to address the above questions it is necessary to investigate:

1. the alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by Year 9/10 Geography *students*

2. the alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by experienced *teachers* of secondary school Geography

3. the depth of understanding of experienced Geography teachers in this topic area

4. the teachers' epistemological beliefs about learning and teaching

5. the intended purpose of the teaching practices employed by these teachers.

Chapter 3 - Research design, theoretical rationale and method

3.1 Overview

In this chapter the research context is outlined, followed by a detailed description of the research design, theoretical rationale, instruments used and procedures for collecting data. This is followed by an overview of the data analysis techniques used to address the major research questions. The detailed data analysis is described with the results (see Sections 4.2.1 and 5.1.1).

3.2 The context

This study is situated in the NSW curriculum context, where teachers are required to implement a mandatory program involving 100 hours of Global Geography in Stage 4 (Years 7/8) and an additional 100 hours of Australian Geography in Stage 5 (Years 9 and 10). The topic of natural hazards is placed within the Stage 5 focus area of 5A1 Investigating Australia's Physical Environments in the NSW Stage 4/5 Geography syllabus. "Tropical cyclones" is one of the options that teachers may choose to present as a case study within this topic. The research framework outlined below aims to explore the nature of teachers' PCK of students' ideas in this topic area and the use of this knowledge to inform instruction.

3.3 The research design

In order to examine teachers' PCK of students' ideas it is important to understand the nature of students' alternative conceptions. The study was therefore divided into two phases. Phase 1 was designed to identify the conceptual understandings of the students and involved two steps:

- Step 1 – using a structured questionnaire to gain a holistic overview of the distribution of specific preconceptions (identified by experts and the literature) across a large sample of students.

- Step 2 – building a rich account of the students' conceptions and depth of content knowledge. This involved a selected sample of students completing a drawing task, semi-structured interview, visualisation activity and stimulus–response task.

Phase 2 focused on the teachers' conceptions of tropical cyclones, their PCK of students' ideas and their use of this knowledge to inform instruction. This phase included five steps:

- Step 1 – using a range of approaches to identify the alternative conceptions held by the teachers and assess their depth of conceptual understanding of tropical cyclones causes, patterns and processes.
- Step 2 – assessing the teachers' level of awareness of the alternative conceptions commonly held by students (PCK of students' ideas).
- Step 3 – providing the teachers with a summary of the Phase 1 student questionnaire data.
- Step 4 – observing and videotaping lessons as the teachers taught tropical cyclone causes, patterns and processes to a new cohort of Year 9/10 students.
- Step 5 – using post-lesson VSR sessions and semi-structured interviews.

The overarching research questions for this study, as outlined previously (see Section 2.6.3), included the following:

1. To what extent are experienced Geography teachers aware of common alternative conceptions held by students (i.e. What is their PCK of students' ideas)?

2. How do teachers use their existing knowledge of students' conceptions and the data provided by the researcher to inform practice? (i.e. How is PCK of students' ideas enacted in the classroom?)

3. What is the relationship between the teachers' PCK development/enactment and their (a) accuracy and depth of content knowledge and (b) epistemological beliefs about learning and teaching?

These questions (together with their related subquestions) are integrated within this chapter and aligned with each of the research phases. The timeline for data collection of data is provided in Table 3-1.

Table 3-1 Data collection timeline

Date	Research Activity
Terms 1-3 2008	Research design and ethics application. Clearance from NSW Department of Education and Training, independent and Catholic schools.
Term 4 2008	Questionnaires administered to students in groups (Phase 1, Step 1)
	Individually administered semi-structured interviews and drawing tasks with selected students. (Phase 1, Step 2)
	Semi-structured interviews with teachers administered individually (Phase 2, Steps 1-2)
Term 1 2009	Feedback regarding students' conceptions distributed to participating teachers. (Phase 2, Step 3)
Terms 1-3 2009	Video recording and observation of teachers' lessons with a new cohort of Year 9/10 students. (Phase 2, Step 4)
Within 1 week of the recorded lesson	Post-lesson VSR sessions and semi-structured interviews with individual teachers. (Phase 2, Step 5)

3.4 Ethics

Before commencing this research, ethics approval was sought from the Macquarie University Ethics Review Committee (Human Research) and the NSW Department of Education and Training (through the State Education Research Approval Process – SERAP). Approval to undertake the research was granted by both the Ethics Review Committee and the NSW Department of Education and Training in September 2008 (See Appendix 2).

The following measures were included in the Macquarie University and SERAP ethics applications and adhered to throughout the research process to protect the participants:

- Participants were fully informed of the nature of the research and provided with an information sheet outlining the details of the study.
- Consent forms were signed and returned by the principals of each participating school and by all participants (see Appendix 3). In the case of the student participants, written consent was obtained from a parent/guardian and the child. Students who did not return the relevant consent form were excluded from the study. All participants were given a signed copy of the consent form to keep.

- Participants were advised that their involvement in the study was voluntary and were guaranteed the right to withdraw from further participation at any time without having to give a reason and without adverse consequence. Students were informed that they could indicate this by telling the researcher, their teacher or their parents that they no longer wished to participate in the study.
- Information was provided about how the confidentiality of data would be maintained. Participants would be identified using codes and pseudonyms would be used in any publication of the data.
- The aggregated and de-identified student data were made available to the participating teachers at the end of Phase 1 of the research so that it could be used to inform their teaching practice.

3.5 Sample characteristics

The key aim of this study was to explore the nature of experienced Geography teachers' PCK of students' ideas and their use of this knowledge to inform instruction. To address this aim it was important to identify schools, teachers and students meeting the specific criteria outlined below.

Participating teachers needed to:

- have taught the case study on tropical cyclone causes and processes (Stage 5 Geography) in the past and be willing to teach tropical cyclones as a component of focus area 5A1 (Investigating Australia's Physical Environment) in 2009;
- have been trained in undergraduate Geography at a tertiary institution;
- have a minimum of 5 years' teaching experience in order to be classified as experienced rather than novice teachers (Berliner, 2001); and
- be working in a comprehensive rather than a selective school.

An overview of the teacher sample is provided in Appendix 4.

Students participating in the study needed to:

- be in either Year 9 or Year 10 in 2009; and
- have not yet formally studied tropical cyclone causes, patterns, processes and impacts at school. Students would have studied some of the underlying processes, including the particle model of matter and changes of state in Stage 4 Science.

Students were selected from a geographic area not subject to tropical cyclones, in order to control for the likely effect of personal experiences on their conceptual development (Driver et al., 1994). It could be expected that students in Sydney would have had a relatively even exposure to cyclones, primarily through the media (including TV weather forecasts) and movies.

3.6 Phase 1 - Student data collection

3.6.1 Step 1 - Gaining a holistic overview of the distribution of specific preconceptions across a sample population of Geography students and their teachers

Research questions:

What are the common alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by Year 9/10 students?

As was demonstrated in Section 2.1.1, knowledge of students' common preconceptions is a core component of PCK. The investigation of students' alternative conceptions in Geography, however, remains a relatively undeveloped area of research. We know little about the nature and prevalence of alternative conceptions in Geography classrooms and their impact on the development of geographical understanding. It is fortunate for geographers, therefore, that the investigation of students' alternative conceptions has been a core focus of research in Science education literature for more than three decades. Although few studies have explored students' beliefs about tropical cyclones and storms, there is an extensive literature investigating alternative conceptions of the science underpinning an understanding of weather phenomena (e.g. beliefs regarding the nature of matter, air pressure, the water cycle, etc.). The following section provides a review of this research in order to inform the development of a questionnaire for assessing the prevalence of specific preconceptions across a sample population of Geography students and their teachers.

Research informing the questionnaire design

The literature exploring students' preconceptions in Science is vast and is not reviewed in detail here. Available research in this area has been catalogued in the *Students' and Teachers' Conceptions and Science Education* (STCSE) database (Duit, 2009). This database contains more than 8400 entries categorised by discipline. Relevant summaries of the research in this field can be found in a number of publications, including Driver, Squires, Ruchworth and Wood-Robinson (1994) and Vosnaidou (2008).

In 2009 Reinfried and Schuler published the Ludwigsburg-Lucerne Bibliography on Conceptual Change Research in the Geosciences (LLBG) which focuses on research relevant to students' conceptions, everyday ideas and conceptual change in Geography and the Earth Sciences. The database contained 509 titles in 2010. Both the STCSE and LLBG databases indicate that research into students' conceptions in the Earth Sciences and Geography is significantly underdeveloped compared with the other sciences including Physics, Biology and Astronomy. Although there is a growing body of literature exploring students' conceptions in Geology (for example, the rock cycle, volcanic eruptions, orogeny, the Earth's internal structure and plate tectonics) there are relatively few studies of students' ideas in meteorology, especially beliefs about specific weather phenomena. A number of researchers have investigated students' general conceptions of weather and climate, including Piaget (1930), Moyle (1980), Bar (1989), Russell, Bell, Longden and McGuigan (1993) and Spiropoulou, Kostopoulos, and Jacovides (1999), and the research in this area has been summarised in two reviews (Dove, 1998a; Henriques, 2002). There are, however, only two documented studies exploring students' conceptions of tropical cyclones and storms (Belknap, 2003; Lee, 1999). At the time of writing, only one of these papers (Lee, 1999) had been published in a peer-refereed journal. Nevertheless, despite the paucity of research exploring students' conceptions in this area, several of the conceptual building blocks for understanding tropical cyclone causes and processes have been investigated (see the following section). There is also a considerable body of research investigating the naive beliefs of pre-service and in-service primary and secondary Science teachers. This literature, while not the main focus of this thesis, is cited here because it has relevance for the focus on teachers in the current research.

This section begins with an examination of the research exploring students' conceptions of the science underlying and understanding of tropical cyclone causes and processes (e.g. conceptions of matter, air pressure and the causes of wind). It then provides a review of the key papers specifically addressing students' alternative conceptions of tropical cyclones and storms. This review aims to provide a research-based inventory of common alternative conceptions in Science that can be used as the basis for the further exploration of both students' and teachers' understandings of tropical cyclones in a geographical context.

Students' alternative conceptions of the scientific concepts and processes underpinning an understanding of tropical cyclones

A number of scientific concepts and principles underpin deep understanding of tropical cyclone causes, patterns and processes. These include, for example, the nature and properties of matter, phase changes in water, the water cycle, air pressure, changes in temperature with altitude, the global heat budget and the relationship between temperature, air pressure and air movement. More than three decades of research in Science education have demonstrated that many of these concepts cause difficulty for both children and adults. These findings suggest that students construct alternative conceptions of these processes and phenomena which have the potential to act as significant barriers to learning if they are not identified and addressed through instruction (Chang, 2007). Knowledge of these common student preconceptions is therefore a vital resource for Geography teachers in planning instruction. In order to inform the investigation of teachers' PCK in this area, the following section examines the conceptual building blocks for understanding tropical cyclone causes and processes and the nature of students' alternative conceptions in each of these areas.

Alternative conceptions of matter and the nature of air

Knowledge of the nature and properties of matter is an essential prerequisite for understanding air pressure and air movement in tropical cyclones. The scientific conception holds that all objects, materials and substances (including water and air) are examples of matter and are composed of particles which take up space. All particles have mass, and therefore weight, within the Earth's gravitational field. In contrast to this, the findings of a significant number of studies in Science education (see e.g. Brook & Driver, 1989; Doran, 1972; Wiser & Smith, 2008) indicate that students' intuitive beliefs about matter tend to be based on perception and action rather than precise and reliable scientific methods. For many students, an entity is material and is “made of stuff” only when it can be touched and seen (Carey, 1991; Stavy, 1991; Wiser & Smith, 2008). Students with this conception believe that matter exists only when it is detectable by the unaided senses. The sensory-based conception of “felt weight”, for example, is common among students. The inability of individuals to see or feel static air leads to the belief that because stationary air cannot be “felt” it does not occupy space, have mass or apparently exert pressure on the Earth’s surface (Stepans, 1994). This belief has significant implications for students’ understandings of air pressure and weather.

According to the research of Stepans (1994) and Brook and Driver (1989), there is a gradual development in children’s awareness that air exists, occupies space and has both mass and weight. The concept of air having weight (and exerting pressure) appears to be particularly difficult for students to grasp. Brook and Driver noted that this is often the last of the above concepts to be developed from the age of roughly 12 onwards. The development of this conception can, however, be very slow and is not guaranteed. Brook and Driver noted that at the age of 16 more than 65% of the students participating in their study continued to hold the conception that air had negative or no weight. Leboutet-Barrell (1976) suggested that the common experience that students have of gases rising and floating may leave them to believe that air has negative weight and that filling objects with air can make them lighter.

Posner, Strike, Hewson, and Gertzog (1982) provide a framework that helps to explain the tenacity of alternative conceptions in this area. They argue that individuals need to perceive concepts as intelligible, plausible, and fruitful before they will adopt them. For many students, the idea that air is matter and that it has both mass and weight is neither logical nor plausible. The category of matter is restricted to objects that can be detected with the unaided senses. For these reasons, the alternative conception that air is weightless can be particularly resistant to change. A number of studies have shown that by the time students reach junior high school they continue to struggle with the concept of air as matter (Carey, 1991; Smith, Macklin, Grosslight & Davis, 1997; Stavy, 1991). Addressing this belief requires major conceptual restructuring as well as shifts in students’ ontological and epistemological assumptions. For this reason it is not uncommon for students who are told during instruction that air is matter to revert to their alternative conception over time (Wiser & Smith, 2008).

Alternative conceptions of air pressure

Students' alternative conceptions of air pressure and pedagogical approaches for addressing them have been studied in detail over the past 30 years. This research began in the early 1980s with the seminal work of Moyle (1980), Sere (1982), Engel (1981) and Brook and Driver (1989) on identifying naive conceptions and extends through to the more recent work of Basca and Grotzer (2001) investigating students' understanding of causal relationships involving air pressure. The results of this research indicate that a significant proportion of secondary school students have difficulty understanding the relationship between air temperature, density, pressure and movement. Students' sensory-based theories of matter, discussed above, have a significant impact on their understanding of air pressure (Driver et al., 1994). Dove (1999) argues that because pressure is not detected by the senses at ground level it is difficult for students to understand. The naive conception of air as "the absence of matter" leads students to believe that air is also weightless (or has negative weight) and cannot therefore exert pressure on the ground (Wiser & Smith, 2008). According to Sere (1982), many students between the ages of 11 and 13 believe that air can only exert pressure when it is moving in the form of wind. Students at this age find it counter-intuitive to accept that air, even when immobile, can exert pressure on the Earth's surface (Sere, 1982; Tytler, 1998). Aron et al. (cited by Dove, 1999) notes that even students who have developed an understanding that air has mass and weight continue to hold the alternative conception that air pressure increases with height above the Earths' surface, and lack understanding of the operation of pressure cells. This is not surprising given Wiser and Smith's (2008) and Tytler's (1998) observation that many students lack the macroscopic concepts of matter, weight, volume and density necessary to support a sound understanding of the relationship between air temperature, density and movement in a pressure cell. Tytler (1998) provides a detailed discussion of the reasons why students struggle with the concept of air pressure. One consequence of these difficulties is students' tendency to avoid references to air pressure in responses to questions both in semi-structured interviews and in classroom activities (Brook & Driver, 1989; Spiropoulou et al., 1999). Students' alternative conceptions of the links between temperature, pressure, density and air movement have the potential to significantly impact on their understanding of tropical cyclone causes, patterns, processes and impacts.

Alternative conceptions of the causes of the wind

Although there is a body of research exploring students' alternative conceptions of weather and climate in general (see Henriques, 2002 for an overview), relatively few studies have focused specifically on students' conceptions of the nature of the wind and its causes. Notable exceptions include studies by Moyle (1980) and Papadimitriou and Londridou (2001). The scientific conception states that "winds are produced by the uneven heating of earth's surface and the resulting rise and fall of differentially heated air masses" (Henriques, 2002, p. 214). Moyle's research with 41 primary and secondary students indicated that the majority (29/41) held conceptions of the wind that were inconsistent with this view. These explanations included references to coldness from the North and South Poles, the movement of the Earth, the rain, clouds moving and the influence of the moon and tides. Moyle also noted a tendency by students to link cold temperatures with strong winds and vice versa. For approximately one quarter of the students, wind was seen to be caused by some other moving object such as a car, cloud or plane.

Papadimitriou and Londridou (2001) investigated children's conceptions regarding the movement of air masses in the troposphere. Their study, which involved semi-structured interviews and drawing tasks with 13 Greek students aged 12-18, found that children across this age range experienced difficulties explaining the mechanisms of air movement in the troposphere. A number of alternative conceptions were also identified, including the belief that gravity is the only factor determining the movement of gases in the atmosphere. Papadimitriou and Londridou noted that the students frequently confused pressure with force and force with heat. Some students also held the utilitarian belief that air masses move in order to "clean the polluted atmosphere of the city" (p. 10). Consistent with the research on air pressure, Papadimitriou and Londridou found that most of the students had a sensory-based understanding of the wind, describing it a "something that blows". Very few students related their explanations of the wind to either temperature (2 students), pressure (1 student) or both (1 student). Students' senses and information obtained from TV weather forecasts were identified as the main factors shaping their conceptions.

Students' conceptions of the global heat budget and the seasons

Understanding of air pressure and the causes of wind also relies on the development of knowledge regarding the distribution and transfer of heat across the Earth's surface (the global heat budget) and how this changes with the seasons. Research in Science education indicates that both students and teachers find these concepts difficult and hold a range of alternative conceptions regarding the causes of latitudinal and seasonal temperature differences (Moyle, 1980; Philips, 1991; Rastovac & Slavsky, 1986; Schoon, 1995). In a review of naive theories related to the causes of the seasons, Brewer (2008) outlines 15 categories of alternative conceptions identified in the literature over the past 50 years. In his review, Brewer notes that a core component of many of the more sophisticated alternative conceptions is the belief that "coming closer to a source of heat will make you hotter" (p. 191). This belief leads to the development of alternative theories that the main factor responsible for seasonal and latitudinal differences in the Earth's temperature is the distance between the Earth and the sun (Philips, 1991; Russell et al., 1993). Russell et al. (1993, p. 69) noted in their research with 58 students as a part of the Primary SPACE (Science Processes and Concept Exploration) Project in the UK that some children made reference to the sun moving "in and out" and being "closer and further away" to explain sunny days. These views are in direct conflict with the scientific consensus which holds that seasonal variations in temperature are the result of the Earth's alignment on its axis (Henriques, 2002) and that differences in temperature by latitude are a function the angle at which energy from the sun meets the Earth's surface.

It is hypothesised by Skamp (2008, p. 437) that the belief that "coming closer to a source of heat will make you hotter" is also likely to affect students' understanding of the relationship between altitude and temperature. Skamp suggests that despite the common images of snow-capped mountains, there is evidence that many students adopt the "closer to the sun theory" and believe that temperatures increase rather than decrease with elevation in the troposphere. These alternative conceptions regarding the seasons and global differences in temperature are commonly held and often highly resistant to change. Brewer (2008) argues that the full scientific model of the seasons, together with an understanding of heat difference by latitude, are commonly not attained by even college educated adults. This finding is consistent with that of Mant and Summers (1993) who found that more than 50% of the primary teachers maintained that variations in the Earth's temperature were caused by the sun being closer to the Earth's surface at midday than in the evening or early in the morning. It is perhaps not surprising that students hold alternative conceptions of the seasons given the prevalence of these beliefs among primary teachers.

Students' alternative conceptions of phase changes, the water cycle and the conservation of matter

In order to understand the causes of cloud formation and precipitation in tropical cyclones, students require a working knowledge of the water cycle, phase changes in water, the Law of Conservation of Energy (energy cannot be created or destroyed, but can change its form) and the Law of Conservation of Matter (during an ordinary chemical change, there is no detectable increase or decrease in the quantity of matter). There is a significant body of research investigating the nature of students' alternative conceptions in these areas (see, for example, Bar, 1989; Bar & Travis, 1991; Ben-Zvi-Assaraf & Orion, 2005; Russell, Harlen & Watt, 1989; Tytler, Prain & Peterson, 2007). That research indicates that students develop their own theories and models of phase changes in water, which become increasingly complex with age (Henriques, 2002). Also apparent from the research is that an understanding of phase change is dependent on an ability to conserve air and water (Ben-zvi-Assarf & Orion, 2005). Both these concepts in turn form important building blocks for understanding of the water cycle and the processes of tropical cyclone formation.

One significant barrier to the development of understanding in this area is the alternative conception that water can "disappear" during phase changes (particularly evaporation). This belief appears to be related to a "sensory" view of matter, that substances exist only if they can be detected by the unaided senses. The inability to conserve matter in phase changes makes an understanding of complex systems such as the global water cycle difficult for students. In a survey of 1000 7-9th graders conducted by Ben-zvi-Assarf and Orion (2005) the majority of students indicated that they did not realise that in a cyclic process, the overall amount of matter is conserved. The authors noted that even students who had developed an understanding of the conservation of matter during phase changes failed to recognise the water cycle as a closed system and believed that water could be "lost" during the cycle (p. 366). The research suggests that alternative conceptions regarding evaporation and the conservation of matter are common among students and can be resistant to change through instruction. There also appears to be significant variation in the development of these conceptions across different study populations. Although Bar (1989) found that students developed the conception of matter being conserved at the age of 9 or 10 and an understanding of evaporation and condensation at around the age of 11, Featherstonhaugh and Bezzi (1992, cited by Ben-zvi-Assarf & Orion, 2005) found that many junior high school students continued to express difficulties understanding the process of evaporation and operation of the water cycle in a natural context. According to Ben-zvi-Assarf and Orion (2005), most Israeli students enter junior high school with partial and fragmented conceptions of the water cycle and its processes and graduate (six years later) with the same misunderstandings. Research conducted by Russell, Bell, Longden, and McGuigan (1993) and Symington and Symington (1983) indicates that even students who have studied the water cycle prefer to use alternative conceptions based on their personal experiences to account for weather-related processes.

An additional area of confusion for students in their learning about phase changes in water is the difference between boiling and evaporation. According to Bar (1989), who examined the progression in students' ideas about the water cycle with age, students hold a range of alternative conceptions about these processes. Bar's research indicated that 10-36% of the 5 to 9 year-olds in this study (n=115) believed that water vapour in the atmosphere was derived from the sun boiling the sea. Up to 15% of students in this age group also held the conception that clouds were made from vapour of kettles (see also Philips, 1991). According to Henriques (2002), many students believe at this stage that the only way water becomes a gas is through boiling. Demonstrations of cloud formation using kettles during classroom activities may be a source of this alternative conception. Bar (1989) notes that by the age of 14, 43% of students held the scientific conception that energy from the sun causes water in the oceans to evaporate.

The belief that water needs to boil to form water vapour is related to another common alternative conception, that evaporation does not occur at low temperatures. Ben-zvi-Assarf and Orion (2005, p. 372) found that 20.7% of the Year 7-9 students studied (n=1000) did not agreed with the statement, "If we put a glass of water in a refrigerator for a week, the amount of water in the glass decreases due to evaporation". These studies highlight the difficulties of many (particularly younger) students with the concepts of "evaporation" and "boiling". Alternative conceptions in this area are likely to create difficulties for students in their understanding of tropical cyclone causes, patterns, processes and impacts.

To understand phase changes in water students must develop some knowledge of particle theory, atoms and molecules (Henriques, 2002). Johnson (1998, 2005) and Papageorgiou and Johnson (2005, cited by Tytler et al., 2007) argue that these concepts are critical in supporting satisfactory representations of evaporation phenomena such as boiling. They argue that without an understanding of particle theory, the notion of the liquid-gas transition cannot be successfully imagined. The abstract and intangible nature of these concepts causes many difficulties for students. As a consequence, students hold a range of alternative conceptions regarding the nature of atoms and molecules. Many of these conceptions are resistant to change and continue to be held by senior high school students (Wiser & Smith, 2008).

One of the most commonly documented alternative conceptions in this area is the belief that the macroscopic qualities of a substance, including colour, hardness, shape and structure, also apply at a microscopic level (Anderson, 1990; Johnston, 1998; Wiser & Smith, 2008). This alternative conception often results in the belief that molecules change size and weight when they are heated and during phase change. Some students also believe that atoms liquefy during melting and dissolution, and disappear when liquids boil (Lee et al., 1993 cited by Wiser & Smith, 2008). According to Wiser and Smith (2008) these beliefs seriously impair the ability of students to develop an understanding of physical transformations including phase changes in water.

Alternative conceptions of cloud formation and precipitation

Cloud formation and the process of precipitation are two key components of the water cycle that are central to an understanding of tropical cyclone causes, patterns, processes and impacts. Research in this area has revealed that students hold a range of alternative conceptions that have the potential to adversely impact on their understanding of weather and climate (Dove, 1998a). Research with 5-9 year-olds conducted by Piaget (1930) and Piaget, Tomlinson and Tomlinson (1929) indicated that students at this age hold a range of conceptions regarding the nature and composition of clouds. Students in the 5-6 age group believed that clouds were solid and made from stones or earth. As students grew older, their conceptions evolved to more sophisticated theories. By the age of 6-9, students suggested that clouds could be composed of smoke or steam "from saucepans". Research conducted by Bar (1989) with 300 Israeli children aged 5-14 also found a range of alternative conceptions regarding the composition of clouds. Almost one third of the 10-11 year-olds (n=82) in Bar's study believed that clouds were composed of "bags of water" (p. 486). The idea that clouds were composed of "cotton wool, smoke or ice" was also put forward by a number of the students aged 10 and younger. Even at the age of 14, 30% of the students in this study did not think clouds were composed of either water or water vapour.

Students' conceptions of the nature and causes of precipitation have also been investigated by a number of researchers, including Bar (1989), Stepans and Keuhn (1985) and Russell et al. (1993). Bar (1989) noted that students aged 5-14 provided two main explanations of rainfall: that rain comes from colliding clouds or that it occurs when drops become too heavy and fall. Stepans and Kuehn also found the conception "rain occurs when clouds become too heavy" to be common among students in Grades 2 and 5. The explanation of "colliding clouds" is typical of the responses provided by students under the age of 7 (see Moyle, 1980), however Bar (1989, p. 486) emphasised that 20-30% of 7-14 year old students in the study continued to hold this conception. Some participants (aged 8-11) also thought that rain was the result of clouds sweating or being scrambled, melted, or shaken by the wind. An example of this is provided by Stepans and Kuehn (1985, p. 45), who quoted 7 year old students explaining that "clouds think it's hot, and one day they start sweating. I guess they start sweating and the sweat falls on us". Few students or primary school teachers are able to adequately explain the link between lower atmospheric temperatures and condensation (Osborne & Cosgrove, 1983). With the exception of Bar (1989), few researchers have investigated the conceptions of precipitation in students above the age of 12. It should also be noted that although research has investigated the alternative conceptions of primary and secondary Science teachers there are few studies exploring the naive conceptions of Geography teachers (see e.g., Hoz et al., 1990; Tambyah, 2007).

The above studies highlight the complex web of concepts that underlie an understanding of tropical cyclone causes and processes. Teachers require an awareness of the commonly held alternative conceptions in each of these areas so they can recognise these ideas in instruction and prevent students from constructing more elaborate alternative conceptions. Research in Science education suggests that students often "enrich" rather than restructure their intuitive beliefs during instruction. This can result in the formation of inconsistent or "synthetic" mental models – combinations of alternative conceptions and "culturally/scientifically accepted" ideas (Vosniadou et al., 2008, p. 6). These conceptions can act as important stepping-stones to understanding provided that Geography teachers have the knowledge and skills to diagnose and address them during instruction.

Alternative conceptions of tropical cyclones and storms

When we look at the topic under consideration in the current study (tropical cyclones) there is very little research. With the exception of Lee (1999) and Belknap (2003), the available research on students' conceptions of tropical cyclones is sparse. Lee's 1999 paper describes students' knowledge of hurricanes following their personal experiences of cyclone Andrew in 1992. This study investigated the scientific knowledge, world views and information sources of 127 fourth and fifth grade students from two elementary schools in areas of Florida significantly impacted by the cyclone. The research focused on the impact of ethnicity, socioeconomic status, and gender on students' conceptions and sources of ideas. The findings indicated that many of the student participants experienced considerable difficulty providing explanations of the causes and processes of tropical cyclones. There were a number of common patterns in the students' explanations, including short and incomplete responses in terms of the mixing of warm and cold air, high and low air pressure or warm and cold fronts, and simple descriptions in terms of warm water, strong winds, heavy rain, storms and tornadoes. Many students also held potential "misconceptions" regarding the shape, size and components of a hurricane, including the belief that hurricanes were much smaller synoptic features than they actually are. These difficulties are perhaps not surprising, given the prevalence of alternative conceptions related to the underlying scientific processes and principles of tropical cyclones (discussed earlier in this section). In contrast to their inadequate understanding of scientific processes and causes, the students generally had a good knowledge of hurricane prediction, preparation and damage. Lee argues that this might be explained by the students' recent experience of hurricane Andrew and its impacts.

These findings were augmented by the research of Belknap (2003), who investigated the preconceptions of tropical storms held by high school students living in Houston, Texas. This research adopted a similar methodology to that of Lee (1999) and produced similar results. Belknap found that the participants' overall scientific knowledge of tropical storms was poor and that students of different ethnic backgrounds differed in their perceptions and preconceptions. Although these findings are consistent with the results of Lee, they conflict with observations of Driver et al. (1994) regarding the uniformity of alternative conceptions across cultural boundaries. Specific alternative conceptions identified in the Belknap study included the belief that tropical storms, like regular storms, are not dangerous and that storms of this type do not impact on the quality of drinking water. Belknap concluded that students develop an adequate knowledge of tropical storms based on their experiences but often fail to develop a coherent understanding beyond those experiences. At the time of writing, this study by Belknap was the only available research exploring secondary school students' conceptions of tropical cyclones and storms.

Although the alternative conceptions discussed above have been documented in Science education, we know little about the ways in which these ideas interact with students' learning processes in Geography. We also know little about students' alternative conceptions of the spatial distribution, scale and impacts of meteorological phenomena such as tropical cyclones, tornadoes and storms. What we do know is that these beliefs are likely to have a significant impact on the development of understanding. Building teacher awareness of these ideas is, therefore, an essential first step in the development of pedagogies for improving geographic literacy (Reinfried, 2006a). The ideas and beliefs identified in the Science literature can be used as a starting point for exploring the nature of students' alternative conceptions and teachers' PCK in geographical contexts.

3.6.2 The questionnaire design

To gain a holistic overview of the distribution of specific conceptions among a sample population of students and teachers, a questionnaire was developed consisting of 40 true-or-false statements. The questionnaire design (Appendix 5) was adapted from the model developed by Ben-zvi-Assarf and Orion (2005) and included both factual and conceptual items related to: (1) the underlying conceptual foundations for understanding tropical cyclone causes and processes – for example, "air is weightless", and (2) the geographical dimensions of tropical cyclones including their scale, spatial distribution and impacts – for example, "tide levels can affect the impact that tropical cyclones have on coastal communities."

Three steps were followed to develop items addressing the underlying conceptual foundations for understanding tropical cyclone causes and processes. The first step was to construct a concept map identifying the key conceptual building blocks for understanding tropical cyclone causes and processes. These concepts were used as organising themes in the questionnaire. This was followed by a review of the conceptual change literature to identify students' common alternative conceptions in each of these areas. Finally, statements were designed to target each of these beliefs.

The 22 statements related to underlying scientific processes and principles are organised by theme and summarised in the table below.

Table 3-2 Questionnaire statements related to underlying processes and principles (organised by category)

Student conceptions of matter, changes in temperature with altitude and the relationship between air temperature, density, pressure and movement.	*
Air has mass.	
Air is weightless.	F
The Earth is heated unevenly by the sun and this results in differences in air pressure at the surface.	
Air pressure directly above a body of water increases as the temperature of the water increases.	F
Cold air applies a lower pressure on the ground than the same volume of warm air.	F
Cold air is denser than warm air.	
Rising air applies less pressure on the Earth's surface than falling air (of the same volume).	
A body of air will rise if it is less dense than the air around it.	
Air temperature increases from sea level to the base of the clouds.	F
Evaporation and condensation	
When water evaporates from the ocean it is a boiling process.	F
The molecules that make up water expand and float away when heated by the Sun's energy.	F
Rates of evaporation are higher from a cool body of water than a warm one.	F
Rain occurs when water droplets in clouds join together and become too heavy to remain suspended in the air.	
Only a small proportion of the water that evaporates ever returns to the Earth's surface as precipitation (rain, sleet, hail or snow).	F
Clouds are tiny water droplets suspended in the air.	
Rain occurs when clouds are disturbed or shaken by the wind.	F
Water evaporates from the sea when heat from the sun causes high energy water molecules to escape.	
The heat budget and causes of the wind	
Cold temperatures are the main cause of strong winds.	F
The weather is generally cold during a cyclone.	F
The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.	F
Winds are caused by differences in air pressure across the Earth's surface.	
The eye or centre of a tropical cyclone is an area with light winds and frequently clear skies.	
* Statements representing incorrect factual data or alternative conceptions are labelled "F".	

Given the lack of availability of research exploring students' conceptions of the distinctively geographical concepts of place, spatial distribution, scale, and interaction (including reciprocal relationships between the biophysical environment and human activities) a separate process was followed for the construction of these items. Information about common student conceptions was collected from a range of sources, including focus group interviews with students who had not yet formally studied tropical cyclones, informal discussions with experienced Geography teachers and academics in Earth Sciences, and an analysis of the alternative conceptions featured in secondary school Geography textbooks from Australia, the United States and United Kingdom. From these sources four categories of likely alternative conceptions were identified, including beliefs related to the impacts of tropical cyclones as well as their location, timing, movement and links with other natural hazards. Each of these beliefs was translated into a statement and included as a separate item in the questionnaire (see Table 3-3).

The content validity of the questionnaire was verified by having each statement checked by a Macquarie University Catastrophe Risk Analyst and Meteorologist, two experienced Geography teachers and a Senior Lecturer in Science Education

Table 3-3 Questionnaire statements related to the geographical dimensions of tropical cyclones (organised by category)

Spatial distribution, movement and timing	*
Tropical cyclones in Australia can move in any direction including sharp turns or loops.	
Tropical cyclones rotate in an anticlockwise direction in the Southern Hemisphere.	F
Tropical cyclones can form over land.	F
Tropical cyclones can form anywhere around the Australian coastline.	F
Australia's cyclone season occurs between June and September.	F
Impacts of tropical cyclones	
Most deaths and injuries in severe tropical cyclones worldwide are due to rising sea levels.	
When the conditions become calm after the initial gale force winds of a cyclone, the danger has passed.	F
Cyclones increase in intensity when they move over land.	F

In a cyclone, wind gusts of 280km/h will cause twice-as-much damage to the built environment as wind gusts of 140km/h.	F
Most deaths and injuries in severe tropical storms worldwide are due to objects flying in the air or structures collapsing.	F
Tide levels can affect the impact that tropical cyclones have on coastal communities.	
The term "storm surge" refers to a sudden burst in storm activity which creates problems in the supply of electricity.	F
Tropical cyclones do not affect either long or short term sea levels.	F
Links with other natural hazards	
Hurricanes, typhoons, tornados and tropical cyclones all contain warm rising air.	
The terms "hurricane", "typhoon" and "tropical cyclone" describe *different types of storms* that occur around the world.	F
Tornadoes differ from tropical cyclones in that they are smaller and can form over land.	
A tropical cyclone is a rotating column of air that is in contact with the ground.	F
Tsunamis can be caused by tropical cyclones.	F
* Statements representing incorrect factual data or alternative conceptions are labelled "F".	

3.6.3 The piloting process

The questionnaire was piloted with 20 final-year pre-service Geography teachers, two experienced Geography teachers and a class of 30 Year 8 students who were yet to formally study tropical cyclones. Several groups of final-year pre-service Science and Geography teachers also provided feedback on the questionnaire design. This piloting and cross-checking process resulted in a number of changes being made to the questionnaire. These changes included ensuring that the language used was accessible to Year 9/10 students, removing items that were unclear or too complex for participants to understand and reordering statements in the questionnaire to minimise student confusion and reduce cognitive load. The results of the pilot indicated that some students were distracted by the random ordering of items in the original questionnaire and found it difficult to shift their mind backwards and forwards between the themes. To address these issues, the items in the student questionnaire were reorganised according to the themes identified in the literature review and focus group interviews (see Table 3-2 and Table 3-3 above). Similar problems of cognitive load were not evident in the pilot with teachers so the statements were left in a random sequence.

3.6.4 Sampling for the questionnaire – teachers and students

To operationalise the selection criteria outlined in Section 3.5 a two-level screening approach was adopted. Schools that had studied tropical cyclones as a case study in the past were identified through discussions with councillors of the NSW Geography Teachers Association. Letters were sent to the principals of these comprehensive state, independent and Catholic schools explaining the selection criteria and inviting them to be involved in the study. The letters explained that participating teachers needed to have studied Geography in their undergraduate degrees and have a minimum of 5 years' teaching experience. According to Berliner (2001), 5 years is the minimum classroom experience required before a teacher can move to a more expert level of functioning. Research on novice teachers suggests that "survival" and the operational aspects of the classroom, including resource preparation and classroom management are their prime concerns (Barrett, Jones, Mooney, Thornton, Cady, Guinee & Olson, 2002; Huberman, 1993). Teachers needed to have taught tropical cyclones in Stage 5 Geography in the past and be teaching this case study as a component of focus area 5A1 (Investigating Australia's Physical Environment) in 2009.

Of the schools meeting these criteria and willing to participate in the study, 18 were selected from a range of school sectors – 5 from the state sector, 9 independent schools and 4 non-systemic Catholic schools. Eleven of the schools selected were single-sex environments, with 5 boys' and 6 girls' schools. Schools were carefully chosen to ensure a geographical spread across metropolitan Sydney. Sydney schools were targeted in this study to control for the likely effect of personal experiences on students' conceptual development (Driver et al., 1994). It was expected that students from Sydney schools would have had a relatively even exposure to tropical cyclones, primarily through popular culture (movies and TV programs), and possibly through media coverage of tropical Australia during southern hemisphere summer (Australia's cyclone season). These students were likely, however, to have had little direct personal experience of these weather events since Sydney is not subject to tropical cyclone activity.

When suitable schools and teachers for the study had been identified, participating teachers and principals were asked to nominate appropriate mixed-ability classes to be involved in the student questionnaire. Consent forms were distributed seeking participation in both the questionnaire and follow-up interviews. These forms were returned by a total of 380 students and 17 teachers (one teacher agreed to allow access to her Year 9 class for the collection of data but declined to be involved in the project herself). A second teacher withdrew from the study after completing the Phase 2 interview. The responses of this teacher to the questionnaire and drawing task were retained, however, only the 16 complete data sets were used to build the rich case studies (see Chapter 6). The individual teachers are identified in this thesis using a combination of numbers and pseudonyms.

From the 380 students who attempted the Phase 1 questionnaire, 339 responses were included in the final data analysis. Decisions were made to exclude 41 of these responses, 30 because of incomplete information and a further 11 because of the likelihood that the data were unreliable. These students either failed to follow the verbal and written instructions provided to them or presented non-serious responses to the questions (e.g. drawings, or comments about their teacher). The composition of the final student sample is summarised in Appendix 6.

3.6.5 Procedure for administering the questionnaire

The questionnaire was administered in class groups during scheduled Geography lessons. Students were reminded at the start of each lesson that the research aimed to identify their personal views about tropical cyclones, that their identities would not be disclosed and that the task did not form a part of their formal classroom assessment.

Specific instructions for completing each part of the questionnaire were provided and classes were guided through a practice response. The questionnaire instructions required students to:

1. rate each item as true or false;
2. explain their response in the space provided; and
3. place a cross along a scale to indicate how sure/unsure they were of their answer.

The confidence scale data was used to differentiate between students who had firmly held beliefs about individual statements and those who were less certain (and might have guessed). The questionnaire was completed under "examination" conditions in approximately one hour and all responses were recorded on coded answer sheets to ensure confidentiality. During the administration of the questionnaire, the focus of individual students was monitored and responses were noted that might indicate a non-serious attempt at the task.

3.6.6 Overview of data analysis

The student data was analysed using descriptive statistics and t-tests to determine differences in confidence between students who answered items correctly and those who were incorrect. Items of low facility and high average confidence were identified, as these statements were more likely to represent strongly held alternative conceptions. Comments under each of the items were also used to assess the validity of individual statements and the reliability of students' true/false responses.

3.7 Step 2 – Building a rich account of the students' conceptions

Research question:

What are the common alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by Geography students?

The aim of Step 2 was to gain a more detailed account of the students' conceptions and to validate/triangulate the findings of the questionnaire (O'Donoghue & Punch, 2003). The method of converging operations (Brewer, 2008) was applied to ensure that the alternative conceptions identified were not merely an artefact of limited communication skills in one area e.g. providing verbal responses. Step 2 involved the use of a variety of methods, ranging from open questions, drawing tasks and visualisation/hypothetical activities through to more structured or closed approaches (e.g. structured interview questions). Given the need to identify the nature of participants' alternative conceptions, every attempt was made to minimise the use of scientific terminology and language that might prompt particular types of responses (i.e. lead the participants).

3.7.1 Tasks

Step 2 commenced with a drawing task in which students were asked to sketch a diagram of a tropical cyclone and use arrows and/or labels to show the causes of tropical cyclones and how they work (i.e. their processes). Dove (1999) outlines the benefits and limitations of using drawing tasks for the diagnosis of alternative conceptions (especially in students). Dove (1999 citing White and Gunstone, 1992) argues that, among other advantages, the use of drawing tasks frees participants from "feeling constrained by trying to match their knowledge with that of the researcher" (p. 24). She also points out the dangers of researchers making inferences about the intended meanings of students' drawings. In the current study, to clarify ambiguities and avoid any potential misinterpretation of drawings, students were asked to describe how they would explain the causes and processes of a tropical cyclone to a classmate or younger sibling, using their diagram as stimulus. This activity was designed to prompt students to expand upon the meaning of their diagrams and provide a more nuanced account of their knowledge and beliefs.

In addition to the drawing tasks, a number of semi-structured interview questions and mapping tasks were included in the Step 2 interviews to explore specific findings of the questionnaire in greater detail. The results of the questionnaire indicated that more than 45% of the students provided incorrect responses to items related to the scientific principles underlying an understanding of tropical cyclone causes and processes (e.g. evaporation, air pressure, air temperature, mass and weight), the links between different types of natural hazards, the global heat budget, tropical cyclone location, movement and impacts. Several open-ended questions and mapping tasks were therefore included in the student interviews (Step 2) to elicit more detailed information regarding these beliefs.

The first question targeted the naive conception that "hurricanes", "typhoons" and "tropical cyclones" were different types of storms, caused by different processes. Students were asked to comment on whether they thought this statement was true or false and to elaborate on their views regarding the differences between these three "storm types". The second question focused on the alternative conception that tropical cyclones and tsunamis are somehow linked. The questionnaire results indicated that approximately half of the students surveyed believed that tropical cyclones could cause tsunamis. This result suggests a fundamental misunderstanding of the nature and causes of these natural hazards. For this reason a question was included in the student interviews (Step 2) to explore these beliefs further. Students were asked to comment on whether they thought that tropical cyclones could cause tsunamis and, if so, to draw a diagram showing how this might happen.

The findings of the questionnaire also indicated that students held a range of alternative conceptions regarding the distribution of the Earths' heat by latitude (the global energy budget) and its impact on the global pattern of tropical cyclone activity. A mapping task was included in the student interviews (Step 2) to explore these beliefs in greater detail. Students were asked to explain which parts of the world they thought were the hottest and to shade these areas on a world map. After completing this task students were asked why they thought these areas of the world were hotter than other areas and how they knew this was the case. The ability of students to apply their knowledge of differences in net radiation across the earth's surface to account for the location and movement of tropical cyclones was assessed in a second mapping task. This task required students to explain where in the world they would expect to find tropical cyclones and to shade these areas on a world map. In a follow-up question, students were asked to explain why they would expect to find tropical cyclones in these locations.
A visualisation activity similar to the approach adopted by Mant and Summers (1993) was also used to provide additional information regarding the students' conceptions (and to enable triangulation with the drawing task and questionnaire data). Participants were asked to imagine that they were at the beach with their family on holidays when a tropical cyclone crossed the coast. With this image in mind, participants were asked to describe what they would see and feel, what the underlying causes of the cyclone might be, how long the event would last and the likely impact of the tropical cyclone on human activities and the built and biophysical environment.

In the final stimulus-response task students were provided with a satellite image of tropical cyclone Larry off the coast of Queensland in 2006. They were asked to identify the feature on the satellite image, to explain what was happening in this location and to describe the likely causes of this activity. Probing questions were used where necessary to extract further detail regarding the participants' ideas and explanations. By combining the above measures of students' conceptions, the researcher was able to determine whether students were applying their mental models of tropical cyclones consistently in response to different forms of questioning. A copy of the detailed interview protocol and task instructions for Phase 1 Step 2 is provided in Appendix 7.

3.7.2 Sample for the student interviews

A total of 18 students from seven schools were selected for Step 2 of the data collection (two state, two independent and three non-systemic Catholic schools). Participants were selected from the total pool of students who provided error responses to more than one third of the items in the Phase 1 questionnaire (including items based on alternative conceptions). The sample was representative of students studying in a variety of school sectors and a range of locations across the Sydney Metropolitan area. The average questionnaire score of the students selected for Step 2 of the data collection was 24/40. Based on their questionnaire responses, it was hypothesised that these students were likely to hold alternative conceptions of the causes, patterns, processes and impacts of tropical cyclones.

3.7.3 Procedure

The tasks in Step 2 were completed during individual interviews organised to coincide with scheduled Geography lessons. Interviews were held in locations adjacent to regular classrooms so that participants could be withdrawn and returned to their classes with minimum disruption.

A script or interview protocol was used to ensure consistency in the delivery of instructions to each participant and a journal was kept of the participants' actions and responses. At the start of each interview students were reminded that their responses would remain confidential and that the data did not form a part of their school assessment. It was also emphasised that the researcher was interested in exploring the nature of their existing ideas. The instructions for the tasks were explained to each student, who was given the opportunity to ask questions before responding. Each interview was videotaped and lasted approximately 30 minutes.

3.7.4 Overview of data analysis

The student drawings, mapping tasks and semi-structured interview responses were coded for evidence of alternative conceptions. The beliefs and conceptions expressed in the student interviews (Step 2) were then compared with those identified in the structured questionnaire (triangulation). Conceptions and beliefs were deemed to be stable rather than generated impulsively if they were used consistently in students' explanations and answers on more than one occasion, for example, through their written explanations, drawings and semi-structured interview responses.

3.8 Phase 2 – Teacher data collection

3.8.1 Steps 1 and 2 – Assessing teachers' content knowledge, conceptual understanding and PCK of students' ideas

Research questions:

To what extent are experienced Geography teachers aware of common alternative conceptions held by students (i.e. What is their PCK of student's ideas)?

What are the common alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by experienced teachers of secondary school Geography?

What is the depth of understanding of experienced Geography teachers in this topic area?

3.8.2 Rationale and interview procedure

The aim of Steps 1-2 was to explore the conceptual knowledge and depth of understanding of the 16 experienced teachers together with their awareness of students' common alternative conceptions (PCK of students' ideas). To collect this data, interviews were conducted with each of the teachers. In contrast to the procedure for the students, where the questionnaire was used as a screening for the interviews (administered at a different time), the procedure for the teachers involved the collection of all data in a single interview.

The interviews with teachers were administered individually and held at a time and in a location convenient for each participant. The interviews were videotaped and lasted approximately one hour. The procedure for the interviews was as follows:

1. Background data was collected about all participants including their undergraduate studies and teaching experience in Geography. This data enabled the researcher to confirm that each teacher met the sampling criteria.

2. Existing practice was explored by asking participants to provide a plan with supporting resources to explain the teacher and student activities used when they last taught tropical cyclone causes, patterns, processes and impacts. Teachers were asked to bring relevant resources with them to the interview.
3. Drawing tasks and semi-structured interview questions were then used to develop a detailed image of the teachers' mental models. In contrast to the instructions for the student drawing task, the teachers were given a choice of either thinking aloud as they constructed their diagram or explaining their diagram to the researcher when it was completed.
4. After completing the drawing task teachers were asked to consider the level of understanding they would expect from a Year 10 student with a thorough knowledge of the nature of tropical cyclones, their causes, spatial distribution and impacts. In this section of the interview each teacher was asked to provide an example of the type of explanation they would expect from a student to indicate a thorough understanding of the following: What is a tropical cyclone? What kinds of impacts do they have? Where do they form? How do they form?
5. To assess the teachers' PCK of students' ideas, a question was included in the semi-structured interview asking each participant to "identify any incorrect ideas about tropical cyclones or the scientific processes underlying tropical cyclone causes and processes that you would expect students to hold prior to studying natural hazards in Stage 5 Geography."
6. The final component of the interview involved the completion of the structured questionnaire described in Section 3.6.2. As noted earlier, the teachers responded to the same 40 statements as the students. The key difference was that items were randomly organised rather than ordered into themes (see Appendix 5B). A think-aloud protocol was also used to maintain the flow of the interviews and to provide opportunities for the teachers to present rich explanations for their beliefs. In each of the video recorded interviews the teachers were asked to:

    1. read each statement aloud;
    2. rate the item as either true or false;
    3. place a cross along a scale to indicate how sure/unsure they were of their answer; and
    4. explain their reasoning before proceeding to the next statement.

The questionnaire was included as the last item in the interview to ensure that content from the true/false items did not influence teachers' responses to either the drawing task or semi-structured interview questions. A copy of the detailed interview protocol and task instructions for Phase 2 is provided in Appendix 8.

3.8.3 Steps 3 to 5: Teachers' use of the data to inform their practice

Research question:

How do teachers use their existing knowledge of students' conceptions (PCK of students' ideas) and data provided by the researcher to inform their practice?

Overview

A central aim of Phase 2 was to investigate the way in which Geography teachers used their PCK of students' ideas to inform their planning and classroom practice. The researcher was also interested in exploring the impact of providing teachers with information that might help to support their PCK of students' ideas. Steps 3-5 of Phase 2 focused on the collection of this data.

Procedure

Step 3 – Providing teachers with the Phase 1 student data.

A summary of the findings of the Phase 1 student questionnaire was sent to each of the 17 teachers 3 weeks prior to their scheduled lesson (see Appendix 9). The teachers were not instructed on how to use this information. The data were provided to ensure that each teacher had equal access to information regarding common student preconceptions that could be used to inform their lesson planning/preparation.

Step 4 – Lesson observations and video recording.

The 16 experienced Geography teachers who remained in the study were observed and videotaped teaching the targeted content to their new cohort of Year 9/10 students in 2009.

Step 5 – Video-stimulated recall (VSR) sessions.

Preparation

Each lesson recorded in Step 4 was imported into video coding software (Studiocode). This software was used to mark out the key transitions between the individual activities in each lesson sequence. For each phase of the lesson, a 10-20-second segment was then tagged so that it could be played back to the participant during the interview. On average, 15-20 individual segments were tagged for each of the lessons. The classroom videos, together with the resources collected from each lesson (e.g. worksheets and samples of student work), were then used as the basis for stimulus–response interviews with each of the teachers.

Procedure

Following the advice of Lyle (2003), the procedure for the VSR sessions was designed to reduce participant anxiety, limit the perception of judgmental probing, reduce intrusion into the teachers' explanations, make the retrospection as immediate as possible, allow the teachers a relatively unstructured response, and employ an "indirect" route to the focus of the research. Individual VSR interviews were conducted as follows:

1. At the start of each interview, participants were informed that they would be watching extracts from the video of their lesson and then discussing their goals and teaching approach with the researcher.
2. The teachers were given a demonstration of how to stop, pause and play video segments and were encouraged to pause the video at any stage if they wanted to make a comment or observation.
3. As suggested by Lyle (2003), Morgan (2007) and Reitano (2006), participating teachers were given time to familiarise themselves with the technology and adjust to the inevitable self-consciousness of watching themselves on video before each interview commenced.
4. Participants then directed themselves through the video segments, stopping to describe their aims and the teaching approaches used. Probing questions were asked at various stages throughout the interviews to redirect the participants or to clarify the meaning of responses. Examples of student work and resources developed for the lesson were also used to stimulate discussion.

Semi-structured interview questions

A series of semi-structured questions was also asked at the end of the VSR interviews to explore the teachers' beliefs about assessment, their views of the student data provided and use of this knowledge to inform instruction. Each teacher was asked: What happened with students' work from the lesson once it had been completed? Did you check/collect student class work and homework? If so, what were you looking for and what kind of feedback (if any) was provided? Participants were also asked if they felt that they had achieved their desired goals during the videotaped lesson and to explain why they had or had not met these aims.

Questions were also asked to explore the teachers' views about the data provided and to assess the extent to which this information had influenced their planning and classroom practice. These questions included the following:

1. What did you think of the information sheet on students' ideas that I gave you? What have you encountered in your class? How typical do you think these ideas are? What is your class like in terms of these beliefs?
2. Overall, did you find the information useful?
3. Was the information at all surprising? Was there anything new?
4. If you found this information useful, how did you use it? Did you use this information in your lesson design? Did it make you change your approach? If so, how? If you did not use it, why not?
5. Did the information prompt you to revise your understanding of tropical cyclones? How did you do this?

3.8.4 Overview of data analysis

Teachers' questionnaire, drawing tasks and interview responses

The teacher and student data from the questionnaire were analysed separately. Given the small number of teachers in the sample (n=16) regression analysis was not undertaken. Analysis of the teachers' responses involved the generation of descriptive statistics regarding items causing the least/most difficulty, average confidence scores, etc. This data is presented in the Phase 2 results (Section 5.1.2) where it is used as one measure of the teachers' general content knowledge.

The teachers' drawing tasks and interview responses were subject to content analysis and the grouping of ideas into levels of understanding (Dove, 1999). Consistent with the approach adopted by Tytler (1994) a framework based on the SOLO taxonomy (see Section 5.1.1) was used to categorise the structure and complexity of each of the teachers' responses to the drawing task and semi-structured interview questions. Evidence of alternative conceptions was also coded on the video recordings, interview transcripts and teacher drawings. Teachers' PCK of students' ideas and their beliefs about learning and teaching were analysed using a separate taxonomy developed by the researcher. A detailed description of the data analysis process is provided in Chapter 5.

Analysis of the VSR data

The literature draws a distinction between "emergent" and "a priori" coding procedures (Haney, Russell, Gulek & Fierros, 1998). The current study used a combination of these approaches to identify the range of justifications provided by the teachers for the instructional approaches adopted. The initial a priori categories were derived from the literature and included references made by the teachers to students' existing ideas, beliefs and conceptions as well as strategies identified by the teacher as being designed to either diagnose or address alternative conceptions. Emergent themes were also identified as the VSR interviews were analysed. A combination of the a priori and emergent themes was then used to develop a coding protocol (see Appendix 10).

3.8.5 Conclusion

This study employed a mixed method approach to investigate experienced Geography teachers' PCK of students' ideas and the use of this knowledge to inform instruction. The two phases of the study involved the collection of data regarding:

- both the teachers' and students' alternative conceptions and depth of understanding of tropical cyclone causes, patterns, processes and impacts;
- the teachers' current practice for teaching natural hazards, their epistemological beliefs about learning and teaching, and awareness of common student preconceptions; and
- the teachers' use of data about common student preconceptions to inform instruction.

A variety of methods was used to collect this data, ranging from open questions, drawing tasks, visualisation/hypothetical activities and VSR interviews through to more structured or closed approaches (e.g. questionnaires and structured interview questions). The following chapter reports the student data.

Chapter 4 - Results/Discussion: Student Data

4.1 Overview

Results, discussion and methods of data analysis for this study are reported in three chapters. The student data (Phase 1) is reported and discussed in this chapter and the teacher data (Phase 2) in Chapters 5 and 6. Common headings are used where possible to enable comparisons between the teachers' and students' ideas.

The student results reported in this chapter are presented in two parts aligning with the two research steps in Phase 1 (see Section 3.3). The first section (Step 1) presents the method of analysis and findings of the student questionnaire. This section aims to provide a holistic overview of the distribution of specific preconceptions (identified by experts and the literature) across a large sample of students (n=339). The second section presents the method of data analysis and findings for Step 2. This section focuses on providing a rich account of the students' conceptions by triangulating the results from the student questionnaire, drawing task, visualisation activity and stimulus-response task. The chapter concludes with a discussion of the results, the implications for student learning and the knowledge requirements of Geography teachers.

4.2 Step 1 – Gaining a holistic overview of the distribution of specific preconceptions across a sample population of Geography students

Research question:

What are the common alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by Year 9/10 Geography students?

4.2.1 Data analysis

The final data set comprised responses from 339 students across the 18 schools, after a small number of incomplete responses (2-4 from each class) was removed prior to analysis. The data were analysed to identify items of low facility and high average confidence, as these statements were more likely to represent strongly held alternative conceptions. Descriptive statistics were generated from the questionnaire responses, and the items answered incorrectly by more than a third of the students were then sorted by confidence.

For each item, the mean confidence scores for correct and incorrect responses were compared using t-tests. Analysis was based on the argument that students holding a conception or coherent mental model will be confident in their response to related questionnaire items. This leads to the hypothesis that students holding alternative conceptions (i.e. those indicating that items representing alternative conceptions were true) will be at least as confident as those providing correct responses. We would expect to see no significant (NS) differences between the average confidence scores for correct and incorrect responses. A significance level of 0.05 was used.

The written comments under each statement were coded and categorised to identify recurring themes in the students' responses. Comments were also used to assess the validity of individual statements and the reliability of students' true/false responses.

4.2.2 Students' conceptions

The questionnaire results demonstrated a range of performance across the student sample, with individual scores varying from 15/40 to 36/40 (average = 24/40). The full range of confidence scores was also used by the students (0 to 100 on a 100 point scale) with a distinct clustering of scores between 50 and 60.

When we examine performance across individual items similar patterns of variability can be seen. The questionnaire items ranged in difficulty from those answered correctly by 92% of the students (high facility) to those answered correctly by only 8% of the sample (low facility).

The data suggest that a number of *deep-seated alternative conceptions* (items of low facility with high average confidence) were widely held by the students (see Table 4-1 below). Three of these items related to students' beliefs regarding the causes of latitudinal temperature differences, evaporation, tsunamis and death/injury during tropical cyclone events. An additional four items related to students' views about the weight of air, the perceived differences between tropical cyclones, hurricanes and typhoons, and temperature conditions during a tropical cyclone. The remaining beliefs identified in Table 4-1 relate to students' conceptions of air pressure (items 8 and 9). Although the average confidence levels on these items were lower, the pattern of confidence is consistent with the other items in the table. For all of the items in Table 4-1, students answering incorrectly were either as confident (items 1,2,4,6,7) or more confident (items 3, 5, 8 and 9) than those answering correctly.

Table 4-1 Common, firmly held alternative conceptions

Statement	**Incorrect (% of students)**	**Confidence correct**	**Confidence incorrect**	**Mean confidence**	**P values for confidence difference (correct vs. incorrect)**
1. The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.	58			73	NS (0.524)
2. Air is weightless.	37			69	NS (0.330)
3. The terms "hurricane", "typhoon" and "tropical cyclone" describe different types of storms that occur around the world.	73	62	70	68	0.014 Incorrect> Correct
4. When water evaporates from the ocean it is a boiling process.	44			63	NS (0.506)
5. Most deaths and injuries in severe tropical storms worldwide are due to objects flying in the air or structures collapsing.	83	45	65	61	<0.001 Incorrect> Correct
6. Tsunamis can be caused by tropical cyclones.	45	62	56	59	NS (0.067)
7. The weather is generally cold during a cyclone.	45			57	NS (0.220)

8. Cold air applies a lower pressure on the ground than the same volume of warm air.	55	34	42	38	0.023 Incorrect> Correct
9. Air pressure directly above a body of water increases as the temperature of the water increases.	59	29	42	37	<0.001 Incorrect> Correct

The lower average confidence scores on items related to air pressure can be explained by the interview responses (Step 2) where several of the students expressed the view that air was weightless and that stationary air could not exert pressure. Given these beliefs, students found items in the questionnaire related to air temperature, pressure and movement confusing and counter-intuitive. One response to this confusion was for students to provide low confidence ratings for these items regardless of whether they got them correct or incorrect. Nevertheless, those students who were incorrect remained more confident than those who answered correctly.

It should be noted that many of the students who demonstrated an awareness of the concept of "weighted air" during the interviews (Step 2, discussed below) also held alternative conceptions about air pressure and its causes. These conceptions included the belief that high temperatures were linked to high-pressure systems and strong winds: *"warm air exerts more pressure and creates strong winds because it is hot"*, and that cold temperatures produce low-pressure cells: *"low-pressure systems only have cold air."*

The remaining items answered incorrectly by more than 1/3 of the participants addressed students' factual knowledge of tropical cyclones (see Table 4-2). The average confidence scores for these items were low (40) compared with the average confidence across all items (54). For three of the statements there were no significant differences in the average confidence scores of students providing correct and incorrect responses. Where significant differences were found (items 1 and 4), those answering correctly were more confident than those answering incorrectly. This, combined with the low average confidence scores on these items, indicates that the participants were aware of the factual knowledge that they did and did not know or understand.

Table 4-2 Factual items

Statement	Incorrect (% of students)	Confidence correct	Confidence incorrect	Mean confidence	P values for confidence (correct vs. incorrect)
1. Tropical cyclones in Australia can move in any direction including sharp turns or loops.	39	46	38	43	0.021
2. Tropical cyclones do not affect either long or short-term sea levels.	37			41	NS (0.850)
3. The term "storm surge" refers to a sudden burst in storm activity which creates problems in the supply of electricity.	70			41	NS (0.420)
4. Australia's cyclone season occurs between June and September.	42	44	33	40	0.003 Correct>Incorrect
5. Tropical cyclones rotate in an anticlockwise direction in the Southern Hemisphere.	58			37	NS (0.848)

The questionnaire results in Table 4-2 indicate that there appeared to be a set of strongly held beliefs about tropical cyclone causes, patterns and processes that fitted the characteristics of alternative conceptions. A range of qualitative techniques were employed in Step 2 of Phase 1 to explore these ideas in greater detail.

4.3 Step 2 – Building a rich account of the students' conceptions

4.3.1 Data analysis

To build rich accounts of the students' conceptions, content analysis of 18 students' drawings, interview transcripts and written responses was undertaken. Student responses were coded and patterns of alternative conceptions identified and recorded. Conceptions and beliefs were considered stable if they were used consistently in students' explanations on more than one occasion, for example through their questionnaire responses, written explanations, drawings and answers to semi-structured interview questions (Vosniadou et al., 2008).

4.3.2 Results

Students used a range of alternative conceptions in their explanations of the causes and processes of tropical cyclones, their spatial distribution and impacts. Analysis of the drawings and interview transcripts revealed two main groups of ideas. The first group included students' conceptions of the foundational scientific concepts underpinning an understanding of tropical cyclones: evaporation, reasons for latitudinal temperature differences, and the nature of air and causes of wind. The second group comprised three categories of beliefs related to the distinctively geographical concepts of scale (for example, tropical cyclones are *"spirals of air about the size of my school"*), location (for example, *"only America experiences cyclones"*), biophysical interactions (for example, *"cyclones create tsunamis or are caused by earthquakes"*) and relationships between natural processes and human activities (*"the main cause of death and injury is the wind"; "storm surge has little impact on coastal communities"*).

Conceptions of underlying scientific processes and principles

(1) Evaporation

Although the students were generally aware of the importance of evaporation in the formation of tropical cyclones, they also held a number of alternative conceptions about this process. These conceptions included the belief that water needed to boil for evaporation to take place *("The water is boiled by the sun causing evaporation . . . water only evaporates when it is boiling")*. This is consistent with the findings of the questionnaire, in which 43% of respondents indicated that water evaporating from the ocean was a "boiling process". A number of the students interviewed also held the related conception that clouds were made of water vapour or steam rather than tiny water droplets and/or ice crystals *("the white stuff we can see in clouds is steam and dirt")*. One source of this belief may be students' literal interpretations of models and analogies such as the "boiling kettle", commonly used in classroom instruction. When explaining their drawings of tropical cyclones a number of the students also suggested that atoms and molecules could expand, change shape or disappear during the process of evaporation *("Atoms expand when heated . . . they float away and get trapped in clouds")*. The belief that water could be lost or destroyed in the water cycle was also widely held among the students, as the following interview extracts demonstrate: *"Some water is lost to pollution"; "Humans and animals interfere and remove water from the water cycle"; "Clouds hold huge quantities of water that is never returned to the Earth's surface."* An inability to see the water cycle as a closed system and to conserve matter during phase changes also created other difficulties for students in their explanations of weather conditions in a tropical cyclone. Having argued that water "disappears" during evaporation, many of the students struggled to account for the sources of water in precipitation.

(2) Reasons for latitudinal temperature differences

As a component of the student interviews (Step 2) participants were asked to shade on a map of the world the parts of the Earth they believed were the hottest and to provide an explanation. In their responses students demonstrated an awareness that the tropics were the hottest area of the Earth's surface however their explanations included a range of alternative conceptions: *"the Earth is heated unevenly because there is boiling liquid underground"*; *"magma close to the edge makes the equator hot"*; *"the tropics are closer to the core of the Earth."* The vast majority of the explanations involved proximity-based understandings of heat, the belief that coming closer to a source of heat will make you hotter. Students with this conception held the view that the equator was "closer to the sun" and therefore hotter than the poles: *"places on the equator like India and South America are closer to the sun so the sun will hit them harder"*. Many of the students interviewed also held the related conception that air temperature increases with altitude in the troposphere "as you get closer to the sun's heat".

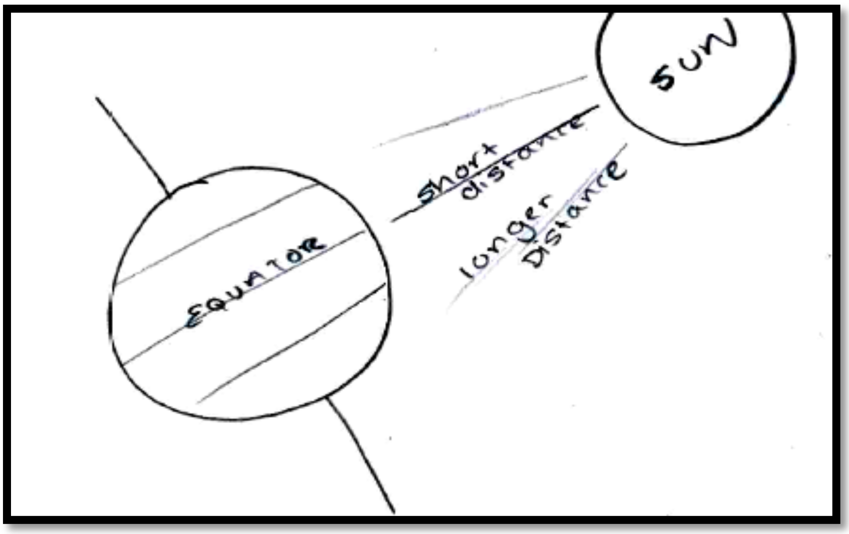


Figure 4.1 *The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun*

(3) The nature of air and causes of wind

The interview responses (Step 2) indicated that students held a range of beliefs regarding the causes of the wind. Students' nominated several possible causes, including the Earth's magnetic field, the rotation of the Earth, cold temperatures, and "retaliation" of the climate in response to rising water temperatures (see Figure 4.2 below). The quotes below highlight the diverse beliefs held by these students: *"Winds are caused by magnetic pulls and different pressures mixing"; "When weather is cold it is usually windy. The cold causes the wind"; "Cyclones need cold weather to form"; "Cold temperatures cause less pressure which causes more violent winds"; "Winds are caused by rising cold air or sinking hot air"; "Winds are caused by the Earth's movement".*

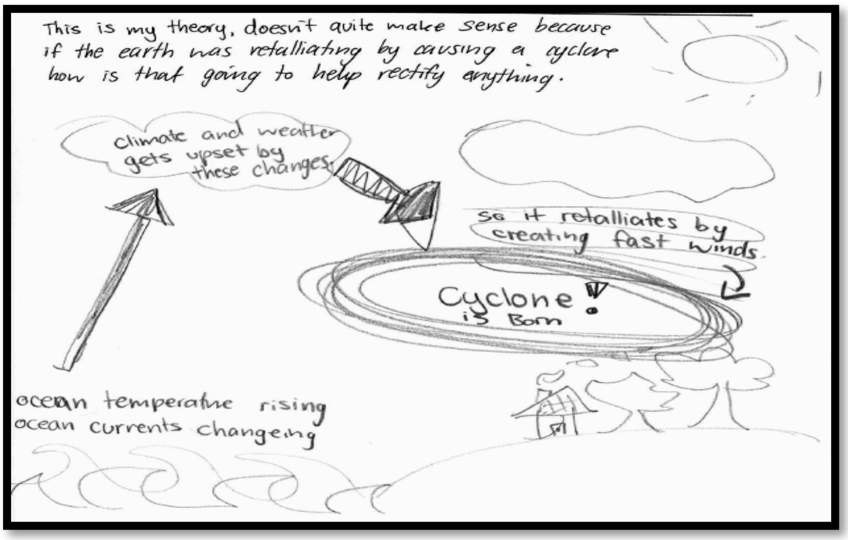


Figure 4.2 The ocean temperature rises and the earth "retaliates" causing strong winds

When asked specifically about the causes of wind in tropical cyclones many of the students referred to colliding warm and cold air and pressure systems "grating together". As one student noted during the visualisation task: *"tropical cyclones are formed when really hot, sunny weather and really stormy weather collide, the circling creates a storm."*

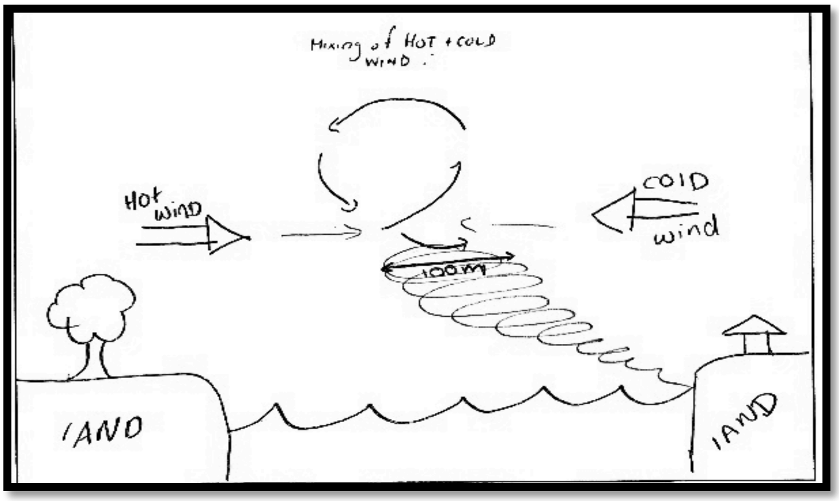


Figure 4.3 *Tropical cyclones are caused by the "collision" of hot and cold air*

The students' beliefs about the nature of air were a key factor limiting their ability to accurately account for the causes of wind in tropical cyclones. Consistent with the research in Science education, the majority of the participants in this study held sensory-based conceptions of "felt weight". They believed that air was weightless, did not have mass and exerted pressure only when moving. The following quotes from the student interviews illustrate these beliefs: *"When I grab it [air] I feel nothing"; "You cannot catch air, it does not have mass"; "It isn't heavy on my shoulders"; "if air had mass it would be too heavy for us to walk . . . we would find it difficult to breathe"; "Air is a gas and gases are weightless."*

The conceptions revealed in the data from Step 2 are consistent with the findings of the questionnaire (see Table 4-3).

Table 4-3 Questionnaire items related to underlying processes and principles

Statement	**Incorrect (% of students)**	**Confidence correct**	**Confidence incorrect**	**Mean confidence**	**P values for confidence (correct vs. incorrect)**
1. The molecules that make up water expand and float away when heated by the sun's energy.	68	48	55	53	NS (0.057) Approaches significance
2. Only a small proportion of the water that evaporates ever returns to the Earth's surface as precipitation (rain, sleet, hail or snow).	30			59	NS (0.152)
3. When water evaporates from the ocean it is a boiling process.	44			63	NS (0.506)
4. The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.	58			73	NS (0.524)
5. Air is weightless.	37			69	NS (0.330)

6.	Cold temperatures are the main cause of strong winds.	39			51	NS (0.088)

A number of contradictions were also identified in the students' responses. One common example was the belief that air could be weightless while still having mass – *"I know air has particles however it does not weigh anything."* It is interesting to note that many of these students also made references to "air pressure" in their responses (a concept built on the assumption that air has mass). A second contradiction was identified in the responses of students who argued, *"high winds are associated with high pressure systems and hot conditions"* while also maintaining that *"cold temperatures are the main cause of strong winds."*

Conceptions of scale, location/spatial distribution and interactions

Other categories of alternative conceptions identified from the multiple data sources related to students' beliefs regarding the distinctively geographical concepts of scale, location/spatial distribution, biophysical interactions and consequences for human activity.

(1) Conceptions of scale

There was a common view among the students interviewed that cyclones were small or localised phenomena *"about the size of a classroom or school"* that had a limited lifespan measured in minutes or hours. The following annotation from one of the students' drawings summarises this view: *"large cyclones can be 2-6 times the size of the school and as high as an office building . . . they often hang around for an hour or two."* This conception appears to be related to students' beliefs regarding the differences between tropical cyclones and tornadoes. It should be noted that none of the 18 students revised their ideas about scale when shown a satellite image of a tropical cyclone over northern Australia with a diameter of more than 500km (see Appendix 7). These students appeared to be comfortable holding conflicting representations/mental models of the scale and dimensions of tropical cyclones.

(2) Spatial distribution and location

A common view that surfaced in many students' responses was the belief that Australia did not experience tropical cyclones or that they occurred very infrequently: *"Tropical cyclones are not found in Australia but America . . . I don't think this stuff really happens that much here."* When discussing the location of tropical cyclone activity the students made frequent reference to images of natural hazards from the United States that they had seen in TV programs, in the news media or in Hollywood movies: *"I am familiar with Cyclone (sic) alley in America"; "the big storm in New Orleans"*; *"guys in cars chasing cyclones in the movie Twister"* and *"cyclones destroying houses in Desperate Housewives, The Simpsons and The Wizard of Oz"*.

Again, the association of tropical cyclones with tornadoes appeared to have a strong impact on students' conceptions. During the student interviews (Step 2), participants commonly described cyclones as land-based hazards or *"tubes of spinning air"* that occur predominantly in the United States. This is consistent with the findings of the questionnaire where 42% of students agreed with the description of a tropical cyclone as "*a rotating column of air that is in contact with the ground*" (see Appendix 9).

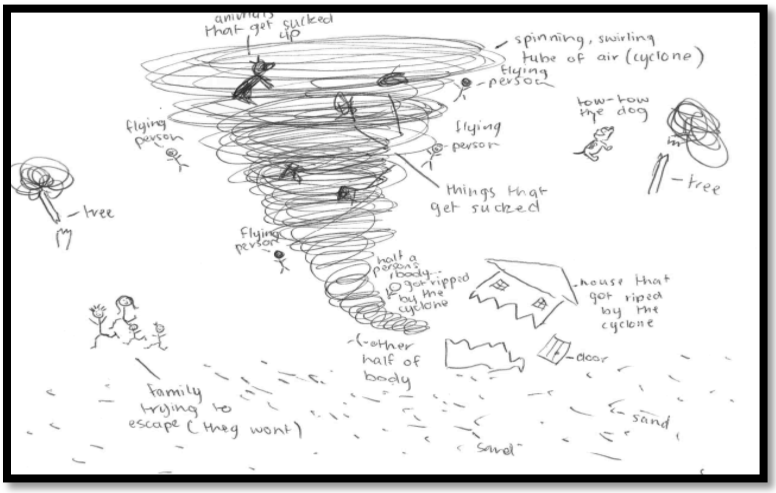


Figure 4.4 *"Tow Tow the dog" (sic) caught in a "cyclone" – students' linked conceptions of tornadoes and tropical cyclones*

(3) Biophysical interactions and consequences for human activity

The participants held a range of alternative conceptions regarding biophysical interactions and the consequences for human activity. Two categories of conceptions were identified, related to (1) links between different types of natural hazards (for example, tropical cyclones, earthquakes and tsunamis), and (2) the impact of tropical cyclones on the biophysical environment and human activity.

Students' alternative conceptions regarding the links between different types of natural hazards included the belief that tornadoes are synonymous with tropical cyclones and hurricanes; movements in the Earth's crust create tropical cyclones; and tropical cyclones are responsible for the formation of tsunamis and whirlpools in the ocean. The following interview excerpts, together with the drawing task response (Figure 4.5), demonstrate the multiple ways in which students linked the causes of different natural hazards: *"The cyclone creates a whirlpool effect in the water. This causes shock waves and ripples on the water. The whirlpool would be about half a kilometre across"; "Cyclones can create a ditch in the ocean [which] pushes water out and creates a tsunami wave."*

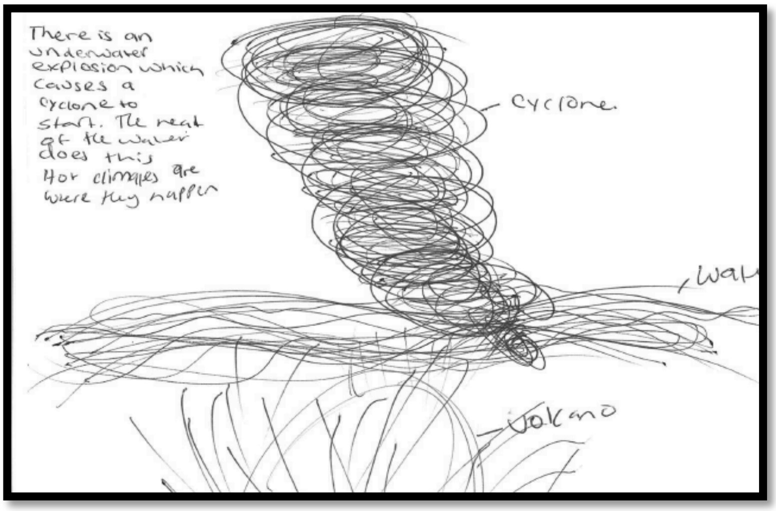


Figure 4.5 Student drawing task response – *"There was a chain reaction I once read about. A cyclone created an earthquake which set off a volcanic eruption and made a tsunami"*

As well as holding alternative conceptions about the causal links between natural hazards, many of the students believed that tropical cyclones, typhoons and hurricanes were different types of storms with contrasting processes and impacts. When asked to explain these differences students frequently responded that hurricanes were *"walls of wind"* rather than rotating weather systems and that hurricanes were more destructive than tropical cyclones – *"A hurricane is more dark and cloudy and stronger than a cyclone."*

The second category of alternative conceptions relevant to this theme related to students' beliefs about the impacts of tropical cyclones. The belief that tropical cyclones "suck-up" large objects and result in the "total destruction" of everything in their path was particularly prevalent among this sample of students (see Figure 4.6). The following extracts from the student interviews provide examples of these views: *"everyone is killed in a tropical cyclone"*; *"the cyclone sucks up water, cars, houses, cows and other objects and spits them out the top"*; *"the biggest thing that a cyclone could lift is the Sydney Harbour Bridge."* Many of the participants also believed that tropical cyclones either die out because of the friction of the land or increase in intensity as they move over the land. Several students provided detailed theories to explain these views – *"[tropical cyclones] fill-up like a vacuum cleaner, get clogged-up, turn dark and stop"*.

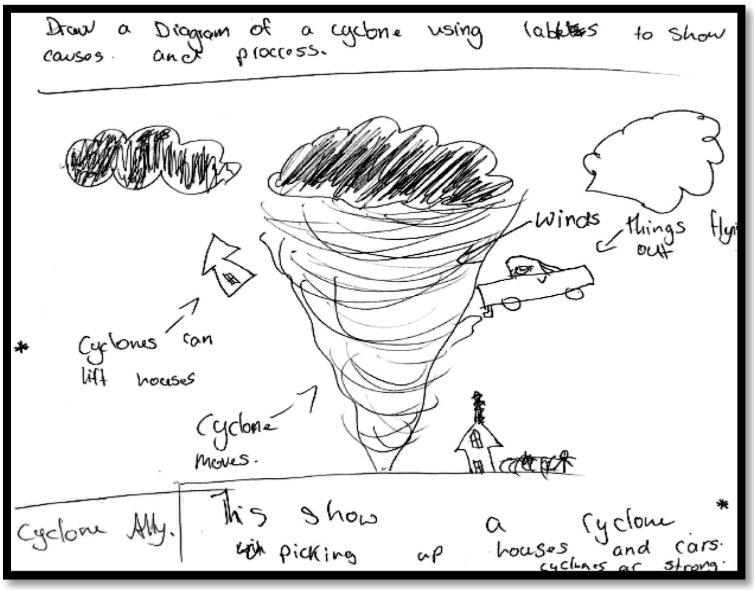


Figure 4.6 *In "Cyclone Alley" storms pick up houses and cars*

Consistent with the results of the questionnaire, many of the students also held alternative conceptions regarding the major causes of death and injury during tropical cyclones. This included the belief that objects flying in the air and structures collapsing were the major causes of mortality during tropical cyclone events on a global scale. It was also perceived by some students that air movement in a tropical cyclone creates a "vacuum" and that fatalities were either the result of *"a lack of oxygen"* or the *"freezing of the Earth's surface"* in the eye of the storm – *"the eye of the storm it is really cold, everything freezes like in the movie Day after Tomorrow."*

4.4 Discussion of the student data

A deep geographical knowledge of tropical cyclones relies on an understanding of both the underlying scientific processes of cyclone formation and the geographical concepts of scale, spatial distribution, interaction, and interdependence. Students with deep or "relational" understandings (see Section 5.1.1) should, for example, be able to use their knowledge of underlying scientific processes to *account for* the location and distribution of cyclone activity and *describe* the interactions (e.g. between biophysical processes and human activities) that take place during a tropical cyclone event. The above results suggest that many students struggled to demonstrate this level of understanding because they held alternative conceptions of both the geographical dimensions of tropical cyclones and the underlying scientific principles/processes.

The results obtained provide support for Brewers' (2008) argument that mixed methodological approaches with a strong reliance on structured interviews provide the most reliable diagnosis of students' conceptions. Although the questionnaire provided a reasonable indication of the distribution of alternative conceptions across the sample and clearly highlighted the most entrenched/firmly held naive beliefs, the semi-structured interviews were needed to accurately identify the alternative conceptions of individual participants and provide further meaning to these overall distributions.

The Phase 1 results suggest that students bring to their study of Geography a number of intuitive scientific beliefs that are inconsistent with current expert views. Many of the sources of these conceptions are consistent with those discussed in the conceptual change literature, including difficulty with counter-intuitive, abstract and intangible concepts such as air pressure (Sere, 1982; Tytler, 1998), the application of macroscopic properties to microscopic processes (Anderson, 1990; Johnston, 1998; Wiser & Smith, 2008), proximity-based understandings of heat (Russell et al., 1993), sensory-based conceptions of felt weight and matter (Bar, 1989; Ben-zvi-Assarf & Orion, 2005; Stepans, 1994) and the literal interpretation of models and analogies (Henriques, 2002; Philips, 1991). Additional sources of the students' beliefs were also identified, including over-generalisation and stereotyping (e.g. *"there are causal links between all natural hazards"* and all natural hazards are *"catastrophic")* and the strong influence of popular culture (see below).

Although many of the students' beliefs have been previously examined in the context of Science education (see Chapter 3), the Phase 1 results provide important evidence of the impact of these conceptions on the development of geographical understanding, including the ability of students to think holistically about weather phenomena. Intuitive beliefs regarding the conservation of matter ("water disappears during evaporation") and the nature of air ("air is weightless") make it difficult for students to develop a deep understanding of air pressure, cloud formation, the causes of wind, the seasons and the water cycle. Without an understanding of these concepts and processes, students cannot account for the development of tropical cyclones, their spatial distribution and impacts. The concept of storm surge (an increase in sea level associated with tropical cyclone activity) provides an example of the importance of understanding foundational principles and processes. Storm surge activity associated with tropical cyclones is a major cause of death and injury on a global scale. It represents an important interaction between natural processes and human activity and is commonly studied by students in Geography. Understanding of this concept, however, is dependent upon an awareness of air pressure and its impact on sea levels. The alternative conception of "weightless air" provides a significant barrier in this regard. Similarly, students will struggle to explain the spatial distribution of cyclone activity on a global scale without an understanding of seasonal differences in temperature and the impact on air pressure and movement. Alternative conceptions regarding the causes of the wind ("cold temperatures" and "moving objects") and the source of the Earth's heat ("heat comes from the Earth's core") make these understandings difficult to achieve.

The prevalence of these alternative conceptions also has implications for the preparedness and vulnerability of populations in cyclone prone areas. Each year around 340,000 Australians move interstate, including 80,000 school-aged students (Gillard, 2008). This includes students and adults moving from Australia's southern states into cyclone prone areas of the country. Individuals without an understanding of tropical cyclones may be at higher risk during a cyclone event. The beliefs that *"Australia does not experience tropical cyclones"* and that "*tropical cyclones do not affect either long or short term sea levels"* have particular implications for the vulnerability of populations. This is of particular concern if these ideas are found to persist into adulthood.

These results also demonstrate that students' beliefs regarding the geographical dimensions of tropical cyclones are strongly influenced by popular culture. This appears to be the case despite the availability of credible information from other sources including weather reports during cyclone season, the internet and classroom instruction. While there was a wealth of information available to the participants in this study, it was the information they chose to access and interact with that mattered. In the absence of personal experience, students overwhelmingly resorted to fictional or stereotyped representations as a foundation for their understanding of tropical cyclones. The key sources of their ideas included TV shows (Desperate Housewives, The Simpsons), Hollywood Movies (Twister, The Day After Tomorrow, Wizard of Oz) and computer games. This is consistent with the findings of Dal (2008) regarding the role of the media as a source of engagement for students. Although many of the participants had been exposed to information in the electronic news media, that coverage tended to focus on the sensational aspects of these events (the visual imagery, impacts and human stories) and did not support students in developing an understanding of tropical cyclone causes, patterns and processes.

A possible explanation for the dominance of popular culture in the students' responses relates to the difficulties they experienced with the underlying scientific concepts. To understand the geography of tropical cyclones (including their location, scale, spatial distribution and impacts) students need to apply knowledge of key scientific concepts within a geographical context. The results of this study indicate that in an *applied context*, students' underlying scientific conceptions were not sufficiently robust so they reverted to representations in popular culture as a basis for building understanding. The students' interview responses indicate that they often "enriched" rather than restructured these intuitive beliefs during instruction.

One important observation to make is that the sample did not include students who had personally experienced a tropical cyclone. Research indicates, however, that first-hand experience does not necessarily guarantee the development of accurate conceptions. Lee (1999) and Belknap (2003) found that students with personal experience of tropical cyclone activity often develop an adequate knowledge of impacts and management but fail to develop similar understandings of underlying causes and processes. It can be hypothesised, therefore, that the main influence of personal experience is a diminution of the power of popular culture in shaping students geographical understandings.

An important step in addressing the influence of popular culture is to employ evidence-based conceptual change approaches to improve students' level of understanding of underlying scientific processes and principles. These approaches include strategies designed to encourage extended substantive discussion and to stimulate conceptual conflict in Geography classrooms. The activities developed by the Thinking Through Geography Group (Leat, 2001), for example, encourage students to articulate their beliefs about core geographical concepts and to identify potential inconsistencies in their views. Consistent with similar research in Mathematics and Science Education (see e.g., Greca & Moreira, 2000), the findings of the current study suggest that students often hold multiple conflicting conceptions of phenomena. The processes of discussion and debriefing can assist students to resolve these inconsistencies and to develop greater depth of understanding (van der Schee, Leat & Vankan, 2006).

A focus on building media literacy skills may also assist students to become more selective and critical consumers of popular culture (Luke, 1999). Together with an understanding of the underlying science, the development of critical literacy skills can help students to question the accuracy of the events depicted in movies, TV programs and video games. An awareness of the multiple purposes of "texts" can also help students to decipher scientific fact from entertainment.

These findings have significant implications for the knowledge requirements of Geography teachers. A crucial step in the development of pedagogy for improving geographical understanding is to ensure that teachers of Geography are adequately equipped in terms of both their domain-specific knowledge and PCK. Effective teachers of Geography require sound knowledge of the scientific principles that underpin key concepts in the curriculum, awareness of the common alternative conceptions students hold in these areas and knowledge of evidence-based approaches for promoting conceptual change.

The research on PCK indicates that knowledge of students' common preconceptions is essential if teachers are to promote deep understanding. As Reinfried (2006a, p. 42) argues: "the diagnosis of students' often incorrect preconceptions and mental models may be seen as a crucial initial step in the process of teacher-facilitated mental model-building at all grade level". This chapter identified these common categories of student beliefs; the next chapter explores the content knowledge of Geography teachers, their awareness of students' common alternative conceptions and their use of this knowledge to inform instruction.

Chapter 5 - Results/Discussion: Teacher Data

Phase 2 consisted of five steps (see Section 3.3) which aimed to examine teachers' conceptions and depth of knowledge of tropical cyclone causes, patterns and processes; their PCK of students' ideas; and their use of this knowledge to inform instruction. To collect this data a range of methods were used, including a structured questionnaire, semi-structured interview, drawing task, and VSR interview (see Section 3.8).

For the purpose of clarity, the results are organised into three sections. These sections include the presentation of data regarding the teachers':

1. mental models and alternative conceptions of tropical cyclone causes, patterns and processes;
2. depth of understanding of tropical cyclone causes, patterns and processes; and
3. epistemological beliefs about learning and teaching and PCK of students' ideas.

5.1 Teachers' mental models and alternative conceptions of tropical cyclone causes, processes and impacts

Research questions:

What are the common alternative conceptions of tropical cyclone causes, patterns, processes and impacts held by experienced teachers of secondary school Geography?

What is the depth of understanding of experienced Geography teachers in this topic area?

5.1.1 Data analysis

The data analysis for the teacher questionnaire differed from the approach used with the students. Given the small size of the teacher sample (n=16), descriptive statistics were generated from the questionnaire results. This included the identification of items answered correctly by more than 14 out of 16 (88%) or incorrectly by more than four (25%) of the teachers, and the average confidence scores for each of these items. The teachers' drawings and interview responses were subjected to content analysis and coded for evidence of alternative conceptions. Appendix 11 provides examples of interview responses indicating possible alternative conceptions. The questionnaire, drawing task and semi-structured interview data was then triangulated to obtain a more nuanced and holistic image of the teachers' beliefs. Conceptions and beliefs were deemed to be stable rather than generated impulsively if they were used consistently in teachers' explanations across all three tasks.

The teachers' depth of understanding was determined using a classification protocol based on the SOLO taxonomy (Biggs & Collis, 1982). The SOLO taxonomy (Structure of the Observed Learning Outcome) describes changes in the way learners structure their oral and written responses as they develop understanding. According to Biggs and Collis, individuals develop the capacity to communicate in more complex ways as they learn. This involves both quantitative changes in the amount of detail provided as well as qualitative differences in the structural complexity and integration. Biggs and Collis developed a five-level taxonomy to describe this sequence of development in the "quality" of students' responses. Levels of complexity vary from "pre-structural" where individuals miss the point or simply rephrase the question, through to "relational" and "extended abstract" levels where learners are able to explain the links between key concepts (relational thinking) and conceptualise key ideas at a higher level of abstraction. Each additional level of the taxonomy (Table 5-1) subsumes and extends the levels below it.

Table 5-1 The SOLO taxonomy

SOLO Stage	**Features of learners' responses typical of each stage**
Pre-structural	Here learners are simply acquiring bits of unconnected information, which have no organisation and make no sense.
Uni-structural	Simple and obvious connections are made, but their significance is not grasped.
Multi-structural	A number of connections may be made, but the meta-connections between them are missed, as is their significance for the whole.
Relational	The learner is now able to appreciate the significance of the parts in relation to the whole.
Extended abstract	The learner is making connections not only within the given subject area, but also beyond it, able to generalise and transfer the principles and ideas underlying the specific instance.

The SOLO framework was operationalised in the current study through the development of a protocol for classifying the structural complexity and depth of teachers' responses (Table 5-2). Classification judgments were made on balance using evidence from multiple data sources including teachers' questionnaire responses, drawings and answers to the semi-structured interview questions.

Table 5-2 Protocol for classifying the structural complexity of teachers' responses

SOLO Stage	**Features of teachers' responses typical of each stage**
Pre-structural	Provides broad, non-specific or tautological responses. Misses the point and provides little evidence of relevant learning.
Uni-structural	Identifies or focuses on one concept relevant to tropical cyclone causes, processes and impacts. Deals with terminology but little more. Can memorise, identify, recognise, quote, recall or recite the details of one relevant concept.
Multi-structural	Describes or lists two or more concepts relevant to tropical cyclone causes, processes and impacts. Demonstrates a *quantitative* increase in knowledge from the uni-structural level. Focuses on "knowledge telling" rather than integrating ideas. Can describe, list, report, discuss, illustrate, select, narrate or outline the relevant facts and concepts.
Relational	Provides a cohesive, internally consistent explanation of tropical cyclone causes, processes and impacts. Demonstrates a *qualitative* difference in understanding over multi-structural responses. Integrates conceptual components by explaining the relationships between two or more concepts. Can apply knowledge in familiar contexts, integrate ideas, analyse causal factors and explain links.
Extended abstract	Demonstrates an ability to apply understanding of tropical cyclone causes and processes to new contexts – can generalise, theorise or hypothesise. Demonstrates creative and/or original thinking.

5.1.2 Results – teachers' conceptions

Although the questionnaire items were the same for the teachers as for the students, they were not organised by theme as in the student questionnaire. The task was therefore intrinsically more difficult for the teachers. Despite these differences, the teachers performed well in the questionnaire (79% average) and their average level of confidence across all items was high (76 on a 100-point scale). In their responses to the drawing task and interview questions the teachers used sophisticated reasoning and made frequent use of geographical terminology, analogies and examples to support their explanations (even if some of these analogies and examples were incorrect or had the potential to be misleading). As might be expected, the responses of the teachers were more detailed than those provided by the students (see Section 4.3) and the prevalence of alternative conceptions was, in most cases, lower.

Teachers' factual and conceptual knowledge

The teachers' grasp of the key ideas was generally sound, but some groups of concepts caused greater difficulty than others. Using the combined results of the questionnaire, drawing task and semi-structured interview, three categories of conceptual knowledge could be identified: concepts already understood by the teachers, concepts where understanding developed throughout the interview, and concepts that were less regularly understood and resistant to change. Each category is discussed in further detail below.

Concepts already understood by teachers

There were 17 questionnaire items (both factual and conceptual) that almost all the teachers (>88%) answered correctly (see Table 5-3).

Although the teachers' overall level of confidence for these 17 items was high (79 on a 100 point scale), the average confidence varied from 60 to 92. Notably, items addressing underlying scientific principles (air has mass), relationships (the link between air movement and pressure) and processes (the behaviour of molecules during evaporation) had the lowest confidence ratings (60-67).

Table 5-3 Questionnaire items answered correctly by more than 14 (88%) of the teachers

Statement	**T/F***	**% correct**	**Mean confidence (100 point scale)**
Cyclones increase in intensity when they move over land.	(F)	88	82
The earth is heated unevenly by the sun and this results in differences in air pressure at the surface.		88	80
Rain occurs when clouds are disturbed or shaken by the wind.	(F)	88	77
The term 'storm surge' refers to a sudden burst in storm activity which creates problems in the supply of electricity.	(F)	88	77
Air has mass.		88	63
Clouds are tiny water droplets suspended in the air.		94	88
Australia's cyclone season occurs between June and September.	(F)	94	84

Rain occurs when water droplets in clouds join together and become too heavy to remain suspended in the air.		94	79
Cold temperatures are the main cause of strong winds.	(F)	94	75
Rising air applies less pressure on the Earth's surface than falling air (of the same volume).		94	67
Water evaporates from the sea when heat from the sun causes high energy water molecules to escape.		94	60
Winds are caused by differences in air pressure across the earth's surface.		100	92
Tropical cyclones can form over land.	(F)	100	88
Rates of evaporation are higher from a cool body of water than a warm one.	(F)	100	85
When the conditions become calm after the initial gale force winds of a cyclone, the danger has passed.	(F)	100	85
Hurricanes, typhoons, tornados and tropical cyclones all contain warm rising air.		100	81
Tide levels can affect the impact that tropical cyclones have on coastal communities.		100	78
* Statements representing incorrect factual data or alternative conceptions are labelled (F).			

Concepts where understanding developed throughout the interview

For some of the key concepts, the accuracy of the teachers' responses developed throughout the interview as they responded to probing questions and reflected on their responses. Three examples of this are outlined below.

Weightless air

During the interviews, five of the teachers made the initial case that air was weightless and that stationary air did not exert pressure on the Earth's surface. As they worked through the questionnaire and discussed the likelihood that air had "mass", the teachers started to question their original ideas and rework their responses. As one participant commented, *"air must have weight if it has mass."*

The need for warm ocean water

Several of the teachers who originally argued that cyclones could form over the land became confused as they attempted to account for the build-up of clouds during a tropical cyclone event. Following extended discussion and probing by the researcher the teachers acknowledged that a source of moisture was required to "feed" the development of such a large storm system and that it was unlikely that this could occur over the land.

The erratic movement of tropical cyclones

Several of the teachers also developed more accurate understandings of the movement of tropical cyclones as they discussed their views with the researcher and reflected on their responses. At the commencement of the interviews a number of the teachers expressed the view that all tropical cyclones move from west to east in the southern hemisphere and that their pathways are predictable: *"All tropical cyclones move in a predictable pattern from west to east"; "Tropical cyclones always move in the direction of an arc";* and *"Tropical cyclones always track in a predictable and linear fashion."*

This is in contrast to the cyclone tracking data provided by the Bureau of Meteorology, which indicates that tropical cyclones can move in any direction, including sharp turns and loops (Bureau of Meteorology, 2011b). As they reflected on their responses during the interview, several of the teachers recalled that they had seen maps tracking the movement of tropical cyclones in textbooks and were able to cite examples of tropical cyclones that followed erratic paths. The unpredictable course of Cyclone Tracey in 1974 was recalled by a number of the teachers during the interview process and this prompted them to adapt their beliefs.

Concepts that were less regularly understood and resistant to change

The items answered incorrectly by one quarter or more of the teachers are summarised in Table 5-4. When these results are viewed together with the drawing task and interview responses, two main categories of robust alternative conceptions can be identified. The teachers' beliefs in each of these areas were consistent across their questionnaire, drawing task and interview responses and were not adapted or modified as the interview progressed. These conceptions included beliefs related to the underlying scientific processes and principles of tropical cyclone formation such as evaporation, air pressure and reasons for latitudinal temperature differences; and tropical cyclone impacts and links with other natural hazards.

Table 5-4 Items answered incorrectly by four (25%) or more teachers

Statement	**T/F***	**Incorrect (% of teachers)**	**Mean confidence (100 point scale)**
The molecules that make up water expand and float away when heated by the sun's energy.	(F)	69	52
The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.	(F)	56	78
A tropical cyclone is a rotating column of air that is in contact with the ground.	(F)	50	70
The terms "hurricane", "typhoon" and "tropical cyclone" describe different types of storms that occur around the world.	(F)	44	84
Most deaths and injuries in severe tropical cyclones worldwide are due to rising sea levels.		44	77
Most deaths and injuries in severe tropical storms worldwide are due to objects flying in the air or structures collapsing.	(F)	44	70
Cold air applies a lower pressure on the ground than the same volume of warm air.	(F)	38	73
Air pressure directly above a body of water increases as the temperature of the water increases.	(F)	38	63
When water evaporates from the ocean it is a boiling process.	(F)	38	63
Tsunamis can be caused by tropical cyclones.	(F)	31	78
The eye or centre of a tropical cyclone is an area with light winds and frequently clear skies.		31	74
In a cyclone, wind gusts of 280km/h will cause twice-as-much damage to the built environment as wind gusts of 140km/h.	(F)	31	70
Tropical cyclones rotate in an anticlockwise direction in the Southern Hemisphere.	(F)	25	84
The weather is generally cold during a cyclone.	(F)	25	76
Tornadoes differ from tropical cyclones in that they are smaller and can form over land.		25	65

Tropical cyclones do not affect either long or short-term sea levels.	(F)	25	64
* Statements representing incorrect factual data or alternative conceptions are labelled (F).			

(1) Conceptions of underlying scientific processes and principles

Conceptions of evaporation

The most difficult item for the teachers related to the concept of evaporation and the behaviour of molecules in this process. Eleven of the 16 teachers (69%) expressed the belief that *molecules that make up water expand and float away when heated by the sun's energy*. The reasoning behind this belief was summarised by one teacher who explained, *"normally when you heat up something it expands. Molecules I expect are no different"*.

Confusion regarding the difference between boiling and evaporation was also evident in over one third (38%) of the teachers' responses. Several of these teachers used the terms "boiling" and "evaporation", "steam" and "water vapour" interchangeably.

The teachers with more developed understandings explained that evaporation occurs from oceans, lakes and rivers at water temperatures much lower than 100 degrees Celsius and that molecules increase in energy rather than expand when heated.

Reasons for latitudinal temperature differences

Proximity-based explanations for the seasons were also popular among the 16 teachers. Nine of the teachers interviewed (56%) indicated that the main reason for the tropics being hotter than the North and South Poles was their *closeness to the sun.* The average confidence scores for this item were also relatively high (78). Two of the teachers suggested that factors other than "angle of incidence" and "closeness to the sun" might be responsible for latitudinal differences in temperature:

> The earth is heated unevenly by the sun because there are trees and vegetation. The heat can't get through the foliage level and therefore the ground is heated unevenly.

Air pressure

Some teachers demonstrated well-developed understandings of air pressure and were able to explain effectively the links between air temperature, pressure and movement in the atmosphere:

> Warm, rising air creates regions of low pressure because the air is not pushing as much on the earth's surface [teacher demonstrates by moving her hands upwards in a circular motion]. As the air rises and cools, more air rushes in to replace it. This forms the wind. When you look at this on a weather map you see tightly spaced isobars, indicating the winds are relatively strong.

In contrast, over one third of the sample provided responses indicating that they held alternative conceptions related to air pressure. A particular area of confusion was the relationship between air temperature, pressure and movement in the atmosphere. An example of this is the belief that hot rising air forms regions of high pressure and that low-pressure systems are the result of "cold conditions". Four of the 16 teachers (25%) also held the view that weather conditions in a tropical cyclone were "generally cold".

These beliefs caused difficulties for teachers when they attempted to explain air movement in a tropical cyclone:

> Yes, cold temperatures are the main cause of strong winds because they are associated with low-pressure systems and low-pressure systems have stronger wind intensity because the isobars are closer together. The cold air in a tropical cyclone is the main cause of strong winds and rain.
>
> June to September is cyclone season in Australia because it is winter so there are cooler temperatures. Cool temperatures are associated with low-pressure systems and tropical cyclones.

In addition to the prevalence of particular alternative conceptions, these findings highlight the low level of confidence of the Geography teachers in their knowledge of the scientific processes and principles. The teachers' average confidence scores on items related to air pressure (69) and evaporation (65) were lower than the average scores for all items (76).

Similarly low levels of confidence regarding these scientific concepts were found in the student sample (see Chapter 4).

(2) Conceptions related to tropical cyclone impacts and links with other natural hazards

Links with other natural hazards

Almost half of the teachers (44%) shared the belief commonly held by students that tropical cyclones, typhoons and hurricanes were different types of storms with contrasting processes and impacts. Teachers with these views were also highly confident about their responses (average confidence = 84). The following quote is typical of the comments made by the teachers holding this belief: *"hurricanes and typhoons are strong winds not spinning storms like tropical cyclones."* One of the teachers also held the view that "tropical cyclones" are referred to as "hurricanes" when they "move onto land."

Half of the teachers in the sample also believed that tornadoes were synonymous with tropical cyclones, hurricanes and typhoons. This view was summarised by one teacher who described tropical cyclones as *"tubes of spinning air in contact with the ground."* It should be noted that all the teachers were aware that hurricanes, typhoons, tornadoes and tropical cyclones were driven by warm rising air.

In addition to the above conceptions, five of the teachers in the sample (31%) made causal links between tsunamis and tropical cyclones in their interview responses. In most cases this was a result of participants using the term "tsunami" to refer to *any* large wave in the ocean rather than one produced by an earthquake, submarine landslide, volcanic eruption, explosion or meteorite: *"If you classify tsunamis as large ocean waves then they can be caused by tropical cyclones"; "Cyclones can cause tsunamis. Especially if the wind is strong enough and the waves generated by the cyclone have enough of a path to travel across".*

Causes of death and injury

Many of the teachers interviewed held alternative conceptions regarding the main causes of death and injury in tropical cyclone events worldwide. Seven of the 16 teachers (44%) believed that deaths and injuries in severe tropical storms worldwide were primarily the result of *objects flying in the air or structures collapsing* and 25% of the sample maintained that *tropical cyclones do not affect either long or short term sea levels*. This is in contrast to the currently accepted view that drowning by storm surge accounts for the majority of deaths in tropical cyclone events worldwide (Bureau of Meteorology, 2011a). Four of the teachers held contradictory positions on this item and indicated that both *objects flying in the air* and *rising sea levels* were the main cause of death and injury in tropical cyclone events. Approximately a third of the teachers (31%) held the related belief that damage caused by a tropical cyclone was directly proportional to the wind strength (i.e. *wind gusts of 280km/h will cause twice-as-much damage to the built environment as wind gusts of 140km/h*).

Teachers' depth of understanding

The responses of the teachers ranged in both structural complexity and demonstrated depth of understanding (see Table 5.5 below). When assessed against the SOLO scale (Table 5-2), approximately half (9/16) of the participants provided responses that could be classified as relational. These teachers were able to identify the key processes involved in the formation of a tropical cyclone and explain the interrelationships between these factors (for example, the interaction between warm tropical waters, rising warm air and the processes of evaporation, air movement and condensation). This relational level of understanding was evident in both their spoken responses and drawings.

The teachers providing **multi-structural** responses were able to *explain* several of the key atmospheric processes in isolation, but there was little demonstrated understanding of the interrelationships between these ideas. The sample multi-structural response in Table 5.5, for example, includes references to water temperature, air pressure and strong winds but does not provide an explanation of how these ideas are linked. Responses in this category generally involved the participants "knowledge telling" or providing the researcher with facts rather than *explaining* processes and/or interactions.

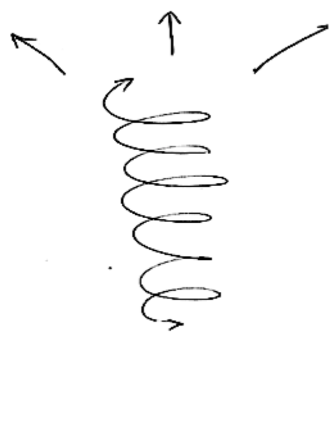
The **uni-structural** responses demonstrated an understanding of a single concept and its role in the process of cyclone formation. The sample response in Table 5.5, for example, focuses on low pressure and the significance of closely spaced isobars. Although making reference to other relevant ideas during the interview (for example, *precipitation* and *condensation*) this teacher was unable to "unpack" the meaning of these terms in any detail.

Only one of the teachers provided responses that could be classified as **pre-structural** (see Table 5.5). The responses of this teacher consisted of general statements about weather, types of human and natural impacts, other natural hazards and generic teaching strategies. The participant was aware of some geographical concepts but did not provide any specific detail in responses. This was particularly the case with interview questions related to causes and processes:

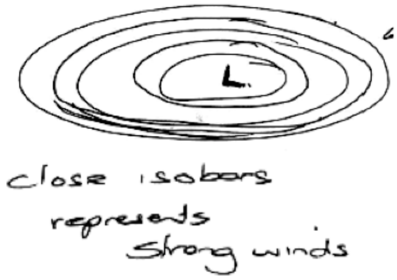
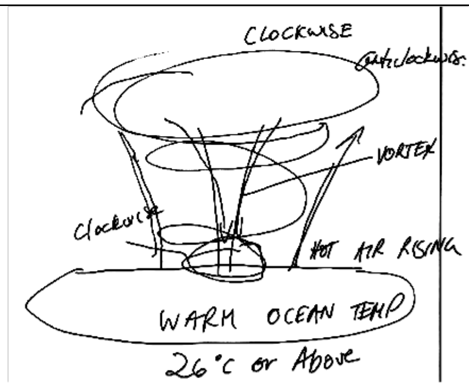
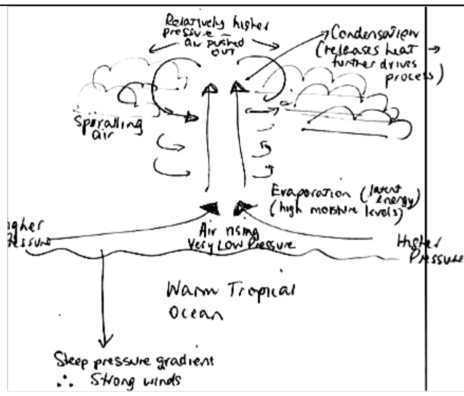
> Facilitator[2]: Can you give me an example of the type of response you would expect from a top Year 10 student when they are asked to explain what a tropical cyclone is?
>
> Participant: I would expect a definition of it, what weather does it bring, where they are located and impacts . . .

Examples of teachers' interview responses and drawings classified at each level of structural complexity are provided in Table 5.5.

Table 5-5 Examples of teacher responses classified by level of structural complexity

SOLO Stage/Number of teachers	**Written/spoken response What is a tropical cyclone and how are they caused?**	**Drawing**
Pre-structural (1 teacher) *(Tautological and provides little evidence of relevant learning)*	"It's a strong weather occurrence that occurs around Australia and around the world. You can also differentiate the different words for a cyclone such as a tornado or tsunami. You also need to know the types of weather that it brings, the location of cyclones and impacts human and physical. It is important to understand what it is and how it develops."	

[2] The researcher – Rod Lane, conducted all of the interviews.

Uni-structural (2 teachers) *(Focuses on a single concept)*	"Low-pressure systems are an important cause of tropical cyclones. Low-pressure systems are associated with rain and high winds. They spin clockwise in the southern hemisphere."	
Multi-structural (4 teachers) *(Describes various processes but does not link them together)*	"Cyclones occur around the equator. Ocean temperatures need to be 26 degrees or above. They are an intense low-pressure system. Normally in Australia you get this NW Monsoonal wind and it all joins up and creates a vortex. Hot air rises and there is latent energy in the process. They spin clockwise in the southern hemisphere and we use different category ratings to describe their potential impacts."	
Relational (9 teachers) *(Integrates conceptual components and explains the relationships)*	"Cyclones form over warm oceans in tropical areas where rising moist air causes intense low-pressure systems to form. The air condenses and forms clouds as it rises and cools. This process releases latent energy which promotes further evaporation. When they reach land they can be very destructive. In addition to the damage caused by the wind, low air pressure can result in storm surges which inundate coastal areas.	
Extended abstract *(Demonstrates creative and/or original thinking)*	No examples were found in the data.	

5.2 Teachers' epistemological beliefs about learning and teaching and PCK of students' ideas

Two additional aspects of PCK explored in this study were the teachers' knowledge of common alternative conceptions (PCK of students' ideas) and their views regarding the nature of learning and teaching. The related research questions included:

To what extent are teachers aware of common alternative conceptions held by students (i.e. What is their PCK of students' ideas)?

What are the teachers' epistemological beliefs about learning and teaching?

As with the classification of the teachers' understanding (see Table 5-2), a framework based on the SOLO taxonomy was developed to assess the teachers' epistemological beliefs and depth of knowledge of students' alternative conceptions. However, since this classification depended on only one source of data (the teacher interviews) rather than the multiple sources used in the earlier classification, a more conservative approach using three levels of the SOLO taxonomy (low, medium and high) was adopted (see Table 5-6).

Table 5-6 Teachers' epistemological beliefs about learning and teaching and PCK of students' ideas

Level	**Surface vs. deep understanding of students' conceptions**
Low (fragmented or uni-structural)	May be able to outline broad areas of difficulty commonly experienced by students but not specific alternative conceptions. Demonstrates no understanding of the constructed and robust nature of alternative conceptions and the implications of these ideas for the development of deep understanding. Views alternative conceptions as errors/mistakes or a lack of knowledge.
Medium (multi-structural)	May be able to identify a number of alternative conceptions held by students. Limited understanding of the interrelationships between students' beliefs and the existence of frameworks/naive theories (i.e. lacks an *integrated* understanding of students' alternative conceptions and why they are important – can cite students' ideas but does not understand their constructed nature and how they may therefore interfere with learning OR cannot identify underlying scientific foundations of these difficulties). For example, might be able to identify some students' ideas yet believes that students' minds are blank slates.
High (relational)	Able to provide detailed and specific examples of students' commonly held alternative conceptions. Understands that alternative conceptions are constructed and theoretically based (i.e. knows what students believe and why – elaborated/integrated understanding of students' alternative conceptions, that they are constructed and that they are likely to rely on underlying theories of how the world works).

The teachers' knowledge of students' conceptions could also be described in terms of the level of detail provided. The four teachers categorised as holding relational understandings were able to provide rich and detailed accounts of specific student beliefs. The other teachers were either able to identify general areas of student difficulty, alternative conceptions in a narrow area of the topic, or believed that students brought "little or no useful prior knowledge with them to class." Examples of teachers' responses illustrating different levels of the taxonomy are provided in Table 5-7 below.

Table 5-7 Examples of teacher responses representing levels of the PCK taxonomy

Level	**Surface vs. deep understanding of students' conceptions**
Low (fragmented or uni-structural) (Teachers – 1, 2, 5, 7, 12, 13 14, 17)	Teacher 17 believed that learning was a surface process which involved the accumulation of factual knowledge (rather than deep understanding). Teachers could "bluff" their way through lessons without an understanding of either the core concepts or the preconceptions held by students. *"I could go in and teach that lesson quite easily [without knowing the content]. I could be traditional teacher . . . for example, 'now we're going to read through cyclones on page 160. Now from that information, what are the main points we got out of that?' and I'd put those on the board . . . You know, like you can bluff your way and as they're learning you're reading it and learning too."*
Medium (multi-structural) (Teachers – 4, 6, 8, 16)	Teacher 1 – could cite two examples of specific conceptions. *"They seem to have this idea that a cyclone will just keep going on and on and on"* and *"there will always be death and destruction happening"* in a tropical cyclone. The teacher argued, however, that students' generally did not have any conception of processes prior to formal instruction: *"they have no idea why it stops and they don't worry about that"*; *"they have no understanding of what causes it"*; *"They don't think beyond the fact that there is a wind and lots of hail and stuff and big seas being generated"*. Teacher 4 provided similar responses: *"That [processes] is something they [the students] don't have any concept about."*
High (relational) (Teachers – 3, 9, 10, 11)	Teachers 3, 9, 10 and 11 provided multiple examples of the specific conceptions students construct prior to formal instruction. They talked about *diagnosing* and *monitoring* students' ideas as well as *building upon* and *challenging* students' existing understandings.

5.3 Discussion – teachers' content knowledge and level of awareness of students' alternative conceptions

5.3.1 Teachers' alternative conceptions and depth of understanding

The combined results of the questionnaire, drawing task and interviews indicate that the teachers' held fewer alternative conceptions than the students (see Section 4.2.2) and were able to provide more nuanced responses, including analogies and references to examples of tropical cyclone events. They were also more confident on average about their responses and made fewer references to popular culture in their explanations than the sample of students.

Many of the teachers, however, were unable to provide relational (integrated and internally consistent) explanations of tropical cyclone causes, processes and impacts. Consistent with the research in Science education (see Abell, 2008; Dahl et al., 2005), the participants also held a range of alternative conceptions that had been previously identified in the research with students (see Chapters 2 and 4). Like the students, they expressed a distinct lack of confidence in their knowledge of underlying scientific processes and principles. Proximity-based explanations of the seasons and the belief that molecules "expand" during evaporation were as prevalent across the sample of teachers as they were among the 339 Geography students studied in Phase 1.[3] However, the alternative conceptions held by the teachers were more tightly focused than those of the students. The teachers did not, for example, experience the same level of difficulty with the concepts of scale and location that were prominent in the students' responses.

One notable finding that was not evident in the student data was the improvement in the teachers' understandings as a result of the interview process. The semi-structured interviews provided many of the teachers with an opportunity to examine their beliefs in detail and develop an awareness of potential contradictions, inconsistencies and obstacles in their thinking. This process appeared to stimulate *cognitive conflict* (Posner et al., 1982) and assist the teachers to evaluate their existing knowledge, identify links between concepts and develop more integrated understandings of key geographical processes.

[3] These comparisons should, however, be considered with caution given the small size of the teacher sample (n=16).

These improvements in understanding appeared to be limited to teachers who were already able to provide multi-structural explanations of tropical cyclone causes and processes. The participants in this category generally held a sound knowledge of the isolated concepts but were often unable to integrate these ideas because of a single alternative conception or inconsistent link. For these teachers, the process probing and extended discussion helped them resolve these inconsistencies.

The type of concept (for example, whether it was abstract or concrete) and nature of the alternative conception also influenced the ability of teachers to improve their depth of understanding through reflection and probing. For concepts such as “the path of a tropical cyclone”, for example, knowledge from personal experience appeared to be a useful tool for stimulating cognitive conflict. Participants’ memories of Cyclone Tracey and the path that it followed helped them to question the belief that cyclones always track in a predictable and linear fashion. Teachers’ alternative conceptions of evaporation and the behaviour of molecules, however, would be less likely to be addressed using this approach. These processes cannot be directly observed and the scientific explanation of the behaviour of molecules during evaporation is in many ways counter-intuitive for both children and adults. It appears plausible to many adults that “molecules expand” because “normally when you heat up something it expands”. It is therefore unlikely that during an interview Geography teachers would recall experiences or beliefs that contradict this idea unless they already have a reasonable understanding of particle theory, atoms and molecules.

5.3.2 Teachers’ awareness of common student preconceptions

There has been little research exploring teachers’ knowledge of students’ alternative conceptions in Geography (see Section 2.5.1), however, the research in other domains (particularly Maths and Science) suggests that teachers often pay a “striking lack of attention to children’s ideas, predictions and explanations” (Smith & Neale, 1989, p. 12) and that they can be insensitive to students’ viewpoints (Osborne et al., 1983). When teachers are aware of students’ preconceptions, their knowledge is often either general in nature or restricted to a narrow range of topic areas (Berg & Brouwer, 1991; Morrison & Lederman, 2003).

The results of the current study, while generally consistent with the research outlined above, indicate that the Geography teachers’ PCK of students’ ideas was both complex and varied. Some of the teachers demonstrated very limited knowledge of the preconceptions of their students. Consistent with the research in Science, these teachers were often able to identify only general areas of student difficulty (e.g. Ian and Ben) or specific student conceptions in narrow areas of the curriculum (e.g. Jane). Other teachers (such as John and Gail) provided a detailed and comprehensive account of the alternative conceptions commonly held by students in their classes. These conceptions were broadly consistent with those held by the sample of 380 students surveyed for Phase 1 of the study.

It is important to note that although a certain level of teaching experience appeared to be necessary for the development of this knowledge base, it did not guarantee better understanding of students' ideas. These findings are consistent with existing research in Science education which has reported a disconnect between teachers' years of teaching experience and their PCK development (Duit et al., 2007; Hashweh, 1996b; Morrison & Lederman, 2003).

5.3.3 The relationship between epistemological beliefs about learning and teaching, content knowledge and PCK of students' ideas

The findings suggest that content knowledge, beliefs about learning and teaching, and PCK of students' ideas are not uniform, even among experienced Geography teachers. Almost half of the sample exhibited high levels of relational understanding and high or medium PCK of students' ideas. However, even in this sample of teachers who had taught for at least 5 years there were examples of teachers with non-constructivist views of learning, uni-structural content knowledge and little awareness of common student preconceptions.

The results support the findings of research suggesting that one of the preconditions for a well-developed PCK of students' ideas is an adequate understanding of the content (Berg & Brouwer, 1991; Lambert, 2002; Morrison & Lederman, 2003; Reinfried, 2006a; Smith & Neale, 1989; Van Driel, De Jong & Verloop, 2002). None of the teachers with uni-structural or pre-structural understandings was able to provide detailed accounts of common student conceptions. Having well-developed content knowledge, on the other hand, was not necessarily a reliable predictor of a teacher's PCK of students' ideas. Two of the teachers classified as having relational understandings of tropical cyclone causes and processes were unable to provide more than two or three examples of common student preconceptions. It may be that expert or accomplished teachers find it difficult to "unpack" or articulate their knowledge and skills during an interview because their thought processes and practices have become intuitive and automatic. Consistent with Hashweh's (1996b) research in Science classrooms, however, the results demonstrate a relationship between the teachers' epistemological beliefs about learning and teaching and the development of their PCK of students' ideas. The teachers with non-constructivist views of learning demonstrated surface (fragmented or uni-structural) understandings of students' conceptions.

Although the above findings provide a number of important insights regarding the depth of content knowledge and PCK of experienced Geography teachers, they do not explain how teachers use this knowledge to inform classroom practice. What happens when teachers are provided with detailed information about the preconceptions of students in a specific topic area? How do experienced Geography teachers use this information to shape their planning and classroom practice? These questions are the focus of the following chapter.

Chapter 6 – Results/discussion: The teachers' use of PCK to inform instruction

Following from the investigation of the teachers' alternative conceptions of tropical cyclones, depth of understanding and PCK of students' ideas (Phase 2, Steps 1-2), this chapter focuses on the final research questions:

What is the intended purpose of the teaching practices employed by these teachers?

How do teachers use their existing knowledge of students' conceptions and the data provided by the researcher to inform practice? (i.e. How is PCK of students' ideas enacted in the classroom?)

As noted in Chapter 3, the collection of data to address this question involved three steps:

Step 3 – Providing teachers with the Phase 1 student data

Three weeks prior to their lesson on tropical cyclones the 16 teachers were provided with a single page summary of the collated data from the 380 students in Phase 1. This data provided an overview of the students' preconceptions about tropical cyclone causes and processes. The teachers were not given instructions about how to use the data.

Step 4 – Lesson observations and video recording

The 16 experienced Geography teachers were observed and videotaped teaching tropical cyclone causes and processes to their new cohort of Year 9/10 students in 2009. Segments of the video were coded and tagged (using Studiocode software) so that samples of each activity in the lesson could be played back to the teachers.

Step 5 – VSR sessions

Within one week of their recorded lessons each of the teachers participated in a VSR interview where they were shown 15-20 individual segments of their lesson and examples of resources they used in class. For each segment the teachers were asked to explain, "what was happening in this part of the lesson?" and "what was your objective or goal?"

Data collected from the above process was analysed in order to produce *holistic descriptions* of the ways in which the teachers used their PCK of students' ideas and the data provided to influence instruction. The development of these holistic descriptions involved the following steps:

1. Identification of clusters of teachers with similar epistemological beliefs, levels of content knowledge, and awareness of students' conceptions

The researcher sought to identify three clusters based on the teachers' depth of content knowledge and PCK of students' ideas: (1) Teachers with relational content knowledge and high or medium PCK of students' ideas, (2) Teachers with relational or multi-structural content knowledge and medium or low PCK of students' ideas, and (3) Teachers with uni-structural or pre-structural understanding and low PCK of students' ideas. It was not expected that any teacher with poor content knowledge would have well-developed knowledge of students' ideas, given that sound content knowledge is required to identify alternative conceptions. The purpose of these clusters was to identify similarities and differences in the teachers' use of students' ideas to inform instruction.

Groups of teachers meeting each of the above criteria can be identified from Table 6.1 which shows the categorisation of teachers by content knowledge and PCK of students' ideas.

1. **Cluster 1** - Teachers with relational content knowledge and high or medium PCK of students' ideas (7 teachers: 3, 4, 8, 9, 10, 11, 16, shown in bold in Table 6.1).
2. **Cluster 2** - Teachers with relational or multi-structural content knowledge and medium or low PCK of students' ideas (6 teachers: 1, 2, 5, 6, 13, 14, shown in italic in Table 6.1).
3. **Cluster 3** - Teachers with uni-structural or pre-structural understanding and low PCK of students' ideas (3 teachers: 7, 12, 17, shown in normal font in Table 6.1).

Table 6-1 Categorisation of teachers by content knowledge and PCK of students' ideas

PCK (Students' ideas)	**Relational**	**Multi-structural**	**Uni-structural**	**Pre-structural**
High	**3, 9, 10, 11**			
Medium	**4, 8, 16**	*6*		
Low	*1, 2*	*5, 13, 14*	7, 17	12
Years Experience (average and range)	Cluster 1: Average = 19; Range = 7-35 years Cluster 2: Average = 15; Range = 5-35 years Cluster 3: Average = 11; Range = 5-23 years			
Note: the numbers in the table represent the 16 teachers in the study.				

It is important to note that this is not the only way to cluster the teachers. This approach does however enable the exploration of how teachers with similar characteristics (CK and PCK of students' ideas) make use of students' ideas to inform instruction.

2. Development of prototypical descriptions of the characteristics of teachers in each cluster

To identify the role of PCK in the teachers' decision making, participants were asked to "unpack" their thinking during an individual VSR interview (see Section 3.8.3). As a component of these sessions teachers were asked to (1) explain the goals that they aimed to achieve in each segment of the lesson, and (2) describe the approach they adopted to achieve these goals. The teachers' responses were videotaped then coded using Studiocode software (see Chapter 3 for a detailed description of the methodology and procedure).

Information from the VSR sessions was combined with data from the Phase 2 interviews and videotaped lessons to create representative illustrations of the knowledge, practices and responses of individual participants.

This chapter provides a general overview of the characteristics of each cluster, including an analysis of the teachers':

1. content knowledge and PCK of students' ideas;
2. rationale for their instructional approach; and
3. use of the Phase 1 student data and existing PCK of students' ideas to inform instruction.

The specialised training and experience of each teacher is also included in the cluster descriptions to facilitate comparison of the teachers' specialised training, experience and content knowledge.

The chapter integrates the reporting of results with a discussion of similarities and differences between the clusters. To facilitate this comparison, the chapter begins with the discussion of Cluster 1 (high or medium PCK and relational content knowledge) and Cluster 3 (low PCK and uni/pre-structural knowledge). Cluster 2 is discussed last because it shares a number of characteristics in common with the other two groups. The teachers in Cluster 2, for example, shared the relational/multi-structural knowledge of Cluster 1, but their rationale for instruction ("engaging" students, identifying "useful" or "correct" understandings and "covering content") was more closely aligned with Cluster 3.

Discussion of the implications of these findings for further research, the theory of PCK development/enactment and professional development is provided in Chapter 7.

6.1 Cluster 1

Cluster 1 consisted of seven teachers with integrated, relational understandings of tropical cyclone causes and processes and sound content knowledge (questionnaire results between 80 and 92%). It included teachers with a range of teaching experience (7-35 years) working in a variety of school types. Six of the seven teachers held undergraduate majors in either Geography or Environmental Science and had some academic background in Physical Geography. Five had completed specific units in climatology in their undergraduate degrees.

There were, however, differences across this cluster in terms of the teachers' PCK of students' ideas and their use of this knowledge to inform instruction (diagnose and address common student conceptions). For this reason, the teachers have been divided into two subgroups. Subgroup 1 includes teachers 3, 9, 10 and 11; Subgroup 2 includes teachers 4, 8 and 16. Detailed descriptions of the subgroups' characteristics are now provided.

6.1.1 Subgroup 1

Overview of PCK and use of knowledge to inform instruction

Teachers adopting a constructivist/conceptual change approach to instruction

A summary of the characteristics of the teachers in Subgroup 1 is provided in Table 6-2. These teachers were aware of the concepts and links essential for building student understanding and were able to provide detailed and specific examples of students' common alternative conceptions in this topic area. This knowledge influenced the teachers' decision making about effective strategies for building student understanding.

Table 6-2 Characteristics of the teachers in Subgroup 1

Teacher number and pseudonym	**Specialised training and experience**	**Content knowledge**
(3) Belinda	Geology, Climatology, Environmental Management, Coastal Studies (BA Dip. Ed - Geography	**Strong relational understanding** with few alternative conceptions
(9) John	Geology, Climatology, Hydrology, Geomorphology, Bio-geography, Industrial Geography, Resource and environmental management, general Human Geography (BSc)	**Strong relational understanding** with few alternative conceptions.
(10) Gail	Geomorphology, Climatology, general Human and Physical Geography (BA DipEd Double major Economics/Geography)	**Strong relational understanding** with few alternative conceptions.
(11) Tina	Geomorphology, Geology, Environmental Management, general Human Geography. Little if any specific study of climatology. (BA DipEd Double major Economics/Geography)	**Strong relational understanding** with few alternative conceptions.

Given their well-developed existing knowledge of students' ideas, the teachers in this subgroup responded to the data provided by the researcher in one of two ways. Three of the four teachers made limited changes to their pedagogy because they felt the data validated their existing knowledge and practice. The fourth teacher (John) used the data sheet to supplement his knowledge of students' ideas and fine-tune his instructional approach.

The strategies employed by these teachers were consistent with the key elements of constructivist-orientated instruction (see e.g., Duit et al., 2008; Duit et al., 2007; Smith & Neale, 1989). These strategies included:

1. setting **explicit goals** for addressing alternative conceptions and developing students' depth of understanding (in contrast to a focus on "covering content" for examinations);
2. promoting the **expression of naive ideas** and alternative theories in class;
3. **probing** beyond "correct answers" to identify students' explanations;
4. using **formative assessment** to collect information about students' understandings and providing feedback used to guide both learning and instruction;
5. developing **engaging and authentic tasks** that motivate students, elicit existing beliefs and encourage students to question these ideas;
6. **promoting cognitive conflict** through the planning of discrepant events;
7. using **multiple representations** and engaging resources to build student understanding of key concepts; and
8. **reflecting on their professional practice** and adapting their approach as required. The teachers were flexible in their approach to both content and pedagogy and responsive to the ideas expressed by students in class.

Evidence from the Phase 1 interviews, videotaped lessons and VSR sessions.

Content knowledge

As noted above, the teachers in this subgroup held strong, relational understandings of the content. In addition to the structural complexity of the participants' responses they demonstrated a sound understanding of the individual concepts – gaining scores on the questionnaire of between 80 and 85%.

In the Phase 1 interview and drawing task, for example, Gail demonstrated her ability to identify and explain the key concepts that students needed to learn in order to understand the causes and processes of tropical cyclones. She provided a detailed explanation of how water temperature, low pressure and the spin of the earth interact to form a tropical cyclone and why it is important for students to understand each of these underlying processes. The other teachers in this cluster provided similar relational explanations of tropical cyclone causes and processes.

Epistemological beliefs about learning and teaching and PCK of students' ideas

The teachers in this subgroup held epistemological beliefs that were supportive of the diagnosis of students' ideas and application of constructivist learning approaches. During the semi-structured interviews the teachers indicated that they were aware of the significance of students' *"misconceptions about weather"* and were able to discuss ways in which these ideas might be constructed. Both John and Tina, for example, spoke of the powerful influence that students' everyday experiences can have on the formation of their beliefs about climatic processes and how difficult these ideas can be to shift through instruction. As Tina noted in her Phase 2 interview "*[the students] have seen on the news the flooding, the damage to the crops, they have seen satellite pictures [during weather reports].*" Later in the interview she added, *"they think that hurricanes – because of the way American media like to sensationalise everything – are more severe than tropical cyclone . . . Hurricane Katrina was so well televised."*

The teachers in this subgroup were also able to provide detailed and specific examples of students' common alternative conceptions and areas of difficulty in this topic area. Gail, for example, was able to identify the following common student beliefs about tropical cyclones in her initial interview: that twisters and tropical cyclones are the same phenomenon; that tropical cyclones can form over the land; that hurricanes are "more intense" than tropical cyclones; and that hurricanes, cyclones and typhoons are different types of storms. Gail was also aware that students regularly believe that Australia does not experience tropical cyclones and that our "storms" are less severe than those experienced in the United States.

Like Gail, Belinda was also able to cite many of the common alternative conceptions identified in the Phase 1 student questionnaire:

> I remember when I was marking papers years ago – I think it was my second or third year of teaching – these kids had done beautiful explanations of a cyclone and they tagged it "tornado".

> Kids always get tornadoes and cyclones confused, always. They always think hurricanes, typhoons and cyclones are all different types of storms. They don't think that they're the same thing . . . They're quite surprised to hear they're the same thing.
>
> They think a cyclone comes over in a day or half a day and it's gone, like a tornado. What they don't realise is one's a huge storm cell, a huge storm cell and the other, the tornado, is tighter. (Belinda – Interview 1 extract)

A common theme among many of the teachers' responses was a recognition of the need to identify students' existing mental models, build on their foundational understandings and when necessary challenge and rebuild students' existing ideas. These findings are consistent with the views of Lambert (2002) and Van Driel (1998), who maintain that teachers with rich, deep and integrated content knowledge are more likely to be open to students' ideas and contributions.

The intended purpose of the teaching practices employed by these teachers

The intention to diagnose and address alternative conceptions is a central component of effective conceptual change instruction (Judson, 2010). These intentions cannot necessarily be inferred from a simple list of the strategies teachers use. This section therefore aims to unpack the VSR data and examine the rationales provided by the teachers for their instructional decisions.

The diagnosis and addressing of alternative conceptions was identified by each of the teachers in Subgroup 1 as a key goal of instruction. John, for example, explained the key aim of his lesson as follows: *"I wanted to try and get them [the students] to understand some of the misconceptions that they had originally"*

John also targeted specific student ideas that had been identified during the pre-test for the unit. In particular, he wanted students to understand that tropical cyclones cannot form over the land and the reasons for this.

Likewise, Gail prioritised the addressing of alternative conceptions as a key goal of her lesson:

> Yes . . . When I was putting those slides together . . . I did choose weather systems and point out that this is how large they are . . . in case they [the students] had, even in their own heads, that it was a tornado they're thinking of, that that would dispel this idea. (Gail – VSR extract)

As a whole, the teachers in this sub-cluster considered it important not only to diagnose students' ideas but to extend and where necessary challenge them.

Strategies used to diagnose students' existing ideas

The teachers in this sub-cluster demonstrated an interest in students' ideas and used a variety of diagnostic/formative assessment strategies to identify alternative conceptions, monitor student understanding and make ongoing adjustments to their practice.

John, for example, diagnosed and monitored student beliefs regarding tropical cyclone causes and processes throughout his lessons. At the start of the unit John asked each student to complete a 10-item multiple choice quiz that had been constructed using a combination of the data from the Phase 1 student questionnaire as well as his own knowledge of common student beliefs. John explained that his aim was to: *"get their [the students'] misconceptions or their conceptions of what cyclones or hurricanes are all about."*

The pre-tests proved to be useful diagnosis tools for John. The information collected from class quizzes was used to help John design activities and select resources for his lessons:

> from what I saw . . . a lot of them [the students] still seem to be confusing the Coriolis Effect stuff. So, Northern Hemisphere, Southern Hemisphere, cloud moving in different ways . . . there was a couple of things that stood out [from the pre-test data]. One was they thought cyclones and hurricanes were different and also that cyclones and hurricanes formed over land. So that was one of things that I noticed from that. (John – VSR extract)

John commented during the VSR interview that he planned to use a similar quiz as a post-test at the end of the unit to identify any changes in student conceptions that might have occurred as a result of instruction.

> my ultimate goal is that they all . . . when they go in there and they do that pre-test again, that they get 100 per cent. So they actually know . . . that it [tropical cyclones] moves in this particular direction. (John – VSR extract)

John also used a data collection and presentation task during his lesson to elicit more of the students' preconceptions about tropical cyclones. After watching a video, the students were required to complete a table describing the key processes as well as the primary and secondary impacts of tropical cyclones. During the VSR interview John explained how he had used the activity to enhance his knowledge of the students' beliefs and mental models:

> I just found [it] was interesting because [of] what they thought was important compared to what I thought was important. So there's "winds of 75 miles an hour" . . . I didn't actually expect that or the fact that they talked about it [the cyclone in the video the students watched] being a category five . . . Some of them also talked about bursting gas pipes. I think what they'd done is they'd gone to their text book and they looked at earthquakes and volcanoes and that was all that was in there and then they've gone, "okay, well then gas pipes have been burst" and at no point were there gas pipes bursting in the video or anything. (John – VSR extract)

John was also keen to ensure that he did not make the assumption that understanding had been developed based on a single student response. To ensure that he had made valid judgments about the students' level of understanding, John probed initial answers, seeking further explanation and elaboration. He used this approach at several points during the lesson to draw out further detail and to encourage students to justify their responses.

Brainstorming was another approach used by several teachers in this sub-cluster to identify students' preconceptions. As Gail explained in her initial interview:

> First off I brainstorm in terms of – "what do you think a tropical cyclone is?" – and get their [the students'] images of what they think it is. Then I would ask –

> "Has anyone been in a cyclone?" Students' ideas would be collected on the board. I would then show something visual [an image or video] . . . I might then come back and say, "have your ideas changed [in response to the stimulus]?" (Gail – Interview 1 extract)

Gail explained how she uses probing questions to monitor students' learning: *"while students are working I will walk around the room and ask them specific questions about key concepts"* (Gail – Interview 1). When areas of confusion or alternative conceptions were identified, Gail developed appropriate simulations and analogies for addressing them. These strategies are discussed in further detail in the following section.

Tina's approach also involved the use of a combination of visual stimulus, brainstorming and probing questions to identify existing views and build student understanding. She began her lesson by showing an image of a synoptic chart and asking students to identify and describe the location of the tropical cyclone over Queensland. This was followed by a series of targeted questions:

Tina:	What do you know about cyclones? What do you think it is like up there at this point in time? [Tina points at the synoptic chart] What sort of weather is occurring in that area at the moment?
Student 1:	Flooding and strong winds
Tina:	Anything else?
Student 2:	Lots of rainfall
Tina:	Yes, lots of rainfall that is probably causing the flooding

This approach assisted Tina to diagnose common preconceptions and to help students make links between the new material on tropical cyclones and their prior knowledge of pressure cells and floods. As Tina explained, scaffolded questions were used to support students to: *"figure some things out for themselves . . . to see how much they can deduce themselves."*

Belinda also used probing questions at the beginning of her lesson to diagnose students' preconceptions of natural hazards and collect information about the students' progress:

Belinda: Can anyone tell me what a natural hazard is?

Student 1: Like hail like droughts and stuff

Belinda: OK you are giving me great examples but I need an actual definition

Student 2: Natural disasters

Belinda: Yes again you are giving me a brief overview of it, a natural disaster. You are all correct but I need something [a response] with a bit more guts in it

Student 3: A disaster like a bushfire or something caused by Mother Nature?

Belinda: OK we are getting closer. Yes . . .

Student 4: A disaster that is caused without human interaction . . . It occurs naturally

Belinda: Very good, so we have human hazards or human disasters and natural disasters. There is more to it than that. Yes . . .

Student 5: A disaster that occurs in the ecosystem?

Belinda: Very good, ecosystem is correct, we are getting closer. So far we've got something that is caused by nature that is maybe a part of an ecosystem . . . Did you want to add to that [Students' name]?

Student 6: Something that has the potential to do lots of damage . . .

Belinda: Very good. To what?

Student 6: To nature and everything in its path

Belinda: Very good. Nature, but more importantly people and property.

A common feature of all of these approaches was the *teachers' interest in students' existing beliefs* and their use of evidence-based approaches to probe and explore these ideas during instruction. The teachers were also aware that students' initial correct responses could mask underlying misunderstandings and that probing questions might be required to determine students' underlying assumptions and beliefs.

The above results are consistent with the findings of Hashweh (1996a, 1996b) who demonstrated that teachers with constructivist beliefs were more likely to employ effective diagnosis strategies and build a comprehensive knowledge of students' ideas. The teachers in this subgroup were comfortable with students expressing, comparing and evaluating their intuitive theories and beliefs and were confident about their ability to influence student learning outcomes (a key dimension of teacher efficacy).

Strategies for addressing alternative conceptions in the classroom

As well as the strategic diagnosis of students' conceptions, the teachers in this subgroup used a range of evidence-based strategies with the *intention of extending and where necessary modifying, students' existing mental models*. These strategies were informed by both their own comprehensive knowledge of students' conceptions and (to a lesser extent) by the student data provided.

A number of common features of the teachers' pedagogical approach could be identified. These include (1) the use of carefully sequenced instructional approaches, (2) acknowledgement of the importance of open and engaging classroom environments, and (3) the use of evidence-based approaches including multiple representations to intentionally target common student "misconceptions" in the classroom. Each approach is discussed in further detail below.

(1) Use of carefully sequenced instruction

Each of the teachers in this subgroup used direct instruction at one stage during the lesson as a method for addressing alternative conceptions. Central to this approach was the teachers' well-developed knowledge of the typical progression of understanding in this topic area. Each teacher thought carefully about the sequencing of ideas to ensure that foundational concepts were covered first. As Belinda noted, "*It's got to be a systematic approach otherwise you lose them.*" Belinda used a tightly structured instructional sequence to teach the core processes and was careful to ensure that students made the key connections. At several points during the lesson she indicated that she was going to *"take note of"* student questions and return to answer them at a more appropriate stage in the lesson.

Several of the teachers in the subgroup combined direct instruction approaches with probing questions and ongoing formative assessment to track student progress and provide feedback throughout the lesson. As Belinda commented during her VSR interview:

> When I went through my training, which was about 20-odd years ago, it was so important to ask questions. Questions were the way kids learnt, inquiry, so that's basically what I was doing there. It also gives you feedback as to whether they've understood it or not. So it's imperative that you ask questions at the end of an explanation. (Belinda – VSR extract)

The data collected from ongoing formative assessment (including quizzes, questioning and in-class observation) enabled the teachers to monitor the effectiveness of their instructional approaches and make changes to their practice where necessary.

Although they did not use the terms "alternative conception" or "conceptual change" in their responses, the teachers in this subgroup were generally of the opinion that *a carefully sequenced instructional approach combined with targeted questioning and ongoing monitoring of student understanding* would reduce the opportunity for students to confuse key concepts and develop further "misconceptions".

(2) Promoting conceptual change by establishing a positive, motivating and engaging classroom climate

Consistent with the recommendations of the conceptual change literature (Pintrich, 1993, cited by Vosnaidou, 2008), the strategies adopted by these teachers focused on both the cognitive and affective dimensions of learning. Three of the key variables mentioned by these teachers were the need to establish positive/supportive classroom cultures, to build students' self-regulation skills and to motivate students with engaging and authentic tasks.

Belinda, for example, placed a high priority on creating a classroom environment where students *"feel comfortable to ask questions"*. To achieve this, students are informed that there are no wrong answers or inappropriate questions (within reason) in Belinda's classroom. Belinda also expressed the view that that students need to be engaged in a lesson before they are likely to *"think seriously about the content and ask relevant questions."* She achieved this level of engagement by varying her teaching approach and by relating the lesson content to the real-world experiences of her students. An indicator of the effectiveness of this approach was the willingness of students to express their views, ask thoughtful questions and debate a range of ideas in Belinda's lessons.

John also recognised the importance of creating a positive, engaging and communicative classroom environment. During his VSR interview, John explained that his approach to instruction was to ensure that conditions were created where students were motivated to ask key questions and challenge their own understandings. John was aware that directly challenging students' alternative conceptions can be an effective tool for improving the understanding of "some students", however, for this lesson he chose to *"engage the students in an inquiry approach that would be fun whilst ensuring that students' misconceptions were also addressed."*

He sought to create an engaging classroom climate by developing class competitions where students working in mixed ability groups, completed a series of challenges in order to score points. This approach is discussed in further detail below.

(3) The use of various evidence-based approaches to intentionally target students' conceptions

The final pedagogical approach common to the teachers in this sub-cluster was the use of various strategies to *intentionally address* students' alternative conceptions. These strategies included the use of analogies, simulations, physical demonstrations and multiple representations to promote student understanding.

Analogies, simulations and physical demonstrations

Gail used a combination of physical demonstrations, simulations and analogies to emphasise the difference between "weather features" and "natural hazards" in her lesson. Her approach involved simulating a tropical cyclone over the sea then over the land by spinning through the classroom and knocking over objects. She also used a simulation and physical demonstration to explain the circulation of air in a low-pressure system and a number of analogies to explain key concepts including "high pressure" and "storm surge".

In John's classroom, cooperative activities and team-based challenges were used to foster conceptual change. The class competition, for example, involved students working both individually and in groups to solve problems. The first task required students to look at a number of stimulus materials: a map showing the distribution of severe weather events across the globe; a diagram showing the causes of the seasons; and a table showing global weather events and their timing. Groups were required to use these materials to explain: *"why we find hurricanes, tropical cyclones and typhoons in these areas of the globe".*

The next two activities in John's lesson involved students sorting and matching a series of cards. The first task focused on the categorisation of tropical cyclone intensity according to air pressure and wind speed. Students were required to match the wind speed and air pressure cards with the appropriate category of tropical cyclone intensity (1-5). The second task focused on the changing weather conditions that a community would experience as a tropical cyclone moved over them. The instructions for this activity required students to match a series of descriptions of local weather conditions with the relevant points on a cross-section diagram of a tropical cyclone.

The final group-work challenge involved a simulation activity in which students were allocated roles as members of a hazard management team during a tropical cyclone event. The class watched a timed PowerPoint presentation containing “live” data regarding the progress of a tropical cyclone over Townsville (Qld). The presentation included a series of synoptic charts, satellite photographs, ground photographs, and messages from the Bureau of Meteorology regarding wind intensity, flooding and rainfall. At key stages during the simulation, groups were required to make predictions regarding the development of the tropical cyclone and the path it was likely to take. Students were also required to make decisions regarding the issuing of cyclone alerts and the evacuation of individual communities. Each of the above activities stimulated intense discussion and debate among the students. These discussions resulted in a number of specific questions being directed to the teacher regarding the development, movement and management of tropical cyclones.

John also used a number of analogies and metaphors in his lesson to support student understanding. One example of this was the use of a “tea and toast” analogy to explain causes of the wind and differences in the thermal capacity of land and ocean. As John explained in his VSR interview:

> the way I teach it is that if there’s two kids . . . it’s a weekend, they are sitting down for breakfast, they just made a cup of tea or a coffee and they’re just having a piece of toast or whatever it is. All of a sudden the phone rings. So the tea and toast is very, very fresh. The phone rings. They’re on the phone for 5 or 10 minutes talking to their mates or whatever it is. They then come back and then I ask what’s happened to the tea and what’s happened to the toast. They come back where the tea’s generally luke-warm but the toast is dead cold. Then what that leads me on to then talk about is the fact that solids and liquids lose and gain heat at different rates. From that, we then go in to talking about prevailing winds where we would look at global climates, so prevailing winds and differences in temperature. So, winter times, coastal environments and coastal areas are much milder than in inland areas because they’ve still got the ocean by it. So I call it tea and toast. (John – VSR extract)

The analogies used in John’s lesson helped the students remember the important links between biophysical forces in a tropical cyclone, including the relationship between water temperature, air movement and condensation. Throughout the observed lesson, students applied these models, analogies and metaphors with great enthusiasm to justify the predictions and management decisions they had made. Like their teacher, these students took ownership of their learning during this lesson. John's knowledge of relevant representations of the content was in turn supported by an extensive knowledge of specific curriculum resources and stimulus materials that could be used to build student understanding of tropical cyclone causes and processes.

Visual representations

The teachers in this subgroup also used visual representations and links with real-world events to address alternative conceptions. As discussed above, John used a range of visual stimuli in his lesson to stimulate the students' thinking about the key concepts. Tina used a Photo Story presentation including images of cyclones Hamish (2009), Larry (2006) and Katrina (2005) to help students better understand the scale and impacts of tropical cyclones. She also used current synoptic charts from the Bureau of Meteorology webpage to explain the process of tropical cyclone formation and its impact on wind strength and rainfall.

The teachers' use of PCK and the research data to inform pedagogy

The teachers in this subgroup responded to the Phase 1 data summarising students' conceptions in different ways. Three of the teachers (Belinda, Gail, and Tina) demonstrated a well-developed knowledge of students' ideas in the initial interview. The teachers noted during the VSR sessions that they were already familiar with the ideas on the data sheet and therefore did not make changes to their practice. For these teachers, the Phase 1 data validated their existing pedagogy and knowledge of students' ideas.

John, in contrast, used the research data to fine-tune his approach to diagnostic assessment and modify the instructional strategies in his lesson:

> So I just looked at that [the Phase 1 student data] and went, okay, so I'm thinking I've got to be doing this, this, this, this . . . That's where I thought I would take key things in to try and . . . teach [these concepts] in these lessons.
>
> I just figured that, if that is what came out of it [the Phase 1 research] – and this is what [the students'] weren't understanding then this is something I need to

> respond to . . . If [this] is what kids in Year 8 or 9 . . . didn't get right then . . . that was also going to apply to [my] students. So it's a general consensus of opinion, I suppose. (John – VSR extract)

The findings support the views of Park and Oliver (2008) and Magnusson (1999) regarding the integrated nature of PCK. Park and Oliver (2008, p. 264) maintain that "PCK for effective teaching [requires the] integration of all aspects of teacher knowledge in highly complex ways" and that "increased knowledge of a single component may not be sufficient to stimulate change in practice." The four teachers in this subgroup integrated knowledge from a range of sources when making instructional decisions. These sources included their existing knowledge of: students' common preconceptions; the key concepts in the topic; diagnostic and formative assessment approaches; evidence-based strategies and resources for improving geographical understanding; and strategies for maintaining student motivation and engagement. Their ability to reflect both in and on their practice enabled them to be flexible in their thinking about both content and pedagogy.

6.1.2 Subgroup 2

Overview of PCK and use of knowledge to inform instruction

Subgroup 2 consisted of three teachers and differed from the first subgroup in a number of ways (see Table 6-3). These teachers shared the relational understanding and well-developed conceptual knowledge of Subgroup 1 and held clearly articulated beliefs about knowledge and learning. The teachers in Subgroup 2 differed, however, in their depth of knowledge of student conceptions and their beliefs about how students develop an understanding of geographical processes.

One of the teachers (Jane) was able to provide detailed descriptions of common alternative conceptions in some areas of the topic (for example, cyclone impacts), but assumed that students were unlikely to have "any idea" or "conception" of the processes driving tropical cyclones because of the complex, scientific and technical nature of these ideas. The other two teachers in this subgroup (Ian and Ben) identified several common "areas of confusion" but only one or two specific examples of the alternative conceptions held by students.

The teachers in this subgroup also responded in contrasting ways to the Phase 1 student data. They either, as in the case of Jane, made minimal changes to their existing practice, or increased their focus on students' ideas, their own content knowledge and strategies for promoting conceptual change (Ian and Ben).

Table 6-3 Characteristics of the teachers in Subgroup 2

Teacher number and pseudonym	**Specialised training and experience**	**Content knowledge**
(4) Jane	Human Geography including settlement, population Geography, Economic Geography. Physical Geography studies in Geomorphology and Climatology. (Teaching qualification included a double major Economics/Geography)	**Outstanding relational understanding** with few alternative conceptions
(8) Ian	Certificate course in Teaching. No formal study in either Human or Physical Geography. Learned on the job. Certificate in Gifted and Talented Education. Teaches NSW curriculum and International Baccalaureate in Geography. Extensive marking experience School Certificate, and HSC	**Strong relational understanding** Interpretation of some of the statements was an issue. Admitted *lack of confidence with scientific processes and principles*.
(16) Ben	Atmospheric Science, Resource and Environmental Management (BA Dip Ed – Geography)	**Strong relational understanding** with very few alternative conceptions.

Evidence from the Phase 1 interviews, videotaped lessons and VSR sessions.

Epistemological beliefs about learning and teaching and PCK of students' ideas

The three teachers in this subgroup were classified as having "medium" (multi-structural) PCK of students' ideas. They differed from Subgroup 1 because they either lacked a detailed understanding of the specific alternative conceptions of students in this topic area (Ian and Ben) or they assumed that students did *not develop* conceptions of tropical cyclone *processes* prior to formal instruction (Jane).

When asked to identify the common ideas they might expect students to hold prior to formal instruction, Ben spoke generally about "confusion" regarding the different names for tropical cyclones and students' "misunderstanding" of the power of tropical cyclones. Similarly, Ian spoke about broad areas of student confusion, generalisations and *"incorrect factual* *knowledge".* Both teachers were aware that popular culture, including *"movies like Twister"* (Ben, Interview 1), play an important role in shaping students' beliefs about the processes and impacts of tropical cyclones.

Jane's epistemological beliefs and knowledge of common student conceptions differed from those of Ian and Ben. Although she was aware of the constructed nature of students' knowledge and could identify specific conceptions in this topic area – *"students don't think hurricanes and cyclones are the same thing . . . they are very confused about what a cyclone and a tornado is"* – she held a firm, clearly articulated belief that students did not develop conceptions of tropical cyclone causes and processes prior to formal instruction:

> I don't think they have that understanding of high and low pressure . . . that is something I don't think they have any concept about . . . Their main idea is the impacts . . . They're not thinking about all those things they're not familiar with [processes]. (Jane – Interview 1 extract)

The above quotes reflect Jane's belief that students spend little time "thinking about" the causes of weather events and are therefore unlikely to hold personal theories about these processes.

Rationale and use of PCK to inform instruction

As noted above, the teachers in this subgroup responded in one of two ways to the Phase 1 student data. They either (1) made minimal use of the data and continued to adopt a "build understanding from scratch" approach to the teaching of processes or (2) increased their focus on students' preconceptions, their own content knowledge and strategies for promoting conceptual change. Each response is discussed now in further detail.

Building from "correct" prior understandings and making regular links back to these ideas

Throughout her lesson Jane used a number of strategies that had the potential to be effective in diagnosing students' alternative conceptions. These strategies were similar to those used by Subgroup 1 however their purpose was to build on "correct" prior learning rather than to *diagnose* and *address* alternative conceptions. Role-plays (students presenting weather reports using images from the Bureau of Meteorology webpage), visualisation tasks (asking students to imagine what would it be like if they were caught in a tropical cyclone) and electronic portfolios were used to monitor the development of students' understanding (an assessment for learning approach). Jane also made extensive use of metaphors and analogies (cold air from the fridge sinks like air in a high pressure system in the atmosphere), story-telling (personal recounts of actual cyclone events), class discussions, scaffolded questioning, structured student inquiry (locate reports of actual cyclone events from the newspaper) and case studies/examples to illustrate the processes of tropical cyclones.

Janes' approach to instruction was consistent with her views about student learning. When asked to justify her instructional approach Jane responded that the purpose of these strategies was to "remind" students of *relevant* prior learning from previous lessons. She explained that her main aim was to "build on" the students' existing "correct" understandings – and connect one sequence of formal learning with another:

> They [the students] reviewed what they had previously done. They used that knowledge. We built on it [the students' ideas identified during the class discussion]. I think most of them, next time around, would be able to give me a couple of key ideas or key processes and knowledge about that. We'd probably have to build on it again. (Jane – VSR extract)

Examples of this approach include Jane's use of cloze passages, to assess whether students could put the "correct" ideas in the spaces on the whiteboard, and targeted questioning to draw out knowledge "covered" in previous lessons. This contrasts with the approaches of teachers in Subgroup 1 who focused on diagnosing and addressing students' *alternative conceptions* of atmospheric causes and processes. Morrison and Lederman (2003) argue that this focus on the "right answer" forces students into the role of "suppliers of correct answers" (p. 863), denying them the opportunity to voice their own views and to question and reconstruct their existing beliefs.

At one point in the videotaped lesson Jane asked the students to explain whether it was cooler or warmer at high latitudes than it is at the tropics. One of the students responded *"it is cooler at the tropics"*. During the VSR session Jane explained that this response "concerned" her and was likely to be the result of the student being "confused".

Facilitator: The girls started answering your questions there? What did you think about their responses?

Jane: What, when they were saying [it is] cooler [at the tropics]?

Facilitator: *Yes.*

Jane: I was a bit concerned. [Laughs] I don't know.

Facilitator: Any ideas about what was going on there?

Jane: Maybe I'd confused them with higher latitudes. They weren't on it with that . . . I think they're confused, yes, I'd say. I bet the higher latitudes may have got them.

The possibility that this student might hold an alternative conception of the global heat budget that could act as a barrier to future understanding was not considered.

Use of PCK to inform instruction

Jane used her own knowledge of students' common difficulties (PCK of students' ideas) to guide instruction but made minimal changes to her practice in response to the data provided by the researcher because she believed that she generally taught processes well and that her students were better than those described in the Phase 1 student data. When asked what she thought of the student data Jane responded:

> Yes. I did look at it. The focus of a few things there like the latitude, Tropic of Cancer and all that sort of thing [was changed]. The fact that it is both. It said in there [in the data] . . . that the kids thought it [the high temperature at the equator] was just because it was closer to the sun or whatever. So I thought, well, yes, that is the case, but we need the other bit [angle of incidence] as well. (Jane – VSR extract)

Jane explained, however, that she did not need to make extensive changes to her lesson because she had:

> I've already probably covered some of that [the ideas identified in the Phase 1 student data] . . . if you hadn't had all that background to low-pressure systems and high pressure systems and things, you would take a lot of time doing that before you then got to the next stage. (Jane – VSR extract)

Jane believed that because she had "covered" this content the students were unlikely to have any difficulties with the related items in the questionnaire: *"So all of the stuff on pressure systems, my kids, I think by now, would have got them correct anyway"*. This view is inconsistent with the results of the Phase 1 interview and questionnaire which indicated that the students in Jane's class were likely to hold a number of alternative conceptions of atmospheric processes. More than 70% of the students in Jane's class, for example, responded incorrectly to questionnaire statements related to air pressure, the causes of the seasons and the process of evaporation.

An increased focus on students' ideas, subject content knowledge and strategies for promoting conceptual change.

Involvement in the research process had a profound impact on the approach to instruction adopted by Ian and Ben and served as a powerful professional development tool. Access to the student data increased their awareness of the importance of students' preconceptions, prompted them to question and refine their own content knowledge and experiment with methods for diagnosing and addressing students' alternative conceptions.

The following quote from Ben's VSR interview provides an example of how the research process stimulated his thinking about the nature and construction of students' ideas:

> I guess they [the students] think it [a tropical cyclone] is quite small in terms of what it is . . . Yes and when you look at things like Twister – they probably haven't seen Twister – it [the storm] is quite concentrated and it's a lot smaller as a force. Because most of them haven't experienced it . . . the size of the thing you don't know about. It's one of the things that really makes it [a tropical cyclone] distinguishable from things like tornados, I've since discovered after doing the quiz with you. (Ben – VSR extract)

The intentional targeting of alternative conceptions

Ben and Ian recognised the significance of students' preconceptions and set the addressing of alternative conceptions as key goals for their lesson. Ben, for example, explained that his key aim of instruction was to *"mov[e] away from the myths or the conceptions that people have."*

When Ben was asked why he used video to highlight the importance of torrential rain during tropical cyclone events he replied:

> Just because people's conception is that's all a cyclone is; it's wind. So just to try and say it's more than wind; it's the wind and the rain. It's the rain and the flooding really that causes a lot of the damage. (Ben – VSR extract)

Similarly, Ian maintained that he wanted to use his knowledge of the students' ideas to promote the *"biggest rate of learning"* possible. This involved *"getting through"* the content as *"simply as possible"* so that he could attend to *"weaknesses"* identified in the Phase 1 student data. Ian's view of students' ideas as "weaknesses" to be overcome aligns with Larkin's observations regarding the orientations of the pre-service secondary Science teachers, several of whom also held the view that students' ideas are evidence of "blockages to understanding" (Larkin, 2012, p. 935).

Refining own content knowledge

The process of completing the questionnaire also helped Ben identify gaps in his content knowledge and "misconceptions" that were similar to those held by the students. This prompted Ben to undertake further research to check the accuracy of his content knowledge.

> There's stuff there where I suddenly thought, I don't know this. Just like when the students are asking those two questions, [I thought] "I don't know that", so I need to check it out a little bit more

> There was a question vaguely about that [in the Phase 2 Questionnaire] and that triggered this thing in my mind about it and that's why I had to check that out and see how that happened

> I went to the Bureau website to have a look at what they had – especially about the formation of it [tropical cyclones] and stuff. (Ben VSR extract)

Ben focused his lesson on areas of the topic where he identified weaknesses in his *own knowledge* and that of the *students*.

Use of strategies for diagnosing students' ideas

Ian and Ben also developed a range of strategies for identifying students' existing beliefs about the causes, processes and impacts of tropical cyclones. Ian, for example, used a pre-test to identify common conceptions. He found that *"Yes, there were a lot of very broad generalisations and some incorrect facts that they [the students] thought they knew."* Ian used a globe to "*explain the tilt of the earth"* during the videotaped lesson because his pre-test results indicated that students did not understand this concept. He also planned to use a multiple choice post-test at the conclusion of the unit so that the students could see "*some form of progression and feel like they haven't just accumulated a lot of facts without a purpose."*

Ben was also interested in diagnosing students' ideas and sought to identify the alternative conceptions of students in his class by using video and visual stimulus to prompt students to reflect on their views and beliefs. This involved showing a one-minute video of a tropical cyclone and its impacts at the start of the lesson followed by a class discussion in which students were encouraged to reflect on what they already knew about the causes and impacts of tropical cyclones.

Use of data and own PCK of students ideas to develop instructional strategies

The Phase 1 student data and information collected from in-class diagnostic assessment assisted both Ben and Ian to refine their existing PCK of students' ideas and develop strategies for addressing these conceptions in the classroom.

> I went through the questions and I looked at some of the things that they [the students] had definitely thought that [were] not true
>
> I really thought it [the student data] was terrific because it was so intensely put together with so much involved in it
>
> I just wish that I had other data like that for other topics because to me it was incredibly worthwhile to find out just what they [the students] had preconceived ideas on and what they hadn't. Just yeah – just to get away from teaching the same thing to the same kids at the same level because "that's the topic and here are the kids and just do it". But to be able to see where the weaknesses were first was fabulous. (Ian – VSR extract)

Ian addressed students' alternative conceptions using a combination of strategies he *"knew would work"* (his existing PCK of effective strategies) and other approaches structured around the *"weaknesses"* (students' understandings of the underlying Science) identified from the Phase 1 student data sheet.

Examples of these strategies included physical demonstrations where Ian used his own weight pushing down on a desk to simulate a high-pressure system – *"They love me making an absolute fool of myself because I always do it right from Year 8 – [I use] a big bottom, [pressing down on the table to represent] heavy air because often they [students] think of a high pressure system as high temperature ."*

Ian also used "hands-on" model-building activities and targeted questions, such as, *"Who already knows the distinction between storm surge and a tsunami?"* to address students' non-scientific beliefs. During the VSR interviews Ian provided a number of reasons for adopting this approach: *"I wanted to try and benefit from the answers to the questions that you had gone through with them [during the Phase 1 student questionnaire]. That was my basic aim* *with that. That [students' alternative conceptions of storm surge] was something that stood out [in the data]. That was one thing my boys scored very lowly on."*

The "hands-on" model-building activity was used to help students understand the difference in structure of a tropical cyclone and tornado. Ian justified this approach by explaining: *"if you play with something, touch it and feel it you will remember the concepts. This should trigger their memory."* This activity was followed by a worksheet designed to *"draw the ideas [of tropical cyclone structure and processes] together."*

The student data also prompted Ben to adapt his instructional approach:

> Normally I would have associated tornados with cyclones and said they were similar, but I've looked it up and seen that they are different in terms of how they work and their scale. If I had more time in class I probably would have drawn that distinction out and saying cyclones, hurricanes, typhoons, they're all these massive things, whereas you see these movies about twisters in the States, they're a different phenomena. (Ben – VSR extract)

Ben sought to address the alternative conceptions identified in the Phase 1 data using video and class discussion. At the beginning of his videotaped lesson he asked one of the students to relate her personal experience of being trapped in a tropical cyclone to ensure that the class understood that *"tropical cyclones do not just fly through in 5 mins."* He also used video to try and *"break the myth"* that tropical cyclones are *"all about just wind."* Ian was keen to ensure that students understood that *"the rain is a really important factor in [the processes of a tropical cyclone] too."*

Ian's and Ben's relational content knowledge enabled them to make sense of the Phase 1 data and appreciate the implications of these ideas for the development of student understanding.

The above results suggest that access to information about students' common preconceptions can serve as a powerful professional development tool for Geography teachers. These findings are consistent with the research of Reinfried (2006a) and Jones, Carter and Rua (1999) who found that engagement with students' preconceptions can induce conceptual change in teachers' mental models and increase teachers' understanding of the role of students' existing ideas and beliefs in the learning process.

6.2 Cluster 3

Cluster 3 consisted of three teachers with pre-structural and uni-structural understandings and relatively low levels of factual and conceptual knowledge (questionnaire results between 55 and 60%). These teachers also differed significantly from Cluster 1 in terms of their epistemological beliefs and PCK of students' ideas. They believed that learning involves the accumulation of factual knowledge and did not therefore consider students' preconceptions when planning instruction. The cluster included teachers with a range of experience (5-23 years) working in co-educational and single-sex (boys) schools. Two of the teachers held undergraduate majors in Geography and had some academic background in Physical Geography. Specific studies in climatology were limited. A summary of the characteristics of the teachers in this cluster is provided in Table 6-4.

Table 6-4 Characteristics of the teachers in Cluster 3

Teacher number and pseudonym	**Specialised training and experience**	**Content knowledge**
(7) Rachel	Minor in Geography including Geography Teaching Methodology. Modern History major. Training involved mix of Human Geography including population studies and general Physical Geography. Has not taught Senior Geography.	**Uni-structural – Provided tautological responses.** Able to list some key concepts. Avoided questions. Many alternative conceptions (8). Some understanding of the importance of evaporation and the water cycle
(12) Kate	Focus on Human Geography including development studies. First year Geology. Experience working for NGOs on development projects. Has not taught Senior Geography.	**Pre-structural – Provided tautological responses.** Gave little detail, general answers. Many alternative conceptions (9).
(17) Nathan	Balanced studies in both Human and Physical Geography including Geology, Environmental Management, Atmospheric Sciences.	**Uni-structural** – Very brief responses. Very high number of alternative conceptions (14).

Evidence from the Phase 1 interviews, videotaped lessons and VSR sessions.

Content knowledge

Overall, the content knowledge of the teachers in this cluster could be described as fragmented or atomised. They demonstrated relatively low levels of factual and conceptual knowledge in the questionnaire (55-60%) and provided interview responses with low levels of structural complexity (pre-structural and uni-structural). Although they provided some information about isolated concepts (for example, evaporation or air pressure) they struggled to explain the related concepts in any detail or the links between these ideas. Two of the teachers were reluctant to draw diagrams illustrating their understanding of how a tropical cyclone was formed and asked if they could copy a diagram from the textbook. One of the participants with more than 20 years teaching experience argued, *"teachers' knowledge is not important because you can teach from the textbook . . . Students do not know the science and neither do I"* [Interview extract – Kate].

Tautological responses with low levels of detail were also common among teachers in this cluster, as the following extract demonstrates (see Chapter 5 for further detail and examples):

Facilitator: Can you give me an *example* of the type of response you would expect from a top (Band 6) Year 10 student when they are asked to explain what a tropical cyclone is?

Kate: Natural Hazard . . . it's a build-up in the atmosphere in terms of pressure. I'd probably expect them to define it quite well for a Band 6.

Facilitator: Is there anything else you would expect in their answer?

Kate: Cyclones occur in certain parts of the world, location-wise and there is a reason for that. That there is a tropical cyclone and a hurricane and they might be able to tell me the difference. They may tell me the result of a cyclone . . . I would expect them to tell me the process behind how a cyclone develops . . . I would be

> wanting them to go into a lot of detail, what is it? And why? (Interview 1 extract – Kate)

Each of the teachers in this group held alternative conceptions similar to those of the students' surveyed in Phase 1. These conceptions were consistently applied in the teachers' responses to the questionnaire, drawing tasks and semi-structured interview questions. Unlike some of the teachers in Cluster 2, (discussed in the following section) these teachers did not appear to reflect on or resolve their alternative conceptions during the interview process.

Epistemological beliefs about learning and teaching

In contrast to Cluster 1, the teachers in this group did not clearly articulate their beliefs about learning in response to the interview questions. However, their beliefs about learning and teaching could be readily inferred from both the comments made about their own knowledge and the justifications provided for their instructional approach. Two of the three teachers were quite specific in noting that they did not have a deep knowledge of the concepts in this topic area. In addition they *did not* consider it important for either the teacher or the students to develop a deep understanding of the core concepts. Their main aim was to "*cover the content"* from the textbook. Given these beliefs it was not surprising that the teachers in Cluster 3 lacked awareness of the conceptual understandings developed by their students both during and prior to formal instruction. They were completely unengaged with the process of knowledge construction and mental model development.

Knowledge of students' ideas and recognition of their significance

The teachers in Cluster 3 were able to identify some broad areas of difficulty commonly experienced by students in this topic, but they were unable to provide examples of specific student beliefs. The following examples of "common preconceptions" were identified by the teachers: students experience difficulties with *"which way cyclones spin", "the weather that goes with each"* and *"the way the air flows."*

The development of effective strategies for promoting conceptual change relies on an understanding that students construct knowledge prior to formal instruction and that some preconceptions may need to be restructured to facilitate deep understanding. Explanations provided during the VSR sessions suggest, however, that the teachers in this cluster believed that the process of learning involves the accumulation of knowledge and that their role in this process was to "fill in" knowledge gaps and enrich students' existing understandings. Several of the teachers assumed that students would have accurate understandings of tropical cyclone impacts "*because they see it on the news, they see what's happening"* (Nathan – VSR extract) but would need to learn more about the underlying scientific processes – "*it's just the scientific nature of the beast that they don't know and neither did I"*.

The teachers in this cluster used the terms "misconception", "lack of knowledge" and "error" interchangeably in their responses and demonstrated little understanding of the constructed and robust nature of alternative conceptions. The potential implications of these beliefs for future student learning were not discussed. It was generally understood by these teachers that "misunderstandings" identified during instruction could be addressed through teacher exposition and lecturing. Rachel, for example, used a lecturing approach to address students' misunderstandings about the naming of tropical storms – *"I wanted them [the students] to know this because it is highlighted in the textbook."* Similarly, Kate spoke about the importance of *"adding value"* to students' existing understandings. For Kate, this involved questioning students to find out what they recalled from previous lessons about cyclone processes and *"adding to"* this knowledge by *"discussing"* diagrams of storm surge and by asking students to look for additional information in the textbook.

As a result of the teachers' relatively weak content knowledge and knowledge of students' ideas, they often avoided teaching "difficult" concepts (for example, those related to underlying scientific processes), deflected challenging student questions and failed to recognise alternative conceptions expressed by students during instruction. Rachel, for example, deflected the questions of a student when he asked *"What is air pressure?"* and *"Does air move in different directions at the top and bottom of a cyclone?"* When students expressed alternative conceptions in class she failed to recognise and respond to them, as shown in the following extract from her VSR interview:

> Facilitator: One of the students actually mentioned as a major impact, the ripping up of sewerage pipes and things. . .
>
> Rachel: I wonder where that – where would he have come up with that?
>
> Facilitator: It's in here. One of the students said it.

Rachel: I remember that. I remember it was the impacts.

Facilitator: It's very common.

Rachel: Yes, okay. *I probably didn't pick that up, it probably just went way over my head.* [Emphasis added].

Similarly, the students in Kate's class made references to the earth freezing and the movie *"The day after tomorrow"* during the videotaped lesson (Phase 2). Kate did not recognise these alternative conceptions in the students' responses and was therefore unable to develop strategies for addressing them. Nathan used a video in his lesson that focused on impacts (rather than processes) because this was content that he was more comfortable with: *"So that's why I found that little video that fit the looking at the causes and process, but also just had a little bit on where I would rather be (laughs)."* [Nathan – VSR extract]. When discussing the teaching of the concept of vortex, Nathan also noted: *" . . . I probably don't even really understand how the vortex, that concept, even works myself. So I didn't want to go there."*

The teachers in Cluster 3 were open about their lack of knowledge in this topic area and about the strategies they used to avoid engaging with difficult student questions. These responses are consistent the observations of Smith and Neale (1989) and Halim and Meerah (2002) in their research with Science teachers. These researchers noted that teachers with limited content knowledge often responded to students' ideas by either providing "correct answers" or by ignoring students' responses and "moving on" with the lesson. In addition to accepting, correcting or ignoring students' incorrect responses, teachers in Cluster 3 dealt with their lack of content knowledge by: (1) restricting the focus of their lessons to avoid difficult scientific concepts such as air pressure, (2) focusing on areas of the topic that "engage students" such as the impacts of tropical cyclones, (3) relying on teacher exposition as a pedagogical approach, (4) scripting the delivery of content to "avoid making mistakes", or (5) minimising opportunities for debate, argument and questioning in their classrooms. These responses are discussed further in the sections that follow.

The intended purpose of the teaching practices employed by these teachers

Consistent with Pinnegar's (1989) research in Science education, the teachers in this cluster gave low priority to students' preconceptions when describing their rationales for instruction. They used a range of strategies that had the potential to be effective in diagnosing students' ideas, including brainstorming tasks (Nathan and Rachel), KWL activities (What do I know? What do I want to know? What have I learned?) (Nathan) and jumbled word activities (Kate). These strategies were not, however, used by the teachers for identifying students' ideas.

Although the teachers' intentions were inconsistent with constructivist-orientated instruction, the data highlights an alignment between the teachers' beliefs about learning and teaching and their rationale for instruction. Rachel explained that she used brainstorming to *"acknowledge the range of views of students and engage them in the class activity."* For Rachel, one of the key aims of this approach was to ensure that all students were *"actively involved"* in the lesson and that their contributions were *"acknowledged"*.

> I just enjoy listening to their responses. I think it's important that students have a say in my lessons, rather than me talking. It's about getting them actively involved and not just sitting there. Yes, I tend to listen to their ideas and thoughts before I put forward my own or if they say everything, I don't necessarily need to say anything and I can just praise them and give them encouragement. (Rachel – VSR extract)

Nathan also used brainstorming to draw on the *"past knowledge"* of students however the communication of incorrect ideas was not encouraged – *"The students come up with some ridiculous things and I will say – no I don't think that happens."* When Nathan asked students to complete a KWL chart, his aim was to remind students of concepts covered in earlier lessons rather than to identify areas of difficulty or potential alternative conceptions.

During the Phase 2 interviews Kate talked a lot about the importance of brainstorming approaches, peer assessment, and jumbled word activities in her lessons. When probed about the role of these activities Kate explained that she used these approaches to engage students, stimulate curiosity and ensure that all members of the class were at the *"same level"* before starting a new unit of work.

> because we start off the lesson and everyone had different levels of knowledge about cyclones. So we need to sort of make that common understanding of where we're all at, so this [the brainstorm] did that. (Kate – VSR extract)

Kate noted that she was particularly interested in the *"number of words"* students were able to brainstorm before and after completing the unit of work and the amount of correct prior knowledge they could recall. During the VSR interview she questioned the usefulness of identifying students' incorrect beliefs:

> Sure they would have related some of their prior knowledge [to the questionnaire] but where's that coming from – it's from most probably their personal experience. Some of the movies that they were talking about, how accurate is that? (Kate – VSR extract)

Although Kate recognised that students generated beliefs prior to formal instruction she did not see that there was anything to be gained from the diagnosis of these ideas. Her focus, like Jane in Cluster 1, was on students' *"correct"* and *"useful"* prior knowledge.

Rather than aiming to diagnose and work with students' alternative conceptions as a key goal of instruction, these teachers focused on the practical and affective goals of maintaining classroom control and ensuring that students were "involved" and "engaged". The dominant instructional approach employed by the teachers in this cluster involved a combination of PowerPoint presentations, lecturing and student note-taking. When asked about the rationale for their instructional approach the teachers in this cluster focused overwhelmingly on student engagement, classroom management issues and the need to *"cover content"* accurately in a limited amount of time. Rachel, for example, explained that she used a narrative about the impacts of Tropical Cyclone Tracy *(Santa came to town)* because it was important to *"engage students through stories."* The need to *"cover content"* was also central to her approach. During her VSR interview she explained that it was important to ensure that students were *"given notes on everything so that they can revise."* Her lesson was therefore designed to help students make these notes: "*I wrote most of those things there for their own notes. So if they needed to go back and look at it in the future, they've got this clear explanation, whereas their textbook doesn't have a clear explanation."* [Rachel – VSR extract]. Rachel explained that she used *"the internet"* as a source for this information. Consistent with his epistemological beliefs, Nathan explained that he used a lecturing approach and video to *"fill* *in gaps"* in the students' knowledge. Like Rachel, he aimed to ensure that the syllabus content was *"covered"* and that students made the required notes in their books. Students' existing beliefs about tropical cyclones were not mentioned by any of the three teachers as a consideration in the planning process.

The teachers' use of PCK and the research data to inform pedagogy

The teachers in this cluster sought to *minimise their engagement with students' ideas* because they (1) held epistemological beliefs that were not supportive of the diagnosis of alternative conceptions, (2) did not have the necessary content knowledge to understand the implications of the students beliefs, and (3) lacked confidence in their ability to teach the topic.

The VSR responses of these teachers indicated that they lacked content knowledge and confidence in their ability to teach the scientific processes of tropical cyclones. They avoided engaging with students' ideas because of a fear that student comments and questions might "derail" their lesson. These issues of anxiety and lack of confidence have features in common with Bandura's concept of self-efficacy (Bandura, 1977, 1986) – an individual's belief in their competence to complete a task or meet a goal.

None of the teachers in this cluster made specific use of the individual ideas presented in the Phase 1 student data to inform their teaching practice. As Nathan noted:

> I was just sort of looking at the questions and the percentages . . . I was mainly photocopying all the stuff to make sure I had everything that I needed for your visit. More so than actually looking and thinking in my own mind "what does this all mean?"

The teachers noted that the data was difficult to work with because it was not directly aligned with the dot points in the syllabus. The teachers did not, for example, recognise the link between the global heat budget and the location of tropical cyclones because this was not explained to them on the data sheet. Kate noted during her VSR interview that she would prefer *"black and white"* information about what the students need to know so that she can make sure that this content is *"covered"* during class. For Kate, looking at the student data was *"too time consuming."*

The data did, however, highlight for these teachers the inadequacy of their content knowledge in this topic area:

> Well it made me realise that I needed to learn a little bit about cyclones before I taught them . . . When you interviewed me it made me realise that I didn't have the depth of knowledge that I needed . . . to be able to continue with your project. So I needed to get a little bit of background, gain a little bit more background knowledge in order for me to go in and teach about cyclones . . . I needed to know the particulars. Like probably what I'd consider the scientific background which I don't know. (Nathan – VSR extract)

Normally Nathan would not have worried about understanding the core concepts in the lesson because he could use *"bluffing"* strategies to draw the required information out of the students:

> Facilitator: Okay, so it was a combination of the interview and the data sheet, sent you to go and look stuff up and make sure you knew the nuts and bolts.
>
> Nathan: Yeah, I had to, yeah. *Because I wanted to at least look as though I knew something . . . I mean as a teacher you can normally bluff it in a classroom,* but when you're being interviewed by a [lecturer] from the university or whatever, you want to be . . .
>
> Facilitator: No, sure and what I'm interested in is how teachers use kids' ideas. Essentially, what ended up happening for you, is it [the student data] highlighted for you things that you needed to get straight?
>
> Nathan: Yeah well I mean like I could go in and teach that lesson quite easily [without knowing the content]. I could be traditional teacher . . . for example, "now we're going to read through cyclones on page 160. Now from that information, what are the main points we got out of that" and I'd put those on the board . . . You know, like *you can bluff your way and as they're learning you're reading it*

> *and learning too*. You do that, I do that occasionally and it made me just realise from the interview if I was going to continue with this project that I needed to know a little bit more about cyclones. [Nathan – VSR extract. Emphasis added]

Nathan went on to explain how teachers could get away with minimal content knowledge and understanding of students' conceptions:

> Well it [content knowledge and knowledge of students' ideas] is important but you can get round it. Like I said . . . I'd give them a comprehension for homework as well and from that I would have been able to draw this information [using questioning]. I wouldn't have necessarily had to stand out the front and give a full-on lesson.

Each of the teachers in this cluster was keen to ensure that the content they delivered during their videotaped lessons was "correct." To achieve this Rachel adopted a highly structured teaching sequence to *"avoid making mistakes"* and limited the scope of her lesson to concepts that she was confident she understood. This involved reducing the emphasis on scientific processes and increasing the focus on impacts that were more *"interesting"* and easier to understand and explain:

> Rachel: There are a lot of scientific questions [in the Phase 2 interview] which I tried to steer away from and make it more geographical. Yes, I remember those definitely.
>
> Facilitator: So your approach with the Science stuff was to move towards the Geography so that then you didn't have to harp on Science?
>
> Rachel: Exactly, yes, because I'm not a scientist so *I don't know the scientific approach to teaching this disaster*. [Rachel – VSR extract, emphasis added]

To avoid making these "mistakes", Rachel conducted background research about key scientific concepts such as the Coriolis effect prior to teaching her lesson. This focus on "avoiding mistakes" provided important clues about Rachel's epistemological beliefs – in particular her assumption that knowledge is absolute and uncontested. There was no recognition that the development of deep understanding often involves argument, debate and disagreement.

Although Rachel made limited use of the student data in the videotaped lesson, she noted that she could see herself using the data for reflection in future lesson planning:

> Maybe that [the student data] would have been a good starting point as well, thinking about, okay, how do they think a cyclone is formed?
>
> Thinking about it now, that would be useful . . . I'd go back now and think about, okay, what did I do and I'd actually look on the sheet now to see, did I talk about this or did students mention [this idea] in the lesson. I think it would be a useful exercise. (Rachel – VSR extract)

6.3 Cluster 2

This section outlines the characteristics of Cluster 2 while providing a comparison with the other two clusters. Cluster 2 is discussed last because it had characteristics in common with the other two groups. Wendy and Ken in Cluster 2, for example, shared some epistemological beliefs with Jane in Cluster 1. Their rationales for instruction and their pedagogical approaches, however, were more closely aligned with the reasoning provided by the teachers in Cluster 3.

Description

Cluster 2 consisted of six teachers with relational or multi-structural understandings and sound factual/conceptual knowledge (questionnaire results between 78 and 88%). A summary of the characteristics of the teachers in this cluster is provided in Table 6-5. As in Clusters 1 and 3, the teachers ranged in their level of experience (5-35 years) and worked in a variety of school contexts. All the teachers had some academic background in Physical Geography, but only three of them had specific units in climatology in their undergraduate studies. Two teachers (Tim and Roy) identified themselves primarily as human geographers.

Table 6-5 Characteristics of teachers in Cluster 2

Teacher number and pseudonym	Specialised training and experience	Content knowledge
(1) Wendy	Both Physical and Human Geography including Climatology at undergraduate level. Long-time member of Professional Associations supporting Geography teachers. Masters degree including studies in Physical Geography.	**Strong relational understanding** and few alternative conceptions
(2) Ken	Both Physical and Human Geography including Geomorphology, Climatology, Agricultural Geography, Urban Geography, Population Geography.	**Strong relational understanding** and few alternative conceptions.
(5) Tim	Focus on Human Geography. Basic first year Physical Geography - Geomorphology (BA Dip. Ed - Geography).	**Multi-structural understanding –** able to explain isolated concepts and some links (wind/pressure). Sound diagram shows pressure cell, storm surge, and evaporation.
(6) Sue	Focus on Physical Geography including Geology, Ecology, some Human Geography in first year studies (Environmental Management Degree).	**Multi-structural understanding.** Able to explain isolated concepts and some links. "Snowed the researcher" with terminology and facts. Struggled to explain the interrelationships.
(13) Roy	Focus on Human Geography. Basic first year Physical Geography (Bachelor of Teaching, BA – Geography Major).	**Multi-structural understanding.** Gave general answers. Repeated questions during the interview to avoid giving specific answer that might be incorrect.
(14) Rhys	Focus on Physical Geography including Resource and Environmental Management, Climatology and Marine Science. (Major in Environmental Science). Teaches NSW curriculum and International Baccalaureate in Geography. Experience in Environmental Education outside schools.	**Multi-structural understanding.** Brief answers to process questions. Had a basic idea of the key concepts (e.g. tropical cyclones are low-pressure systems associated with warm oceans). Got confused when making links. Could cite many facts (e.g. duration, location).

Evidence from the Phase 1 interviews, videotaped lessons and VSR sessions.

Content knowledge

Two of the teachers (Wendy and Ken) exhibited a strong relational knowledge of the content with few alternative conceptions (questionnaire scores 85%). The remaining teachers in this cluster provided responses that could be classified as multi-structural (Tim, Sue, Roy and Rhys). They demonstrated a sound knowledge of the isolated concepts involved in the process of tropical cyclone formation but were unable to provide comprehensive explanations of the interrelationships between these ideas. Despite gaining scores between 78 and 88% on the questionnaire, the four teachers with multi-structural understandings held a number of alternative conceptions similar to those identified in the student sample (Chapter 4).

Epistemological beliefs about learning and teaching and PCK of students' ideas

The teachers in this cluster could be divided into two groups according to their epistemological beliefs. The first group included two teachers (Tim and Rhys) who believed that students bring little useful prior knowledge with them to class. The second group (Wendy, Roy, Ken and Sue) acknowledged that students gain some ideas about tropical cyclones prior to formal instruction but did not believe that students' preconceptions are stable, theorised or constructed. These contrasting epistemological beliefs are discussed in further detail below.

Group 1 – Understanding needs to be built "from scratch"

The teachers in this group assumed that students' minds were essentially "blank slates" prior to formal instruction and that there was a need to "start from scratch" to build student understanding. Tim, for example, observed that his students came to class with *"with little if any useful background knowledge"*. He explained, *"even if they [the students] had learned something in the past I would expect that they would have forgotten . . . I would start from scratch in terms of what I wanted them to know."* As Rhys noted during his VSR interview: *"you can't expect the kids to know [about] this [tropical cyclones] . . . [it] is your job to teach them."*

The teachers in this group also associated the terms “misconception” and “alternative conception” with “inadequate” or “incomplete knowledge” and “student error”. Like the teachers in Cluster 3, they felt that their primary role was to identify “gaps” in students’ knowledge and *fill these in* during instruction. Given these epistemological beliefs, the teachers were generally surprised to see the number of common alternative conceptions held by students in the Phase 1 data.

Group 2 – Students have some ideas but do not construct stable conceptions prior to formal instruction

The teachers in this subgroup (Wendy, Roy, Ken and Sue) recognised that students “*gained some ideas*” from their personal experiences, but were unaware of the constructed, robust nature of students’ conceptions or the implications of these ideas for the development of deep understanding.

Sue and Roy, for example, believed that students developed only a surface knowledge of tropical cyclones prior to formal instruction:

> Students do not know the details, only what they see on the news. They only see destruction . . . I don’t think they [students] really know the anatomy of a cyclone – they know there is wind and rain . . . They just think of it as a bad thing that has happened” “I don’t think they know the specifics of it yet.” (Sue – interview 1 extract)

Roy felt that the ideas students gain from experiences outside the classroom were likely to be unpredictable and indicate only a surface level of understanding: “[students have] *very basic views from the media and their parents . . . They just get a glaze of what is going on . . . they do not dig deeper for a full understanding.”* He also commented that he did not believe students carried useful prior learning from one year to another.

Like Jane (Cluster 1), Wendy and Ken believed that students held ideas about the impacts of tropical cyclones but had “*no concept”* of causes or processes:

> they [the students] have no understanding of what causes it [tropical cyclones]. They just think it just happens. It’s like created. They don’t think beyond the fact

> that there is a wind and rain and lots of hail and stuff and big seas being generated. (Wendy – Interview extract)

> Often they have no idea of how they [tropical cyclones] are formed. No idea, at all, how they are formed. Or they just think they can occur haphazardly around the world because they often watch movies like Twister and some of those American movies where they think these things just suddenly appear down from the sky like a twister does. (Ken – Interview extract)

The intended purpose of the teaching practices employed by these teachers

Like Cluster 1, the teachers in this group used a range of strategies that had the potential to be effective in diagnosing and addressing students' alternative conceptions. In contrast to Cluster 1, however, these strategies were not used for this purpose. The teachers cited the following reasons for using brainstorming activities, mapping and drawing tasks and visualisations: engaging students, making students comfortable, addressing classroom management issues, identifying "correct" prior understandings, correcting errors and "covering" content in order to prepare students for exams. In this respect the responses were similar to those of the teachers in Cluster 3.

Engaging students and making them "comfortable"

Wendy provided the following explanation for the use of brainstorming and questioning strategies in her classroom:

> I capture their interest by asking: what do you remember about cyclones? What are they called in other countries? It is called by other names? They all want to talk about Katrina and cyclones like that, hurricanes etc. and the fact that they are so devastating. So we talk about the devastation to start with which always captures their interest keeping in mind we have 70% boys here. (Wendy – Interview extract)

Similarly Tim noted that his main priority during the lesson was to *"spark interest"*, create a positive learning environment, and engage students in a variety of activities while sticking to the prescribed syllabus content. To achieve this aim, Tim showed students videos of natural hazards, asked students to complete hazard maps of Australia and work in groups to summarise information from the textbook. Tim also asked the students to "draw an illustration" of what it would be like to personally experience this natural disaster. Although this task had the potential to elicit students' preconceptions it was used by Tim to assess the knowledge of impacts that students had extracted from the textbook. As Tim explained, it was an engaging alternative to *"finding, reading and copying out"* information from the textbook (Tim – VSR extract).

Ken's lesson involved the use of a PowerPoint presentation with a large number of images. He explained that the photographs and images were chosen because they were *"quite dramatic"* and were therefore likely to *"engage"* the students. Some of the slides, however, included cartoons depicting flying cows and images of tornadoes. While these images had the potential to be entertaining for the students, they were also likely to reinforce students' alternative conceptions regarding the differences between tropical cyclones and tornadoes.

Prioritising classroom management

Apart from motivating and engaging students Ken emphasised the importance of brainstorming and questioning as strategies for keeping students "busy" and "quiet." When asked to outline the main aims of his lesson, Ken responded: "*I don't have any aims apart from just survive that bloody class and keep them quiet."* To ensure the maintenance of classroom control Ken used a lecturing approach and issued students with workbooks that contained a number of highly structured activities. A structured lesson with clear expectations was a key component of Ken's teaching approach:

> if you don't [maintain a structured lesson] they just chat, have fights, whatever . . . some of them – just like Ben – refuse to bring a book and whatever. Mind you apparently they're far better behaved for me than they are for most people . . . (Ken – VSR extract)

Rhys also emphasised the importance of using a "range of instructional approaches" in his classroom: *"you're going to have behavioural problems, [if] you have children inattentive, uninterested children who don't want to know . . ."*

Identifying gaps, "correcting" errors and building links

Like the teachers in Cluster 1, Sue, Tim and Roy used various strategies to assess students' prior knowledge and to help students make links with new concepts introduced in their lessons. Tim, for example, provided students with several opportunities to ask questions and communicate their existing ideas. Students were asked to predict the distribution of hazards, compare this with the map in the textbook and discuss any differences they noted. During the VSR interviews Tim also explained that he encouraged students to record their views on the whiteboard so he could "check" their understandings.

Sue also acknowledged that students bring ideas from their personal experiences into the classroom:

> I know that field can kind of get a little bit mixed up with Hollywood type stuff, you know when they're watching movies. So I wanted them to come up and I wanted a little bit of an insight into what the class thought cyclones were before we actually got into the nitty gritty and into the geographical process side of it. (Sue – VSR extract)

Her priority, however, like that of the teachers in Cluster 3, was to identify accurate prior understandings and fill any "gaps" in the students' knowledge.

> Yeah so it was a bit more of an interesting look at what the class knew and . . . the gaps we could have possibly filled in the lesson. (Sue – VSR extract)

Some of the teachers in Cluster 2 also used questioning to build understanding and link old and new learning. Tim, for example, used open questions to see if students could work out the difference between hazards and disasters: *"If I was to tell you there are a lot of fires around northern Australia but when we map disasters we tend to locate them in the south east corner of Australia. What's going on there?* Likewise, Roy used "directed questioning" to help students make links between key concepts.

While these diagnostic and formative approaches are similar to the strategies used by teachers in Cluster 1 they are based on different epistemological beliefs. The teachers in Cluster 2 were primarily focused on reminding students of the concepts covered previously in class, namely their "correct" prior understandings. They viewed students' intuitive beliefs as "errors" or "mistakes" that needed to be either ignored (see Sue below) or challenged using exposition or teacher-directed questioning.

Identifying "correct" prior understandings

In the initial semi-structured interviews Sue commented that she made use of brainstorming as an instructional approach in her lessons on tropical cyclone causes and processes. Although she felt that students often possessed little useful background knowledge on this topic, she thought that the brainstorming approach might help to motivate students to "get involved" in the lesson. When this strategy was used during the videotaped lesson sessions in Phase 3 of the project, students contributed a range of ideas including: *"cyclones need hot water"* and *"cyclones are like tornadoes, they suck things up and spit them out"*. Sue praised a number of the students for their contribution to the brainstorm session and recorded their ideas on the whiteboard. Students who presented ideas that were perceived as being "incorrect" or "off the topic" were asked to rethink their responses. The ideas of these students were not included on the whiteboard summary. In the VSR session Sue explained that she was reluctant to explore *"incorrect ideas"* during the lesson or include them in the class brainstorm because students *"might memorise this information and recite it in an examination."*

Similarly, Tim and Roy used strategies such as rhetorical questioning to identify "correct" prior knowledge and to "engage" students. When "incorrect" ideas were expressed, the teachers "corrected" these "mistakes" or briefly acknowledged the students' responses, before continuing with their teaching. Elaboration of these ideas was not encouraged. Tim interpreted students' incorrect responses as a cue to *"explain concepts again"* rather than probe students explanations further.

"Covering" syllabus content and "making notes" to prepare for exams

The teachers in this cluster shared the belief that a key purpose of instruction was to get "notes in books" so the students could prepare for their exams. As Rhys noted during his VSR interview: *"the main thing is you need to have stuff written in the books . . . What they need to know for the test needs to be in their books. You know what I mean?"*

Tim facilitated the process of note-taking by synthesising and summarising the syllabus content for students: *"I'll just summarise it down because it's more information than they really need or they're really going to learn properly for the exam . . . So this is a way to just filter that down and give them the important things"* (Tim – VSR extract).

During the VSR interviews teachers were asked what they did with student work once it had been completed during class: Was it collected? Checked? If so, what was the work checked for? The teachers in this cluster indicated that they collected student work twice a term (at the most). The purpose of collecting work was to check for neatness and task completion rather than diagnose areas of difficulty or track student progress. Rhys, for example, puts stickers in students' work *"if they write down all of the information."* Only one of the teachers, Wendy, commented that she checked students' work *during the lesson* and provided targeted feedback.

One consequence of the desire to *cover content* for exams was an anxiety among some the teachers to ensure that their lessons remained "on track" and that they were not distracted from the core requirements of the syllabus. This often involved deflecting or ignoring student questions. During Sue's lesson, for example, a number of questions were asked by students which indicated that the students might hold an alternative conception that could interfere with their understanding of tropical cyclone causes and processes. One student asked: *"do tropical cyclones cross the equator?"* and another asked, *"Is a water spout a cyclone?"* Sue did not engage in answering these questions, preferring to continue with the flow of her lesson. In the VSR interview she gave several reasons for this approach. Sue explained that she overlooked some student comments and questions because she was unaware that they might represent alternative conceptions that could potentially interfere with students' learning. Other comments and questions from the students were intentionally *"shut down"* because they were not perceived as being in line with the lesson goals or would have taken the lesson away from its focus on the syllabus: *"In my lesson I didn't think these were important things for students to know . . . You can't let the students take over the class with their own ideas . . . we need to keep them on track."* She added, *"students need to be prepared for the School Certificate[4] exams and I am very conscious of this."*

[4] Prior to 2012 all students in NSW sat for the School Certificate test at the conclusion of their Stage 5 (Year 10) studies. The School Certificate consisted of assessments in English, Maths, Science, History, Geography, Civics and Citizenship. Although the role of the test as an exit credential diminished as retention rates rose, many schools and Geography/HSIE departments viewed the results as an important indicator of the quality of teaching provided in years 7-10.

During Tim's lesson students also asked questions indicating that they had stereotyped and inaccurate ideas about the distribution of climate regions in Australia. When Tim was asked about the nature of the students' questions during his lesson he responded:

> Well, they were tapping into things which were not incorrect but were not necessarily relevant to the answer that I was seeking. So I'm just trying to accept what they're telling me and then try and encourage them that they've got some logic behind what they're saying, but it's not the information that I'm seeking for that particular question . . . I didn't want to go too far down the side-track. (Tim – VSR extract)

Tim was reluctant to answer the students' questions because he saw them as a side-track from the lessons' main aims. By responding in this way, however, he might have inadvertently reinforced the students' alternative conceptions.

Rhys and Roy also used questioning in their lessons to involve and engage the students. This process was tightly controlled, however, to ensure that students remained "on track" and the necessary syllabus content was addressed. Consistent with the findings of Sequeira et al. (1993), the teachers in this cluster believed that instruction should lead directly to the targeted concept and avoid errors commonly made by students.

The teachers' use of PCK and the research data to inform pedagogy

The teachers in this cluster can be categorised into two groups according to their response to the student data. Three of the teachers (Wendy, Tim and Sue) made little if any use of the data because they were *"short for time."* Tim's priority was to ensure that the lesson was student-focused, relevant to the syllabus and engaging. He had a set area of content he wanted to cover and did not want to be *"side-tracked"* with additional information. Sue was unable to make use of the data because she could not see the link between the "scientific" items in the questionnaire and the syllabus content she was required to teach:

> I suppose I was just trying to cover all the dots in the syllabus like most teachers so yeah. So I was trying to cover what I thought needed to be covered in the program . . .

> I get scared of going down tangents that aren't irrelevant to their overall learning but irrelevant to syllabus outcomes . . . That's, I think a problem that I have is that sometimes I get too security blanketish with the syllabus. (Sue – VSR extract)

While Sue integrated some of the students' ideas within her lesson, she paid little attention to the items describing students' conceptions of underlying scientific processes and principles, such as matter, the global heat budget and evaporation. Sue's lack of knowledge of the underlying science also meant that she failed to recognise the significance of comments made by students in class, dismissing them as *"random"* and irrelevant to her lesson.

In the VSR interview Sue explained her reasons for adopting this approach:

> like I was saying before, you have a goal to get to when you plan a lesson. If there are questions thrown at you that aren't in the previous planning progression towards that goal you kind of [think] – "no, no we don't need to know that we need to know this."
>
> Maybe you should let the boys in a little bit more in terms of being more inquisitive on certain questions where maybe to me as a teacher because I've set and planned this, this is the way I want it to go. That question is probably too random – well it's not random it's very relevant. But it's *random in terms of the plan that I've taken to teach the lesson*. (Sue – VSR extract, emphasis added)

The student data prompted the other three teachers in Cluster 2 (Rhys, Roy and Ken) to reflect on their beliefs about learning and make modifications to their instructional approach. Rhys and Roy were surprised by the similarities in the students' ideas and by the pervasiveness of many of the beliefs. This prompted them to question the assumption that students do not develop preconceptions of tropical cyclone causes and processes:

> I was a bit surprised that a lot of students got wrong – it was only one or two that were quite relatively simple things that I found well geez, I didn't realise that a lot of kids would get that wrong. So that was probably the most surprising thing [in the student data]. (Roy – VSR extract)

The data also provided Roy with some ideas about how he could change his practice in the future:

> I suppose it does give you an insight into how you can structure your teaching to not avoid the areas [of difficulty] but make sure that you direct the kids to understand . . . these misconceptions or direct them to areas where you know that some kids . . . don't understand what's going on. (Roy – VSR extract)

Roy sought to achieve this in his lesson by asking questions that directly targeted common alternative conceptions. He also used the students' existing knowledge of geographical skills (for example, distance, scale, longitude and latitude) to help them gain a better understanding of the location, structure and processes of tropical cyclones.

The data sheet also prompted Rhys to reflect on the importance of student preconceptions and the effectiveness of his current instructional approach:

> [While planning and teaching] I was thinking more about their [the students'] misconceptions. What are they thinking about what I'm trying to teach them? Only because we've done this thing [the questionnaire] I'm kind of like, I wonder what they are actually thinking? I wonder if I'm teaching this right? (Rhys – VSR extract)

Reading about the students' preconceptions made Rhys increasingly aware of the potential inadequacies of his own content knowledge:

> I was trying to think, "I have to say things correctly because I wouldn't want to teach them the wrong thing by accident." Now I'm thinking, "I hope that was right. I hope that was right." (Rhys – VSR extract)

In response to the student data Rhys made a number of changes to his lesson. These changes involved identifying "relevant" items from the data sheet and including explanations of these concepts in a PowerPoint presentation. Rhys defined relevant items as those directly linked with the syllabus dot points (for example, the naming and location of tropical cyclones) and aimed to ensure he "covered" or "spoke about" these common alternative conceptions during the videotaped lesson. Students' potential alternative conceptions of underlying scientific processes and principles (for example, air has neither mass nor weight) were *not* addressed, however, because they were seen as irrelevant to the syllabus requirements.

For Ken, the data confirmed his original belief that students have little understanding of causes and processes prior to formal instruction: "*I've just been looking at [the data sheet] . . . a lot of kids don't have any idea what evaporation is or even the impacts of cyclones or anything like that.*" "*So overall I would say kids understanding of how cyclones develop or the processes involved aren't very good.*" The key issue, according to Ken, was students' lack of knowledge in this area rather than the possibility that they might develop preconceptions inconsistent with established scientific views.

Like Rhys, Ken sought to address these "gaps" in the students' knowledge by *adding more information* about causes and processes to his lesson slides. Ken used these slides as a prompt during his lesson to ensure that the key processes were explained. He applied the philosophy of building student understanding "from scratch" using a combination of teacher exposition (PowerPoint presentation) and structured workbook activities (labelling diagrams, responding to short answer questions and completing close passages). Like many Science teachers (see e.g., Smith & Neale, 1989), Ken adopted this approach because he was unaware of the robust nature of the students' alternative conceptions and believed that these ideas could be easily changed.

While access to the student data helped Rhys, Roy and Ken develop greater awareness of the significance of students' preconceptions, the strategies they put in place to address these ideas were limited in a number of ways. Their lessons included few opportunities for students to communicate their personal theories and ideas. When ideas were expressed they were rarely probed, discussed or evaluated by the class. The teachers relied on lecturing approaches to address students' "incorrect ideas" rather than strategies designed to promote cognitive conflict and dissatisfaction with existing conceptions.

These findings support Duit's (2007, p. 214) contention that teachers' epistemological beliefs and knowledge of students' alternative conceptions need to be developed "in parallel" with evidence-based instructional practice. As Halim and Meerah (2002) advise, awareness of students' beliefs alone does not guarantee that teachers will develop knowledge of the strategies required to effectively diagnose and address these ideas during instruction. Without models of how to apply this knowledge in the classroom, teachers are likely to default to the practice of "telling students" why their ideas are incorrect rather than providing opportunities for students to evaluate their existing mental models and, where necessary, reconstruct them.

6.4 Summary

The discussion of results in this chapter highlights a number of similarities and differences among the three clusters. These findings are summarised below.

Cluster 1

What is the intended purpose of the teaching practices employed by these teachers?

For the teachers in this cluster, the rationale for instruction focused on both the *cognitive* and *affective* dimensions of learning. They aimed to create positive, motivating and engaging classroom climates and, with the exception of one teacher (Jane), identified the diagnosis and addressing of alternative conceptions as key goals of instruction.

How do the teachers use their existing knowledge of students' conceptions (PCK of students' ideas) and the data provided by the researcher to shape their thinking about classroom instruction?

All the teachers used their existing PCK of students' ideas and/or the data provided to shape their thinking about classroom instruction. The Phase 1 data was used by the teachers to help them improve their content knowledge, refine their already well-developed PCK of students' ideas (Belinda, John, Gail and Tina), enhance their awareness of specific student beliefs (Ian and Ben) and focus instruction on likely areas of student difficulty (Jane). The teachers in this cluster had well-developed metacognitive skills, reflected on their practice and made adjustments to their knowledge base and pedagogy where necessary.

It is important to note that while the teachers in Cluster 1 shared a number of features, there were also differences between the subgroups. The subgroups differed in their *depth of knowledge of student conceptions* and their *beliefs about how students develop an understanding of geographical processes*. Ian and Ben, for example, lacked the detailed understanding of specific alternative conceptions exhibited by the teachers in Subgroup 1.

With access to the Phase 1 data, however, they were able to refine this component of their PCK and develop approaches to instruction that acknowledged the diverse conceptual understandings of their students.

In terms of epistemology, Jane held contrasting beliefs to the other teachers in Cluster 1. Although she was aware that students could construct alternative conceptions about the *impacts of tropical cyclones* she did not believe that students developed conceptions of *processes* prior to formal instruction. In contrast to the teachers in Cluster 2, however, Jane employed a range of evidence-based strategies (e.g. simulations, analogies and visualisation tasks) to build students' depth of understanding. She also used various formative assessment approaches (e.g. assessment for learning tasks and student portfolios) to monitor students' understanding and to provide targeted feedback.

Cluster 3

What is the intended purpose of the teaching practices employed by these teachers?

For the teachers in Cluster 3, the instructional rationale focused on the need to ensure that relevant syllabus content was "covered", that students were engaged and that classroom discipline and order was maintained.

How do teachers use their existing knowledge of students' conceptions (PCK of students' ideas) and data provided by the researcher to shape their thinking about classroom instruction?

The three teachers in this cluster did not initially see any value in diagnosing students' preconceptions. They did not make specific use of the individual ideas presented in the data because (1) they did not recognise the relevance of the statements on the data sheet and (2) they could not see how the data assisted them to "fill gaps" in students' knowledge (one of their stated aims of instruction). The data did, however, highlight the inadequacy of some of the teachers' content knowledge, prompting them to adopt highly structured lessons to avoid "making mistakes."

Cluster 2

What is the intended purpose of the teaching practices employed by these teachers?

The teachers in Cluster 2 used similar diagnostic approaches to the teachers in Cluster 1, but they used them for different reasons. The instructional rationale for these teachers focused on engaging students, ensuring that they had comprehensive “notes in their books”, reminding students of “correct” prior learning, “covering” syllabus content and avoiding classroom management issues. Many of the lessons also included teacher-directed lecturing approaches designed to address student “errors” and “fill in” knowledge gaps.

How do teachers use their existing knowledge of students’ conceptions (PCK of students’ ideas) and data provided by the researcher to shape their thinking about classroom instruction?

The teachers in this cluster either (1) made limited use of the data because they did not see its relevance to the syllabus or its importance for the development of deep understanding, or (2) used the data to reflect on their epistemological beliefs (of teaching and learning) and the adequacy of their current pedagogy and content knowledge. The data prompted the teachers in this second category to question the assumption that students do not develop conceptions of processes prior to formal instruction. These teachers, as a result of their involvement in the study, also developed greater awareness of the prevalence of alternative conceptions. Yet the range of strategies put in place to address alternative conceptions was narrow, and few opportunities were provided for students to communicate or evaluate personal theories in class.

Teachers’ use of PCK to inform instruction

The data presented above indicate that the 16 teachers in the study can be broadly divided into five groups according to their use of PCK to inform instruction. The teachers used their knowledge of students’ preconceptions and/or the data provided to: (1) intentionally diagnose and address students’ alternative conceptions – adopting a constructivist/conceptual change approach; (2) identify “errors” and address them by “adding content” to their lessons and “building understanding from scratch”; (3) reflect on and evaluate their own content knowledge, epistemological beliefs and pedagogical approach; (4) limit the focus of lessons, script delivery of content, and minimise opportunities for lessons to go “off track”; and (5) prioritise the “covering of content” and avoid any engagement with students’ “incorrect” ideas.

These results suggest five different perspectives of (or orientations towards) students’ ideas:

1. **Students’ ideas as a resource** – How can I use these ideas to help build student understanding?
2. **Students’ ideas as a source for reflection** – What does this say about my own content knowledge and beliefs about learning and teaching? How can this be improved?
3. **Students’ ideas as a sign of missing knowledge** – What does this tell me about missing knowledge I need to ‘fill in”?
4. **Students’ ideas as a personal evaluation of the teacher** – How can I tighten the focus of my lesson to avoid making “mistakes”?
5. **Students’ ideas as a distraction from the key goals of instruction** – How can I minimise the interruption caused by students’ ideas and maximise the coverage of content?

It should be noted that the above groups are not mutually exclusive. Some of the teachers used their PCK of students’ ideas in several of the above ways. Rhys, for example, used the data to reflect on his beliefs about learning and teaching and to “cover” perceived gaps in the students’ knowledge.

Factors affecting the development and enactment of teachers’ knowledge of students’ ideas

The ability of the teachers to develop and enact their PCK of students’ ideas in the classroom appeared to be a function of their (1) existing knowledge of students’ ideas, (2) depth and accuracy of content knowledge, (3) epistemological beliefs about learning and teaching, and (4) school/classroom context, including the impact of high-stakes external examinations (encouraging teachers to focus on the dissemination of content rather than the building of deep understanding).

The role of content knowledge

These results support the argument of Magnusson (1999, p. 31) that “teachers’ knowledge and beliefs have a profound impact on all aspects of their teaching as well as how and what their students’ learn.” The depth and accuracy of the teachers’ content knowledge (as well as their epistemological beliefs about teaching and learning) had a strong influence over their instructional goals and their use of PCK to inform instruction. These findings indicate that Magnusson’s views are as relevant to experienced Geography teachers as they are to teachers of Science.

The poor content knowledge of some teachers had several consequences: the selective teaching of syllabus content and narrowing of the curriculum, to avoid difficult concepts such as air pressure; a focus on issues and impacts at the expense of geographical processes; gravitation towards unstructured inquiry-based approaches for teaching scientific processes; over-reliance on textbook-based teaching; a focus on the transmission of factual content through teacher exposition; a reluctance to allow extended open discussion in the classroom; a desire to stick to the script regardless of student feedback; and the “snowing” of students with facts to compensate for gaps in understanding. This was evident in the classroom practice of several of the teachers in Clusters 2 and 3 (see, e.g., Sue in Cluster 2 – p. 167). These approaches are likely to result in students simply memorising content or developing atomistic/disconnected understandings of physical processes such as those documented in Section 4.3.2. Similar findings regarding the content knowledge of experienced teachers have also been documented in Science classrooms (Shulman cited by Berry et al., 2008; Harlen, 1997).

In contrast, the teachers with deep, accurate and flexible content knowledge were in a better position to be able to identify alternative conceptions in students’ responses and to recognise the significance of these beliefs for the development of an integrated understanding of the topic. They were aware of concepts and links necessary for building understanding and used this knowledge when designing classroom activities. When these approaches were combined with constructivist views of learning and teaching, the teachers with sound content knowledge were more receptive to students’ questions and were confident in their ability to respond to them. Consistent with the findings of Larkin (2012), these results suggest that there is a connection between specialised subject matter knowledge and teachers’ ability to respond productively to students’ ideas.

Epistemological beliefs and the development and enactment of PCK

The results suggest that deep/accurate content knowledge was necessary but not sufficient for the development and enactment of PCK (students' ideas). Teachers also require beliefs about learning and teaching that recognise the importance of students' preconceptions in the learning process. As Magnusson (1999, p. 122) explains, "Teachers' knowledge and beliefs serve as filters through which they come to understand the components of pedagogical content knowledge. These understandings, in turn, determine how specific components of PCK are utilised in classroom teaching."

The epistemological beliefs of the experienced teachers in this study were diverse, ranging from views of students' minds as "blank slates" through to an understanding of the robust and constructed nature of students' preconceptions. These beliefs framed the way individual teachers viewed events in their classrooms as well as their rationale and goals for instruction. Teachers with an understanding of the constructed and robust nature of students' preconceptions were more likely to value students' ideas and develop strategies for exploring, extending and, where necessary, challenging students' conceptions. Many of the teachers with non-constructivist beliefs viewed learning as a process of accumulating knowledge. They did not use students' ideas as resources for building understanding because they were focused on other goals such as "engaging" their classes and maintaining classroom control. A number of these teachers also believed that students' alternative conceptions were "surface errors" that could be easily changed. This led to instructional approaches focused on teacher exposition, "filling-in gaps" in students' knowledge and correcting student "errors." These results are consistent with research across a number of domains indicating that teachers' epistemological beliefs shape their thinking about all aspects of teaching (including their work with students' ideas) and have a profound impact on classroom practice (Brownlee, Schraw & Berthlesen, 2011; Grossman et al., 1989).

Role of the system and school context

The findings suggest that school and system context also plays an important role in the development and enactment of PCK. A number of the teachers in the study (e.g. Tim and Sue) felt that their pedagogical choices were constrained by the system of high-stakes assessment within which they taught. These teachers believed that the executive at their schools placed a high priority on the School Certificate Test results and that this influenced the instructional approaches they could adopt. The teachers felt that they needed to “cover” all the potential content that might be addressed in these tests and that listening to students’ ideas was an unnecessary distraction from the core aim of accumulating “correct” knowledge in preparation for the School Certificate Tests at the end of Year 10.

The following and final chapter provides a discussion of the implications of the above results, the methodological strengths and limitations of the research, and the study’s significance.

Chapter 7 – Conclusion

7.1 Overview

This chapter provides a summary of the study's outcomes and presents a preliminary model highlighting the factors impacting on the enactment and further development of experienced Geography teachers' PCK of students' ideas. This is followed by discussion of the implications of this study for further research, the theory of PCK development/enactment, curriculum mapping and program development in schools, teacher professional development and policy formulation. The chapter concludes with an examination of the methodological strengths and weaknesses of the study, along with a discussion of the study's significance.

The major research questions for this study were:

1. To what extent are experienced Geography teachers aware of common alternative conceptions held by students (i.e. What is their PCK of students' ideas)?

2. How do teachers use their existing knowledge of students' conceptions and the data provided by the researcher to inform practice? (i.e. How is PCK of students' ideas enacted in the classroom?)

3. What is the relationship between the teachers' PCK development/enactment and their (a) accuracy and depth of content knowledge, and (b) epistemological beliefs about learning and teaching?

7.2 Summary of the main findings

The study consisted of two phases. Phase 1 was designed to identify the conceptual understandings of the students. Phase 2 focused on the teachers' conceptions of tropical cyclones, their PCK of students' ideas and their use of this knowledge to inform instruction.

The results indicate that the students held alternative conceptions of both the underlying scientific processes of cyclone formation and the geographical concepts of scale, spatial distribution, interaction, and interdependence. A range of sources for these alternative conceptions were identified, including counter-intuitive ideas ("air has weight"), literal interpretations of models and representations (boiling kettles to demonstrate evaporation), representations in popular culture (depictions of hurricanes in TV shows and Hollywood movies), and illogical/counter-intuitive terminology (*low* pressure is associated with *higher* rather than lower relative air temperatures and *high* winds).

In addition to the above, the findings indicate that the experienced Geography teachers differed in their depth of knowledge of students' ideas. Some of the teachers were able to provide rich, comprehensive descriptions of common student alternative conceptions whereas others were aware only of students' "general areas of difficulty", held knowledge of students' ideas in a narrow area of the curriculum, or believed that students did not develop alternative conceptions of key geographical concepts prior to formal instruction. Although length of teaching experience was not closely associated with knowledge development in this area, there was a strong connection between the teachers' epistemological beliefs, their depth of knowledge of students' ideas and their use of this knowledge to inform instruction (see Section 6.4). These findings suggest that the development of this knowledge and its application in the classroom is influenced by a number of factors or filters. Four of these factors were directly examined in the study. These were (1) the teachers' existing knowledge of students' ideas, (2) their content knowledge, (3) their epistemological beliefs, and (4) the teaching context. The central role of these factors in shaping the teachers' knowledge and practice was outlined in Section 6.4.

Careful examination of the Phase 2 data, however, suggests the possibility of other factors influencing the teachers' PCK of students' ideas and the enactment of this knowledge base in the classroom. These factors were (1) the coherence and integration of teachers' diverse knowledge bases, (2) the teachers' self-efficacy, and (3) their metacognitive skills including the ability to reflect both in and on practice. Although these factors were not measured directly in the study they emerged as key variables influencing the teachers' knowledge of and work with students' ideas.

7.2.1 The coherence and integration of knowledge components

The Phase 2 results highlight the interdependence between the various components of teachers' knowledge in the development and enactment of PCK. The teachers in Cluster 1 (Subgroup 1), for example, demonstrated integrated and coherent knowledge across each of the components of PCK identified in Figure 2.1 (model of pedagogical content knowledge for Geography teaching) and used a *combination of these subject-specific knowledge bases* when making instructional decisions. They were able to work productively with students' ideas by integrating their understanding of the requirements of the curriculum, assessment approaches for diagnosing and monitoring students' ideas about tropical cyclones, evidence-based strategies and resources for promoting conceptual development in this topic area, and strategies for building student self-regulation skills, metacognitive awareness, motivation and engagement.

The results also suggest that the teachers in this study were able use their strengths in one area of PCK to help develop other knowledge components. A number of the teachers (e.g. Ian and Ben) used their well-developed knowledge of diagnostic assessment strategies to gain a better understanding of the alternative conceptions of tropical cyclone causes and processes held by students in their classes (increasing their PCK of students' ideas).

Teachers with poor knowledge development and integration across the various components of PCK found it more difficult to work with students' ideas in the classroom. The teachers in Cluster 3, for example, had a general or narrow knowledge of students' alternative conceptions, limited knowledge of evidence-based strategies for working with students' ideas, and an approach to assessment that focused on the identification of correct responses and "gaps" in students' understandings.

7.2.2 Confidence in their ability to influence student learning outcomes – The role of topic-specific self-efficacy

The responses of the teachers during the VSR interviews provide a strong indication of a relationship between topic-specific self-efficacy (a teacher's perception of competence or capability to affect student learning outcomes in a specific topic area) and their willingness to engage with students' ideas.

Although self-efficacy (Bandura, 1977, 1986) was not assessed directly in this study, a number of indicators of topic-specific self-efficacy were noted in the responses of the teachers. These indicators included the teachers' expressed lack of confidence in their knowledge of "scientific" processes and their ability to improve students' understanding of tropical cyclone causes and processes. Evidence from the VSR responses suggests that the teachers' beliefs about their competence in teaching this topic had a significant impact on their behaviour in the classroom. Several of the teachers in Cluster 3 (e.g. Nathan) were open about their lack of content knowledge and their anxiety about teaching tropical cyclone causes and processes. These teachers explained that they were reluctant to allow students to express their ideas because they were unsure of the key concepts themselves and were concerned that the students' incorrect ideas would "derail" their lesson. In general, the teachers expressing these views tended to avoid classroom scenarios in which they felt they might not be able to perform.

In contrast, the teachers in Cluster 1 (Subgroup 1) expressed confidence in their ability to design appropriate activities to address students' ideas and questions. As a consequence, they were willing to open up their lessons and encourage students to share their beliefs and personal theories. This is consistent with the conclusions of Park and Oliver (2008) who, in the context of Science education, concluded that teachers were more likely to enact their PCK when they believed in their ability to execute their knowledge effectively. The current study provides additional evidence of a link between topic-specific self-efficacy and the willingness of teachers to work with students' ideas.

7.2.3 Metacognitive skills including the ability to reflect both in and on practice

The results also suggest that the teachers with the ability to reflect both in and on practice were generally more responsive to students' ideas. Several of the teachers in Cluster 1 (e.g. Ian and Ben) used the Phase 1 student data as a tool for reflection when planning instruction. The reflective process helped them to refine their content knowledge, question their beliefs about learning and teaching and enhance their knowledge of students' common alternative conceptions. With this knowledge, these teachers were able more effectively to identify and respond to students' alternative conceptions during instruction.

The process of reflection-in-action was also important because it enabled several of the teachers to continually evaluate their performance and adjust their teaching in response to events during class. As noted in Chapter 6, a number of the teachers in Cluster 1 commented that they often identified alternative conceptions that were unexpected. Addressing these beliefs involved the teachers adapting their instructional approach "on the spot". John, for example, explained that he continually learned through trial and error about new methods for addressing particular alternative conceptions and for building bridges to connect students' existing understandings with the concepts and processes in the curriculum. This capacity to reflect on and analyse practice during lessons enabled these teachers to be more responsive to the needs of their students by responding directly to alternative conceptions as they surfaced in the classroom.

7.3 A preliminary model of PCK development and enactment: a hypothesis for further research

The results presented in Chapter 6 highlight a range of factors affecting the development and enactment of experienced Geography teachers' PCK of students' ideas. The cluster descriptions indicate that these factors, however, are not at the same level of primacy for all teachers. They appear to act more like a series of filters shaping an individual's PCK development.

Using these findings as a base, a preliminary model can be developed to describe the factors affecting the PCK development and enactment (Figure 7.1). Although models of PCK development and enactment have been proposed in the past (e.g. Park & Oliver, 2008), this model focuses specifically on experienced Geography teachers' *knowledge of common student conceptions* (a sub-component of PCK) and their use of this knowledge to inform instruction.

The results of the current study suggest that experienced Geography teachers vary in their initial knowledge of students' intuitive beliefs (represented by Box A in Figure 7.1). The 16 experienced Geography teachers commenced the project with different levels of knowledge of students' preconceptions. Some had knowledge of students' ideas that was fragmented/uni-structural whereas others were classified as holding multi-structural or relational knowledge (see Section 5.1.2). It is hypothesised that experienced Geography teachers use a combination of sources to develop this knowledge base. These sources include their own classroom experiences, information obtained from other teachers, studies reported in textbooks and (to a lesser extent) the research literature (See Box A – Figure 7.1).

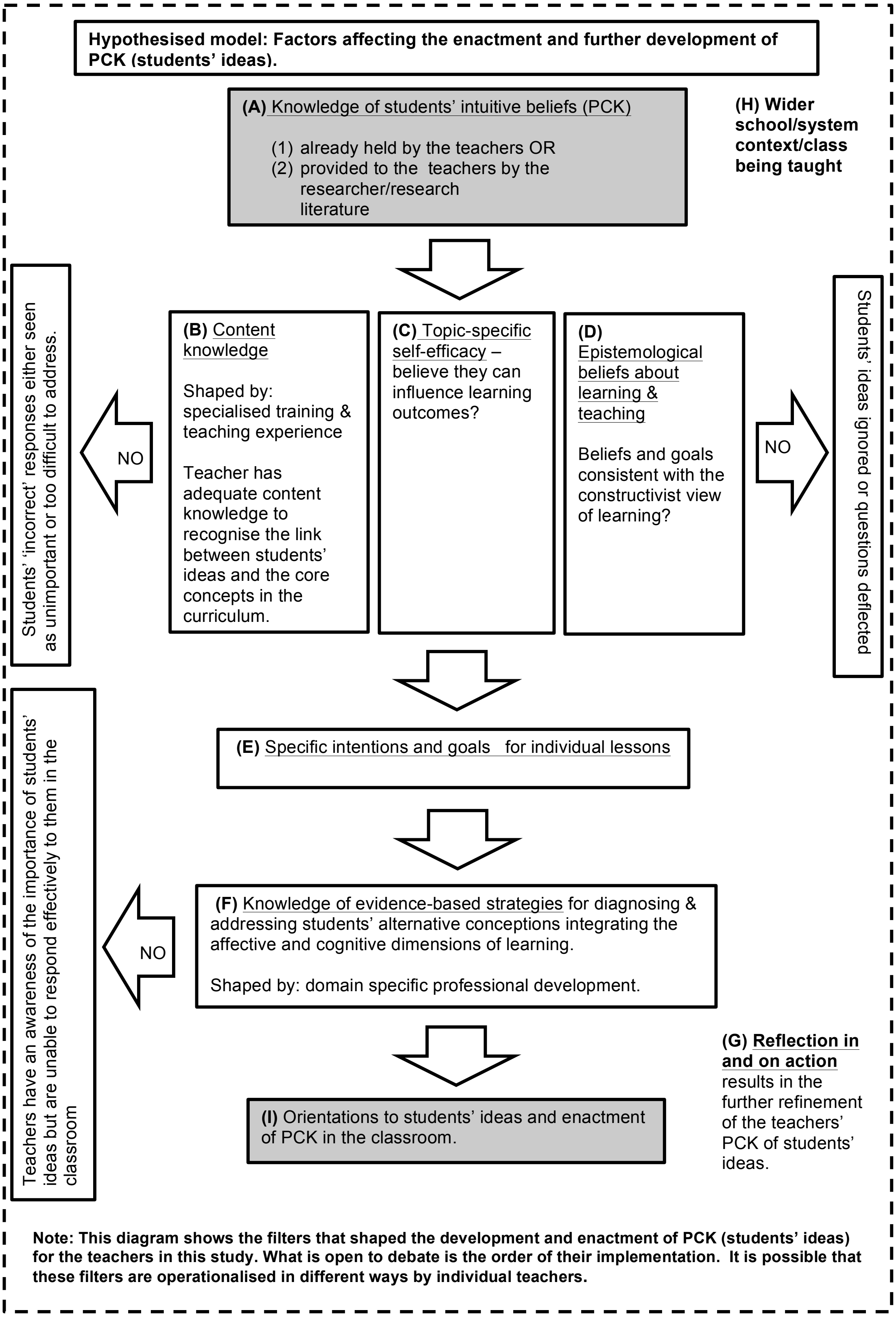


Figure 7.1 Hypothesised model: Factors affecting the enactment and further development of PCK (students' ideas)

The results of Phase 2 suggest that a series of filters (represented by Boxes B-H in Figure 7.1) shape the way teachers use their PCK of students' ideas to inform both planning and instruction. These filters include the teachers' depth and accuracy of content knowledge, their epistemological beliefs about learning and teaching, their topic-specific self-efficacy, their knowledge of evidence-based strategies for working with students' ideas, and their metacognitive skills. The role of these filters, discussed earlier in this chapter and in Section 6.4, are summarised below.

Box B in Figure 7.1 highlights the importance of content knowledge in the development of Geography teachers' PCK. The data presented in Chapter 6 suggest that teachers require a threshold level of *content knowledge* before they are able to identify alternative conceptions during instruction and comprehend the significance of these ideas for the development of deep understanding of the core concepts in the curriculum. Teachers in the current study without this threshold level of understanding either failed to recognise alternative conceptions during lessons or avoided engaging with students' comments and questions that they were unsure about (see Section 6.2).

In addition to their depth of content knowledge the Phase 2 results suggest that teachers need to *believe they can influence student learning outcomes before they are likely to have the confidence to engage with students' ideas*. Data collected from the VSR interviews (Section 6.2) suggest that a teacher's level of confidence and topic-specific self-efficacy can have a significant effect on their planning and professional practice. These findings suggest that teacher self-efficacy (represented by Box C in Figure 7.1) may be important for the development and enactment of Geography teachers' PCK.

As noted in Section 6.3, *constructivist beliefs about learning and teaching* (Box D) also appeared to be necessary for the teachers to recognise and value the role of student preconceptions in the learning process. The Phase 2 data suggests that the teachers with an understanding of the constructed and robust nature of students' preconceptions were more likely to value students' ideas and develop strategies for exploring, extending and, where necessary, challenging these beliefs. These findings imply that adequate levels of content knowledge and constructivist beliefs about learning and teaching are required before teachers are likely to set the diagnosis and addressing of alternative conceptions as key goals of instruction (Box E).

While the results suggest that content knowledge, topic-specific self-efficacy and constructivist beliefs are important for the development and enactment of PCK, these factors alone do not appear to be sufficient. Several of the teachers in the current study developed both their content knowledge (Box B) and their epistemological beliefs (Box D) as a result of their involvement in the study (see Section 6.3). These teachers, however, experienced problems when they attempted to apply this knowledge in the classroom. Although they understood the importance of students' ideas they struggled to identify and implement effective strategies for diagnosing and addressing these ideas. The rich data collected from the VSR interviews suggests that teachers also require knowledge of evidence-based strategies for diagnosing and addressing students' alternative conceptions (Box F) and an ability to reflect both in and on practice (Box G) if they are to work productively with students' ideas. The teachers who were most responsive to students' ideas (Cluster 1, Subgroup 1) demonstrated the capacity to reflect on their practice both during and after lessons. They described their pedagogy as being in a continual state of change, where the responses of students were frequently used to adapt the teacher's approach to instruction. This skill, represented by Box G in Figure 7.1, appears to be key to the refinement and continued development of teachers' PCK of students' ideas.

In addition to the above filters, the findings of this study suggest that the teaching context can play an important role in either encouraging or inhibiting teachers' work with students' ideas. As noted in Chapter 6, the perceived pressure of external examinations (e.g. the School Certificate Test) encouraged a number of the teachers in the current study to focus on "covering" content rather than on seeking to develop the depth of understanding of their students. Such pressures have a significant impact on teachers' priorities in the classroom and warrant further investigation in future research. Box H in Figure 7.1 highlights the likely importance of these factors in the development and enactment of Geography teachers' PCK of students' ideas.

As argued in Chapter 6, the above factors/filters resulted in five perspectives or orientations to students' ideas. The teachers in the current study *viewed students' ideas as*: (1) resources for improving student understanding, (2) sources for reflection and professional growth (3), signs of missing knowledge (4), judgments of their professional skills, and/or (5) distractions from the key goals of instruction. These contrasting views shaped the way individual teachers used their knowledge of students' ideas and the data provided to inform instruction (see Chapter 6). These orientations are represented by Box I in Figure 7.1. Further research is required to determine the extent to which these orientations are typical of experienced Geography teachers.

7.4 Implications of the study

In addition to the theoretical contribution (Figure 7.1) the findings of this study have implications for: further research; curriculum mapping and program development in schools; teacher professional development and the formulation of policy.

7.4.1 Directions for future research

Two general areas for future research can be identified from this study. Firstly, there is a need to further refine and validate the model of PCK development and enactment (Figure 7.1). Secondly, research is required to explore the nature of students' and teachers' mental models of tropical cyclone causes and processes in different locational and cultural contexts.

Refining the model of PCK development and enactment

Once refined and validated, the hypothesised model of PCK development and engagement has the potential to act as a powerful guide for the professional development and practice of Geography teachers. To further refine the model it is recommended that research be conducted in the following areas:

Expanding the sample of teachers to determine the extent to which the findings presented in Figure 7.1 are typical of experienced Geography teachers as a whole.

A key aim of Phase 2 was to identify clusters of Geography teachers with similar characteristics and to create representative illustrations (prototypical descriptions) of their content knowledge, PCK of students' ideas, epistemological beliefs and use of PCK to inform practice. A sample of between 15-20 teachers was considered reasonable for defining these clusters. Teachers were selected for this study if they were currently teaching in the state, independent or Catholic sectors in Sydney, had at least 5 years' experience, had taught tropical cyclones in the past, were intending teach this unit again, and had a background in undergraduate Geography.

Despite the existence of some common characteristics, the data shows *great variability* in the teachers' depth and accuracy of content knowledge, epistemological beliefs, PCK of students' ideas and use of PCK to inform instruction. The differences caused some difficulty in creating unambiguous classifications to define the clusters and prototypical descriptions. Future studies focusing on teachers' knowledge and practice would require a larger sample size to determine whether the differences observed in this study are particular to this sample of 16 teachers or more generalisable across experienced teachers of Geography. Accurate definition of these clusters will enable professional development to be more effectively targeted to the needs of specific groups of Geography teachers.

Exploring the PCK development and enactment of pre-service and early career Geography teachers.

The current study focused specifically on the knowledge and practice of experienced Geography teachers. Further research is required to determine whether Figure 7.1 accurately represents the process of PCK development and enactment for pre-service and early career Geography teachers working in a range of locational and system contexts. It could be hypothesised that the specific goals and intentions of teachers at this early stage of their careers are more likely to be driven by self-efficacy concerns and a preoccupation with the procedural and practical aspects of day-to-day teaching. That hypothesis needs to be tested.

Investigating the role of filters, including metacognitive skills and topic-specific self-efficacy, in the development and enactment of PCK.

As noted above, this study focused primarily on the role of teachers' content knowledge and epistemological beliefs in shaping PCK development and enactment. Data collected from the VSR interviews, however, suggests that other factors, including the teachers' topic-specific self-efficacy and metacognitive skills, might also be important in the development and enactment of PCK. Further research is required to examine the role of these factors in greater detail. In particular, it would be useful to examine the individual elements of topic-specific self-efficacy, their impact on teachers' work with student's ideas, and the role of reflective practice in the refinement and development of PCK.

Exploring the role of additional factors/filters in shaping the development and enactment of Geography teachers' PCK of students' ideas.

Further research using semi-structured interviews, lesson observations and VSR sessions (similar to those employed in the current study) may also help to identify *additional factors/filters* shaping the development and enactment of Geography teachers' PCK of students' ideas. It is likely, for example, that teachers' own school experiences play a role in shaping their work with students' ideas. Data collected from the exploration of these factors could be used to further refine the preliminary model of PCK development and enactment (Figure 7.1).

Investigating the nature of experienced Geography teachers' PCK of students' ideas in other areas of the curriculum.

This study intentionally focused on Geography teachers' PCK in a narrow area of the curriculum. It is important that the focus of future research is broadened to examine the nature of students' preconceptions in other areas of the discipline, teachers' knowledge of these ideas and their use of this knowledge to inform instruction. There is, for example, a distinct lack of research exploring students' conceptions and teachers' PCK in Human Geography.

Exploring the link between enactment of PCK and student learning outcomes in Geography.

While this study examined the link between teachers' knowledge of students' ideas and their classroom practice, it did not explicitly investigate the impact of instruction on student learning. It can be hypothesised from the findings of this study that changing teachers' awareness of students' ideas, alone, is unlikely to result in improvements in student learning. The findings suggest that teachers also require sound content knowledge, constructivist beliefs about learning, knowledge of evidence-based instructional strategies and confidence in their ability to shape student learning outcomes before they are likely to work effectively with students' ideas in the classroom. The link between PCK development and student learning, however, warrants further attention.

Broadening the investigation of students' and teachers' mental models

In this study the sample of schools was intentionally restricted to ensure that students had limited first-hand experience of tropical cyclone events. Students were sourced from a range of school types and locations across Sydney to ensure that the sample (n = 380) was as representative as could be obtained for a large metropolitan city. It is expected that the findings would be generalisable to similar populations.

The bigger question, however, is whether the same results would be found with students' from cyclone prone areas. It is an open question as to whether first-hand experience would mitigate the impact of popular culture or reinforce it. One hypothesis is that students in this context might hold more accurate understandings of impacts but similar alternative conceptions of the underlying processes and principles. The work of Lee (2000) and Belknap (2003) suggest that this is likely to be the case.

It would also be useful to explore the impact of cultural background and context on the development of both students' and teachers' mental models of tropical cyclones. Driver (1994) argues that students' conceptions are often universal and transferable across cultures. This claim could be tested by exploring the conceptions of students from different cultural backgrounds (e.g. Aboriginal and Torres Strait Islander students).

7.4.2 Curriculum mapping and program development in schools

The current research has implications for the organisation and delivery of the curriculum in secondary schools. The results indicate that students apply common alternative conceptions across disciplines when attempting to make sense of key concepts in the curriculum. Conceptions of "weightless air" and water "boiling" during evaporation, for example, were found in the current study with Geography students and in previous research with students studying secondary Science (Sere, 1982).

Given the similarities in the conceptual building blocks for student understanding across subject domains (especially Science and Geography), an integrated or whole-curriculum approach to the mapping of students' alternative conceptions is necessary. Cross-curricular mapping of foundational concepts and common alternative conceptions could foster valuable dialogue across discipline boundaries regarding the role of students' intuitive beliefs in the learning process. This mapping would also enable teachers from different subject domains to share their knowledge strategies and resources for diagnosing and addressing students' common alternative conceptions. The renewed focus on "core knowledge" and "unifying ideas" in the development and revision of national curriculum documents (e.g. in Australia and the UK) should make this process of identifying common foundational concepts easier.

7.4.3 Implications for teacher professional development

The results of this study suggest that if we want to improve experienced Geography teachers' work with students' ideas we need to focus professional development on the six filters identified in Figure 7.1: teachers' knowledge of evidence-based strategies for diagnosing and addressing students' ideas, the depth and accuracy of teachers' content knowledge, teachers' epistemological beliefs, teachers' topic-specific self-efficacy and their metacognitive skills. Research should also be undertaken to monitor the impact of professional development interventions on the PCK development of Geography teachers, their classroom practice and student learning outcomes.

Addressing teachers' knowledge of evidence-based instructional approaches

The results of the current study suggest that teachers require knowledge of evidence-based strategies for building student understanding if they are to work effectively with students' ideas. Targeted professional development may assist teachers to develop this knowledge base.

Although there is no singular agreement among researchers regarding the mechanisms of conceptual change (Clement, 2008), a number of possible approaches for improving the conceptual understanding of students can be identified from the literature. Vosnaidou (2008) argues that instruction for conceptual change should include "moderate uses of cognitive conflict" (p. xix) or dissonance (strategies designed to promote dissatisfaction with current conceptions) combined with constructive, long-term approaches for fostering conceptual understanding. Users of these strategies need to consider the epistemological (views of knowledge and learning), ontological (views of reality – "air is matter not a vacuum") and affective dimensions (emotions, motivation and social aspects) of learning (Duit et al., 2008, p. 633). Detailed discussion of evidence-based conceptual change strategies is beyond the scope of this chapter. A list of strategies for addressing the epistemological, ontological and affective dimensions of learning is provided in Appendix 12.

Strategies for increasing teachers' accuracy and depth of understanding in Geography

The findings of this research highlight the importance of enhancing both the depth and accuracy of Geography teachers' content knowledge – especially their understanding of (and confidence with) underlying scientific processes and principles. This knowledge is vital because of its links with other dimensions of accomplished practice, most importantly the development of PCK. As Reinfried (2012) notes, conceptual understanding is required before teachers can engage in effective reasoning and problem solving, including the development of strategies for improving student understanding. The discussion below outlines a number of strategies that could be used to improve the conceptual knowledge base of teachers.

1. Improving the content knowledge of pre-service Geography teachers

Internationally, jurisdictions typically have specific standards for defining the minimum content knowledge requirements of teachers. This section focuses on the impact of these standards in an Australian context.

As noted in the introduction (Chapter 1), the Australian Institute for Teaching and School Leadership (AITSL) has recently moved to mandate minimum *discipline-specific content requirements* for teachers in Australia. Students wishing to teach Geography as a first teaching subject will be required to complete at least six units of study in the discipline, with no more than two units at a first year level and at least two units at third year level. There is no specific requirement, however, for students to have a background in Physical Geography. The findings of this study suggest that these requirements are inadequate as a foundation for secondary Geography teaching. An academic major in Geography, with a balance of units across Human and Physical Geography, would provide graduating teachers with a better foundation for building PCK. While it is not possible for pre-service teachers to complete undergraduate studies in all aspects of the curriculum, foundational studies in Physical Geography would appear to be essential. The results of the current study indicate that it was the teachers without a background in Physical Geography who found it most difficult to provide relational explanations of the processes and impacts of tropical cyclones.

Ensuring that graduate teachers have a threshold understanding of physical processes may also improve their confidence levels and willingness to engage with these concepts during instruction (key elements of topic-specific self-efficacy). This is particularly important given the alignment in content in the Australian curriculum: Science and Geography. For example, students study weather related hazards in Year 7 Geography while learning about the water cycle in Science.

2. Promoting a culture of lifelong professional learning

There is significant evidence to suggest that engagement with the professional community and a motivation towards lifelong learning can help teachers maintain the accuracy and currency of their content knowledge (Catling, 2003). Through active participation in the activities of professional associations teachers can keep up-to-date with developments in the discipline and engage with others teaching similar content. These networks provide invaluable opportunities for critical reflection with colleagues and can help build motivation for lifelong learning. The resources provided by professional associations, including journals, conferences and workshops, can also provide important content knowledge support. Additional internal and external opportunities for enhancing the professional knowledge of Geography teachers, including web-based support materials (e.g., the GEOGstandards site http://www.geogstandards.edu.au/), online learning communities, formal accredited study, non-award study and teacher mentoring programs, are discussed by Purnell (2010).

3. Providing differentiated professional development to cater for the specific needs of teachers

The results of this study suggest that, as well as the generic strategies for building teachers' content knowledge (discussed above), differentiated professional development might be appropriate for teachers depending on their current depth of understanding of the content in the curriculum.

Probing and extended discussion with Socratic/supportive dialogue might assist teachers with multi-structural understandings of the content to identify inconsistent beliefs and to resolve contradictions and obstacles in their thinking. Some of the teachers in the current study (particularly in Cluster 2) were able to increase their depth of understanding of the content by using the interviews and VSR sessions as an opportunity for reflection. The Phase 2 results suggest that this approach is most likely to be effective when teachers already have a sound (multi-structural) knowledge of the individual concepts and can draw upon their personal experiences to create cognitive conflict. This approach does not appear to work with teachers who lack an understanding of the underlying concepts, and it is unlikely to improve teachers' understandings of abstract processes such as the behaviour of molecules during evaporation.

Finding opportunities to reflect, either individually or with colleagues, is challenging given the commitments of classroom teaching. The results of this research suggest, however, that such an investment of time may have significant benefits. As Purnell (2010) notes, the very act of sharing experiences and ideas with colleagues can stimulate professional learning, and the *Professional standards for teaching School Geography* (University of Melbourne et al., 2010) can provide an effective scaffold for structuring these conversations. Other constructivist approaches which promote reflection and cognitive conflict, such as the mental model-building strategy (Reinfried, 2006b) and modified learning cycle (Jones et al., 1999), may also help practising Geography teachers identify inconsistencies in their explanations and develop more accurate mental models. Similarly, the knowledge development of early career teachers can also be effectively supported through mentoring relationships with more experienced staff.

In contrast to the above, more direct/explicit mental model-building might be appropriate for improving the depth of conceptual understanding of teachers with uni-structural and pre-structural understandings. Professional development for these teachers should also involve the explicit discussion and evaluation of a range of explanations for geographical processes and phenomena, including the teachers' intuitive mental models and beliefs.

Strategies for addressing the epistemological beliefs of experienced Geography teachers

Teachers' epistemological beliefs have an important impact on their orientations towards students' ideas and their work with these ideas in Geography classrooms. The teachers in the current study required both an awareness of students' common alternative conceptions and an understanding of the constructed nature of learning before they were likely to engage with students' ideas.

The results of the current study suggest that professional development focused on teachers' understandings of learning processes and the importance of students' alternative conceptions is required to promote sustained changes in teachers' beliefs and practices. Reinfried's research (2006b, 2007; 2012) using the model of educational reconstruction (Duit, Gropengieβer, Komorek & Parchmann, 2012) and the mental model-building approach (Taylor et al., 2003) provides a useful framework for professional development aimed at reconstructing teachers' epistemological beliefs. These approaches provide teachers with the opportunity to experience conceptual change for themselves so that they gain a better understanding of the nature of students' intuitive beliefs and the importance of these ideas in the learning process.

7.4.4 Implications for policy development

The findings of this study help to inform policy developments in a number of key areas. These include: the mandating of minimum content requirements for teachers of secondary Geography; emerging state and national teacher performance, accreditation and appraisal schemes; and standards for the accreditation of pre-service teacher training programs (Australian Institute for Teaching and School Leadership - AITSL, 2011, 2012). The outcomes of this research suggest that policy developments in each of the above areas need to emphasise the importance of teachers' rich, discipline-specific content knowledge and their understanding of and ability to work with students' ideas.

7.5 Methodological strengths and limitations

A key strength of this study was the mixed methodological approach used to identify common alternative conceptions and to explore the teachers' PCK of students' ideas. The approach adopted for Phase 1 (questionnaire, semi-structured interview drawing task, visualisation activity and stimulus-response task) enabled the triangulation of data from multiple sources to support the development of a rich account of the students' and teachers' alternative conceptions. Likewise, the combination of semi-structured interviews, classroom observations and VSR sessions used in Phase 2 provided rich qualitative data which was essential for the identification of factors and filters affecting PCK development and enactment. An additional advantage of this approach was its ability to elicit honest and detailed responses from the teachers. Given these strengths, this methodology is likely to be of value to future studies investigating elements of teachers' PCK and their impact on classroom practice.

The disadvantage of using such a data-rich approach was that the study was inevitably constrained to a relatively small sample. This limited the extent to which the findings can be generalised. As noted in the discussion of implications, the sample size of 16 teachers made it difficult to identify clearly defined clusters or to develop distinct descriptions of the teachers' knowledge and practice. While important differences were noted in the characteristics of each cluster, some of the boundaries were not well defined. Applying this research approach with a larger sample of teachers would help to determine whether the actual clustering of teachers is more distinct and whether differences identified in this particular study are generalisable across the wider population of experienced Geography teachers.

7.6 Significance of the study

This study is the first substantive investigation of experienced Geography teachers' PCK of students' ideas and the factors affecting the development and enactment of this knowledge base. The study highlights some parallels with the Science literature, but it goes beyond that to demonstrate the impact of PCK on the teaching practice of experienced Geography teachers and the implications for curriculum development, pre-service teacher training, in-service teacher professional development and the formulation of policy.

From a theoretical perspective, this study recontextualises and extends earlier work in Science education (e.g. Morrison & Lederman, 2003; Park & Oliver, 2008) by presenting a hypothetical model for the development and enactment of Geography teachers' PCK of students' ideas. The model (Figure 7.1) is significant in that it highlights the importance of a range of filters in shaping experienced Geography teachers' work with students' ideas. It also provides a framework for future research, teacher appraisal and professional development in this area.

7.7 Concluding remarks

This study has been completed within the context of the most substantial curriculum development process in Australia's history. It is, therefore, both timely and significant. It can be anticipated that the findings of this research would help inform current and future curriculum development processes, act as a guide for policy and enhance the delivery and design of pre-service and in-service teacher professional development programs. Over time, the study has the potential to enhance the quality of Geography teaching and student learning in schools.

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Chapter 8 Appendices

Summary List of Appendices

APPENDIX 1

PUBLICATIONS FROM THE THESIS

APPENDIX 1: Publications from the thesis

Lane, R. (2008). Students' alternative conceptions in Geography. Geographical Education, 21, 43-52.

Within the contexts of learning and teaching there is a substantial (and growing) body of research indicating that students often bring to class a range of 'alternative frameworks' and 'naive theories' (constructed from their prior experiences) that are inconsistent with currently accepted 'expert views'. While there is a significant body of work related to students' conceptions in some subject domains (namely Physics), there has been little research undertaken on the relationship between teacher awareness of student conceptions and effective pedagogy in Geography. The National Curriculum debate in Australia provides geographers with a unique opportunity to consider the role of students' preconceptions in the development of conceptual understanding in Geography and the implications of this for its pedagogy. This paper argues that an understanding of students' common preconceptions regarding core geographical concepts is a central component of a teacher's pedagogical content knowledge and that this knowledge is essential for the development of pedagogies that promote conceptual change and deep understanding in this domain. The paper provides a review of the literature concerning the nature and development of students' pre-instructional ideas and foreshadows an agenda for future research that will enhance our understanding of the relationship between student preconceptions and classroom practice in Geography.

Lane, R. (2009). Articulating the pedagogical content knowledge of accomplished geography teachers. Geographical Education, 22, 40-49.

This paper reports an analysis of the pedagogical content knowledge (PCK) of two experienced teachers; it examines how this knowledge is used to inform classroom practice and how it might assist in the process of the development of the 'accomplished' standard for Geography teaching. A detailed case study of the teachers examines their beliefs and practices as they teach a unit on tropical cyclones to Stage 5 (Year 9/10) students. The study highlights differences in the teachers' content knowledge and their pedagogical understandings and contrasts their approaches to investigating and assessing students' preconceptions. These case studies suggest that a willingness to allow students' expression of naïve theories in class, and a teacher's confidence and awareness to use common preconceptions to shape teaching and learning may assist students' educational development and their deep understanding of key geographical concepts. Recommendations are presented that have implications for the setting of the 'accomplished' standard for Geography teaching.

Lane, R. (2011). Exploring the content knowledge of experienced Geography Teachers. Geographical Education, 24, 51-63.

This paper explores the content knowledge of sixteen experienced teachers in an area of the Geography curriculum that has previously been investigated with students – tropical cyclone causes, patterns and processes. Data collected using a questionnaire, drawing task and semi-structured interview enabled the analysis of the teachers' conceptual knowledge and depth of understanding. Three categories of conceptual knowledge were identified including: concepts already understood by the teachers; concepts where understanding developed throughout the interview; and concepts that were less regularly understood and resistant to change. The paper concludes with the implications of these findings for classroom practice and the development of Geography teachers' pedagogical content knowledge. Strategies for promoting the development of Geography teachers' substantive (content) knowledge are also explored.

Lane, R., & Coutts, P. (2012). Students' alternative conceptions of tropical cyclone causes and processes. International Research in Geographical & Environmental Education, 21(3), 205-222. doi: 10.1080/10382046.2012.698080

While Shulman (1987) argues that an important component of pedagogical content knowledge (PCK) is teachers' understanding of the alternative conceptions commonly held by students, relatively little is known about what students believe about many topics in the school curriculum. This paper focuses on a content area typically featured in Geography curriculum as the first phase of a larger study designed to investigate Geography teachers' PCK. Common student conceptions of tropical cyclone causes and processes were identified using a variety of methods. Results indicate that secondary school Geography students (n=339) hold a range of alternative conceptions related to foundational scientific principles as well as the geographical concepts of location, scale, spatial distribution, interactions and interdependence. Implications for the knowledge requirements of Geography teachers are discussed along with suggestions for future research.

APPENDIX 2

ETHICS DOCUMENTATION

2A Ethics Approval Letter – Macquarie University
2B Ethics approval – NSW Department of Education and Training

Appendices 2A – 2B of this thesis has been removed as they may contain sensitive/confidential content

APPENDIX 3

SAMPLE PARTICIPANT INFORMATION LETTERS AND CONSENT FORMS

3A **Participant Information letter: Principals**
3B **Participant Information Sheet: Parent/Caregiver**
3C **Consent from: Student/Parent/Caregiver – written tasks and interviews**
3D **Consent from: Student/Parent/Caregiver – videotaped lessons**

Appendix 3A Participant Information Letter: Principals

Date:

Dear Principal,

I am a PhD student at Macquarie University engaged in research on the use of students' pre-instructional understandings to guide pedagogy in Geography. My supervisors are Associate Professor Pamela Coutts (02 9850 8665) pamela.coutts@mq.edu.au and Dr. Wilhelmina Van Rooy (02 9850 8664) Wilhelmina.VanRooy@mq.edu.au.

The study, which will involve 17 schools from the State, Catholic and Independent sectors, seeks to identify the pre-instructional understandings of students and the way in which this information can be used to adapt the classroom practice of expert Geography teachers.

The purpose of this letter is to invite your school to be involved in this research project and to provide you with information regarding the intended benefits for participating schools.

In particular, I would appreciate your support in identifying the following participants for the study:

- A **trained Geography teacher** who has taught a lesson on cyclone causes and processes sometime in the past (Investigating Australia's Physical Environment – Natural Hazards); who will be teaching Stage 5 Geography in 2009; and is happy to incorporate a lesson on cyclones into their teaching program; and
- A **year 8 or 9 class** that has not previously studied cyclones in either Geography or Science.

Although I have spoken to [teacher's name] about the research, this was not a formal request to participate. I am now approaching you as principal to seek permission to invite staff and students to be involved in the project.

The research will involve interviews with teachers to determine their current teaching practice, the completion of a drawing task and questionnaire to identify the teacher's and students' current ideas; a videotaped lesson and a post lesson teacher interview. In addition to this, one or two students from the class may need to be interviewed in order to clarify the ideas represented in their responses to the drawing task and/or questionnaire.

As a component of the research design, each teacher will be given access to information regarding the understandings of students from all 17 participating schools. The researcher will also provide follow-up professional development training for participating schools.

The expected time line for each stage of the project and time commitments for participating staff and students are outlined below:

Milestone	**When?**
Phase 1 – Collection of baseline data from teachers (1 hour interview)	October – December (Term 4) 2008
Phase 2 – Collection of baseline data from students using a drawing task and questionnaire (a single 45 min lesson). Interviews with 1 or 2 students (20 mins each).	October – December (Term 4) 2008
Phase 3 – Feedback to teachers regarding common student understandings.	February (Term 1) 2009
Phase 4 – Observing and recording a single lesson with Stage 5 Geography (a single lesson in its regular timetabled location)	March – April (Term 1) 2009
Phase 5 – Video-stimulated recall (a one hour interview with participating teachers)	Within two weeks of the lesson

The interviews with students and teachers will be video-taped and coded. All aspects of this study, including the results, will be strictly confidential and only the researcher will have access to information about participants. A report of the study will be submitted for publication however individual participants will not be identifiable in such a document. All the data collected in this study will be stored securely at Macquarie University. Each researcher involved in this project is employed of Macquarie University, and has a commitment to the ethical conduct of research.

The students' and teachers' participation in the study is completely voluntary and they are under no obligation to consent. The participants may withdraw from the study at any time at which point all records of their participation will be destroyed. The students' and teachers' withdrawal from this study will in no way affect their relationship with Macquarie University.

The administrative commitments of participating schools in the research project are summarised below:

Administration:

- Consent forms distributed and collected from parents.
- Allocation of space for student interviews

I will be contacting you shortly to make arrangements for a meeting to discuss your school's possible participation in the project.

If you would like to know more about the research and how your school can benefit from the results, please feel free to contact either of the supervisors listed below or myself.

Rod Lane, PhD Student and Lecturer in Education, School of Education, Macquarie University.
Email: rod.lane@mq.edu.au
Phone: 9850 9172

Yours sincerely

Mr Rod Lane	A/Prof. Pamela Coutts	Dr. Wilhelmina Van Rooy
Researcher	Supervisor	Associate Supervisor

The ethical aspects of this study have been approved by the Macquarie University Ethics Review Committee (Human Research). If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Research Ethics Officer (telephone [02] 9850 7854, fax [02] 9850 8799, email: ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix 3B Participant Information Sheet: Parent/Caregiver

PARENT/CAREGIVER INFORMATION SHEET – Phase 1: WRITTEN TASKS AND INTERVIEW
Investigating the relationship between knowledge of students' conceptions and pedagogy in Geography

Your child is being invited to take part in a study being conducted by Mr. Rod Lane from Macquarie University.

It is a part of a Doctor of Philosophy in Education being supervised by Associate Professor Pamela Coutts (ph. 02 9850 8665, email: pamela.coutts@mq.edu.au) and Dr. Wilhelmina Van Rooy (ph. 02 9850 8664, email: Wilhelmina.VanRooy@aces.mq.edu.au). We are asking if it is okay for your child to take part in this project.

We are trying to find out what students know about natural hazards before they study this topic in either Geography or Science. The information from this study will be used to make suggestions for improving the teaching of Geography in the middle school years.

As a component of this research, participants will be asked to complete a questionnaire and drawing task to identify their current ideas about natural hazards. The data collected from this research will not in any way be used to evaluate the academic progress of individual students. A sample of one or two students from each class may also be asked to talk through their responses in an informal interview with the researcher. These interviews will take place during school time and will run for approximately 15-20 mins (specific times for interviews will be negotiated with school staff). Please note: Students who have had firsthand experience of a cyclone will be excluded from the study in order to miminise any potential distress that the interview questions might cause. Please indicate on the attached consent form if you would not like your child to be interviewed.

Participation is voluntary and your child will only take part if you and your child agree. If you do decide not to take part, it will not affect your child's results or progress at school. If you or your child changes your mind about taking part, even after the study has started, just let the researcher know and any information already collected about your child will be destroyed.

All aspects of this study, including the results, will be strictly confidential and only the researcher will have access to the information, except when students are identified as being at risk of harm from themselves or others. In this case the names of these students will be given to the school principal. A report of the study may be submitted for publication but individual participants will not be identifiable in such a report.

I draw your attention to the fact that the interview phase of this project will involve the audio recording of participants. These recordings will be conducted within two weeks of the in class written tasks. All data collected from the interviews will be stored in a secure location at Macquarie University for seven years after which they will be destroyed. Data will only be accessed by the researcher and will only be used for purposes consistent with the stated research aims.

If you have any concerns about what has been recorded, you may access recordings of your child within the period of storage. These recordings can be accessed by contacting the researcher rod.lane@mq.edu.au. You may exclude recordings of your child from the study by indicating this on the attached consent form.

When you have read this information Rod Lane will be available to answer any questions that you may have. If you would like to know more at any stage, please feel free to contact:

Rod Lane 02 98509172 rod.lane@mq.edu.au
Associate Professor Pamela Coutts. 02 9850 8665 pamela.coutts@mq.edu.au
or Dr. Wilhelmina Van Rooy. 02 9850 8664 Wilhelmina.VanRooy@mq.edu.au

This information sheet is for you to keep. Your child has also been given information about this project.

Yours sincerely

Mr Rod Lane	A/Prof. Pamela Coutts	Dr. Wilhelmina Van Rooy
Researcher	Supervisor	Associate Supervisor

The ethical aspects of this study have been approved by the Macquarie University Ethics Review Committee (Human Research). If you have any complaints or reservations about any ethical aspect of your participation in this research, you may contact the Committee through the Research Ethics Officer (telephone [02] 9850 7854, fax [02] 9850 8799, email: ethics@mq.edu.au). Any complaint you make will be treated in confidence and investigated, and you will be informed of the outcome.

Appendix 3C Consent from: Student/Parent/Caregiver – questionnaire and interview

Research Project: Investigating the relationship between knowledge of students' conceptions and pedagogy in Geography

I (*print name*)……………………………give consent to the participation of my child (*print name*) ……………………………………in the research project described below.

CHIEF RESEARCHER: Rod Lane, School of Education, Macquarie University, 2109.
Email: rod.lane@mq.edu.au.

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved has been explained to me and any questions I have about the project have been answered to my satisfaction.
2. I have read the Parent Information letter and have been given the opportunity to discuss the information and my child's involvement in the project with the researchers.
3. I am aware that I should retain a copy of the Parent Information letter and letter of consent for future reference.
4. I have discussed participation in the project with my child and my child agrees to their participation in the project.
5. Details of procedures and any risks have been explained to my satisfaction.
6. I understand that that my child's participation in this project is voluntary; a decision not to participate will in no way affect their academic standing or relationship with the school and they are free to withdraw their participation at any time.
7. I understand that my child's involvement is strictly confidential and that no information about my child will be used in any way that reveals my child's identity.
8. I understand that audio recordings will be made as part of the study. These recordings will be of approximately 15-20 minutes in duration take place during regular scheduled Geography lesson in Term 4, 2008.
9. I understand that if I have any questions relating to my child's participation in this research, I may contact the supervisors and researcher of this study.
10. I acknowledge receipt of a copy of this Consent Form and the Parent/Guardian Information letter.

Intended research activities:

a. The questionnaire and drawing task to be conducted at school in Term 4, 2008,
b. The interviews will be conducted at school within 2 weeks of the questionnaire and drawing task.

Please cross out any activity that you do not wish your child to participate in.

Signed………………………………………………………………………

Name………………………………………………………………………

....	....
Signature of Parent/Guardian	Signature of Child (optional)
....	....
Please PRINT name	Please PRINT name
....	....
Date	Date

Appendix 3D Consent from: Student/Parent/Caregiver – video recorded lessons

Research Project: Investigating the relationship between knowledge of students' conceptions and pedagogy in Geography

I (*print name*)……………………………give consent to the participation of my child (*print name*)……………………………………in the research project described below.

CHIEF RESEARCHER: Rod Lane, School of Education, Macquarie University, 2109. Email: rod.lane@mq.edu.au.

In giving my consent I acknowledge that:

1. The procedures required for the project and the time involved has been explained to me and any questions I have about the project have been answered to my satisfaction.
2. I have read the Parent Information letter and have been given the opportunity to discuss the information and my child's involvement in the project with the researchers.
3. I am aware that I should retain a copy of the Parent Information letter and letter of consent for future reference.
4. I have discussed participation in the project with my child and my child agrees to their participation in the project.
5. Details of procedures and any risks have been explained to my satisfaction.
6. I understand that that my child's participation in this project is voluntary; a decision not to participate will in no way affect their academic standing or relationship with the school and they are free to withdraw their participation at any time.
7. I understand that my child's involvement is strictly confidential and that no information about my child will be used in any way that reveals my child's identity.
8. I understand that video recordings will be made as part of the study. These recordings will take place during a regular scheduled Geography lesson in Term 1, 2009.
9. I understand that if I have any questions relating to my child's participation in this research, I may contact the supervisors and researcher of this study.
10. I acknowledge receipt of a copy of this Consent Form and the Parent/Guardian Information letter.

Intended research activity:

- Video recording of a regular scheduled Geography lesson in Term 1, 2009

Please cross out any activity that you do not wish your child to participate in.

Signed……………………………………………………………………..

Name………………………………………………………………………

Date………………………………

....	....
Signature of Parent/Guardian	Signature of Child (optional)
....	....
Please PRINT name	Please PRINT name
....	....
Date	Date

APPENDIX 4

COMPOSITION OF THE TEACHER SAMPLE

APPENDIX 4: Composition of the teacher sample

Teacher number and pseudonym	Years of experience	School type	Specialised training and experience
(1) Wendy	35	Co-educational	Both Physical and Human Geography including Climatology at undergraduate level. Long-time member of Professional Associations supporting Geography teachers. Masters degree including studies in Physical Geography.
(2) Ken	24	Co-educational	Both Physical and Human Geography including Geomorphology, Climatology, Agricultural Geography, Urban Geography, Population Geography.
(3) Belinda	21	Single sex - Boys	Geology, Climatology, Environmental Management, Coastal Studies (BA Dip. Ed - Geography
(4) Jane	25	Single sex - Girls	Human Geography including settlement, population Geography, Economic Geography. Physical Geography studies in Geomorphology and Climatology. (Teaching qualification included a double major Economics/Geography)
(5) Tim	10	Co-educational	Focus on Human Geography. Basic first year Physical Geography - Geomorphology (BA Dip. Ed - Geography).
(6) Sue	5	Single sex - Boys	Focus on Physical Geography including Geology, Ecology, some Human Geography in first year studies (Environmental Management Degree).
(7) Rachel	6	Co-educational	Minor in Geography including Geography Teaching Methodology. Modern History major. Training involved mix of Human Geography including population studies and general Physical Geography. Has not taught Senior Geography.
(8) Ian	23	Single sex - Boys	Certificate course in Teaching. No formal study in either Human or Physical Geography. Learned on the job. Certificate in Gifted and Talented Education. Teaches NSW curriculum and International Baccalaureate in Geography. Extensive marking experience School Certificate, and HSC

(9) John	13	Co-educational	Geology, Climatology, Hydrology, Geomorphology, Bio-geography, Industrial Geography, Resource and environmental management, general Human Geography (BSc)
(10) Gail	24	Single sex - Girls	Geomorphology, Climatology, general Human and Physical Geography (BA DipEd Double major Economics/Geography)
(11) Tina	18	Single sex - Girls	Geomorphology, Geology, Environmental Management, general Human Geography. Little if any specific study of climatology. (BA DipEd Double major Economics/Geography)
(12) Kate	5	Single sex - Boys	Focus on Human Geography including development studies. First year Geology. Experience working for NGOs on development projects. Has not taught Senior Geography.
(13) Roy	8	Single sex - Boys	Focus on Human Geography. Basic first year Physical Geography (Bachelor of Teaching, BA – Geography Major).
(14) Rhys	5	Co-educational	Focus on Physical Geography including Resource and Environmental Management, Climatology and Marine Science. (Major in Environmental Science). Teaches NSW curriculum and International Baccalaureate in Geography. Experience in Environmental Education outside schools.
(16) Ben	7	Single sex - Girls	Atmospheric Science, Resource and Environmental Management (BA Dip Ed – Geography)
(17) Nathan	23	Single sex - Girls	Balanced studies in both Human and Physical Geography including Geology, Environmental Management, Atmospheric Sciences.

APPENDIX 5

STUDENT AND TEACHER QUESTIONNAIRE

5A Student questionnaire
5B Teacher questionnaire

Appendix 5A Student questionnaire

Code:____________________________

Instructions:

- Indicate whether each of the following statements is true or false on the answer sheet provided.
- Place a cross on the scale to the right to indicate how confident you are about your response.
- If you wish to expand on any of your beliefs you can do so in the space provided under each statement on this sheet.
- The purpose of the quiz is to find out your current thoughts about this topic. Neither your classmates nor your teacher will see your answers.

Record your ideas after each statement.

- Air has mass.
- Air is weightless.
- The earth is heated unevenly by the sun and this results in differences in air pressure at the surface.
- Air pressure directly above a body of water increases as the temperature of the water increases.
- Cold air applies a lower pressure on the ground than the same volume of warm air.
- Cold air is denser than warm air.
- Rising air applies less pressure on the earth's surface than falling air (of the same volume).
- A body of air will rise if it is less dense than the air around it.
- Most deaths and injuries in severe tropical cyclones worldwide are due to rising sea levels.
- Air temperature increases from sea level to the base of the clouds.
- Cold temperatures are the main cause of strong winds.

- The weather is generally cold during a tropical cyclone.

- The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.

- Winds are caused by differences in air pressure across the earth's surface.

- Tornadoes differ from tropical cyclones in that they are smaller and can form over land.

- When water evaporates from the ocean it is a boiling process.

- The molecules that make up water expand and float away when heated by the sun's energy.

- Rates of evaporation are higher from a cool body of water than a warm one.

- Rain occurs when water droplets in clouds join together and become too heavy to remain suspended in the air.

- Only a small proportion of the water that evaporates ever returns to the earth's surface as precipitation (rain, sleet, hail or snow).

- Clouds are tiny water droplets suspended in the air.

- Hurricanes, typhoons, tornados and tropical cyclones all contain warm rising air.

- The terms "hurricane", "typhoon" and "tropical cyclone" describe different types of storms that occur around the world.

- When the conditions become calm after the initial gale force winds of a tropical cyclone, the danger has passed.

- Tropical cyclones increase in intensity when they move over land.

- A tropical cyclone is a rotating column of air that is in contact with the ground.

- In a tropical cyclone, wind gusts of 280km/h will cause twice-as-much damage to the built environment as wind gusts of 140km/h.

- Tide levels can affect the impact that tropical cyclones have on coastal communities.

- Most deaths and injuries in severe tropical storms worldwide are due to objects flying in the air or structures collapsing.

- Tsunamis can be caused by tropical cyclones.

- Tropical cyclones in Australia can move in any direction including sharp turns or loops.

- The eye or centre of a tropical cyclone is an area with light winds and frequently clear skies.

- Tropical cyclones rotate in an anticlockwise direction in the Southern Hemisphere.

- Tropical cyclones can form over land.

- Australia's tropical cyclone season occurs between June and September.

- The term 'storm surge' refers to a sudden burst in storm activity which creates problems in the supply of electricity.

- Tropical cyclones do not affect either long or short term sea levels.

- Tropical cyclones can form anywhere around the Australian coastline.

- Rain occurs when clouds are disturbed or shaken by the wind.

- Water evaporates from the sea when heat from the sun causes high-energy water molecules to escape.

Appendix 5B Teacher questionnaire

Code:____________________________

Introduction and instructions:

1. The following statements indicate some common ideas about cyclones or about the Science that underpins an understanding of cyclone causes and processes.
2. The purpose of the questionnaire is to identify commonalities in teachers' and students' ideas.
3. Some of this information you may have learned in high school and/or at uni and never used again.
4. Some of this information you may not have encountered at all.
5. Because you may not have encountered this information before, I would like you to do two things:

- Please indicate whether each of the following statements is true or false on the answer sheet provided.
- Place a cross on the scale to the right to indicate how confident you are about your response.
- If you wish to elaborate on any of your beliefs you can do so in the space provided under each statement.

1. A body of air will rise if it is less dense than the air around it.

2. Tropical cyclones can form over land.

3. In a tropical cyclone, wind gusts of 280km/h will cause twice-as-much damage to the built environment as wind gusts of 140km/h.

4. Air has mass.

5. Cold air applies a lower pressure on the ground than the same volume of warm air.

6. Cold temperatures are the main cause of strong winds.

7. Rain occurs when clouds are disturbed or shaken by the wind.

8. Tropical cyclones rotate in an anticlockwise direction in the Southern Hemisphere.

9. Tropical cyclones in Australia can move in any direction including sharp turns or loops.

10. A tropical cyclone is a rotating column of air that is in contact with the ground.

11. The earth is heated unevenly by the sun and this results in differences in air pressure at the surface.

12. Hurricanes, typhoons, tornados and tropical cyclones all contain warm rising air.

13. Australia's tropical cyclone season occurs between June and September.

14. Air is weightless.

15. Most deaths and injuries in severe tropical cyclones worldwide are due to rising sea levels.

16. Cold air is denser than warm air.

17. Air temperature increases from sea level to the base of the clouds.

18. Rain occurs when water droplets in clouds join together and become too heavy to remain suspended in the air.

19. Rising air applies less pressure on the earth's surface than falling air (per unit volume).

20. Only a small proportion of the water that evaporates ever returns to the earth's surface as precipitation.

21. Tornadoes differ from tropical cyclones in that they are smaller and can form over land.

22. Air pressure directly above a body of water increases as the temperature of the water increases.

23. The term ‘storm surge’ refers to a sudden burst in storm activity which creates problems in the supply of electricity.

24. When water evaporates from the ocean it is a boiling process.

25. The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.

26. The molecules that make up water expand and float away when heated by the sun’s energy.

27. Tide levels can affect the impact that tropical cyclones have on coastal communities.

28. Tropical cyclones do not affect either long or short-term sea levels.

29. Tsunamis can be caused by tropical cyclones.

30. The terms “hurricane”, “typhoon” and “tropical cyclone” describe different types of storms that occur around the world.

31. Clouds are tiny water droplets suspended in the air.

32. Water evaporates from the sea when heat from the sun causes high-energy water molecules to escape.

33. Tropical cyclones can form anywhere around the Australian coastline.

34. Winds are caused by differences in air pressure across the earth’s surface.

35. When the conditions become calm after the initial strong winds of a cyclone, the danger has passed.

36. Rates of evaporation are higher from a cool body of water than a warm one.

37. Most deaths and injuries in severe tropical storms worldwide are due to objects flying in the air or structures collapsing.

38. The weather is generally cold during a tropical cyclone.

39. The eye or centre of a tropical cyclone is an area with light winds and frequently clear skies.

40. Tropical cyclones increase in intensity when they move over land.

Code:

Student/Teacher response sheet

No.	Is the statement true or false?		Place a cross on the line to indicate how sure or confident you are about your answer.
			Unsure ——————————X—— Sure
1.	True	False	Unsure —————————— Sure
2.	True	False	Unsure —————————— Sure
3.	True	False	Unsure —————————— Sure
4.	True	False	Unsure —————————— Sure
5.	True	False	Unsure —————————— Sure
6.	True	False	Unsure —————————— Sure
7.	True	False	Unsure —————————— Sure
8.	True	False	Unsure —————————— Sure
9.	True	False	Unsure —————————— Sure
10.	True	False	Unsure —————————— Sure
11.	True	False	Unsure —————————— Sure
12.	True	False	Unsure —————————— Sure
13.	True	False	Unsure —————————— Sure
14.	True	False	Unsure —————————— Sure
15.	True	False	Unsure —————————— Sure

No.	Is the statement true or false?		Place a cross on the line to indicate how sure or confident you are about your answer.
			Unsure ———————————— X —— Sure
16.	True	False	Unsure —— Sure
17.	True	False	Unsure —— Sure
18.	True	False	Unsure —— Sure
19.	True	False	Unsure —— Sure
20.	True	False	Unsure —— Sure
21.	True	False	Unsure —— Sure
22.	True	False	Unsure —— Sure
23.	True	False	Unsure —— Sure
24.	True	False	Unsure —— Sure
25.	True	False	Unsure —— Sure
26.	True	False	Unsure —— Sure
27.	True	False	Unsure —— Sure
28.	True	False	Unsure —— Sure
29.	True	False	Unsure —— Sure
30.	True	False	Unsure —— Sure
31.	True	False	Unsure —— Sure
32.	True	False	Unsure —— Sure
33.	True	False	Unsure —— Sure

No.	Is the statement true or false?		Place a cross on the line to indicate how sure or confident you are about your answer.
			Unsure ——————————×—— Sure
34.	True	False	Unsure —————————— Sure
35.	True	False	Unsure —————————— Sure
36.	True	False	Unsure —————————— Sure
37.	True	False	Unsure —————————— Sure
38.	True	False	Unsure —————————— Sure
39.	True	False	Unsure —————————— Sure
40.	True	False	Unsure —————————— Sure

APPENDIX 6

COMPOSITION OF THE STUDENT SAMPLE

APPENDIX 6: Composition of the student sample

School number	Type	Sector	Number of Students
1	Co-educational	State	11
2	Co-educational	State	15
3	Single sex - Boys	State	23
4	Single sex - Girls	Independent	12
5	Co-educational	Independent	15
6	Single sex - Boys	Independent	24
7	Co-educational	Independent	20
8	Single sex - Boys	Independent	24
9	Co-educational	Independent	21
10	Single sex - Girls	Catholic	17
11	Single sex - Girls	Catholic	19
12	Single sex - Boys	Catholic	24
13	Single sex - Boys	Catholic	14
14	Co-educational	Independent	20
15	Single sex - Girls	State	18
16	Single sex - Girls	Independent	19
17	Co-educational	State	22
18	Single sex - Girls	Independent	21

APPENDIX 7

STUDENT INTERVIEW PROTOCOL (PHASE 1 STEP 2)

Appendix 7: Student interview protocol (Phase 1, Step 2)

Code:

The purpose of this activity is to further explore your thinking about cyclone causes and processes. There are no right or wrong answers.

Task Instructions

1. **Use the space provided below to draw a diagram of a tropical cyclone. Use arrows and labels to show the causes of a cyclone and how they work (ie. their processes).**

2. **How would you explain your diagram to a classmate or friend?**

   - What is a cyclone? How does a cyclone work?
   - How do cyclones form?
   - How do you know this? Where does this knowledge of cyclones come from?

You were not selected because your answers to the questionnaire were incorrect.

The purpose of this interview is to find out <u>more about</u> your thinking.

1. *The terms "hurricane", "typhoon" and "tropical cyclone" describe different types of storms that occur around the world.*

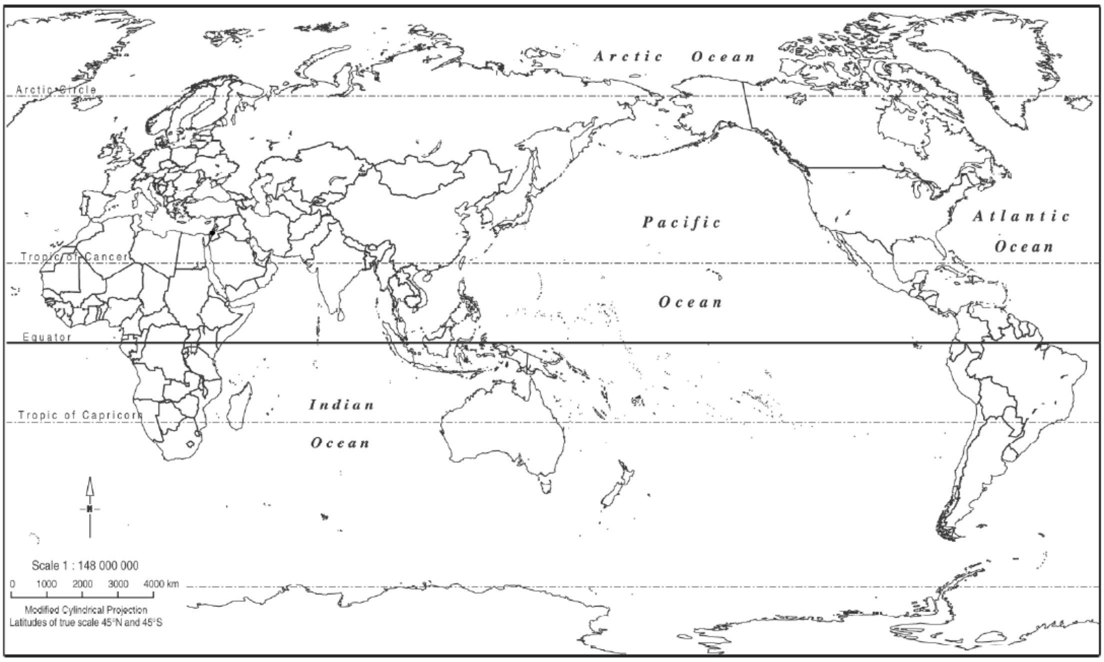
- How are hurricanes, typhoons and tropical cyclones different?

2. *Tsunamis can be caused by tropical cyclones.*

- Can you explain how this might happen or draw me a diagram?

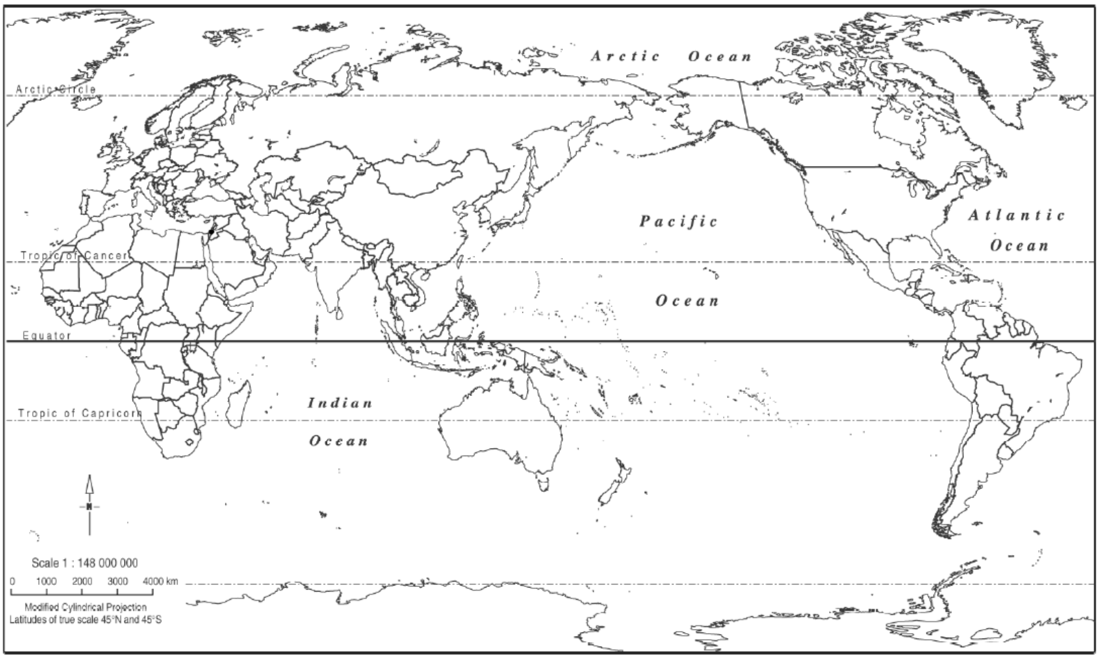
3. Which parts of the world are the hottest? Shade them in on the map below.

- *Why are these areas of the world hotter than other areas? How do you know this?*



4. Where in the world would you expect to find tropical cyclones?

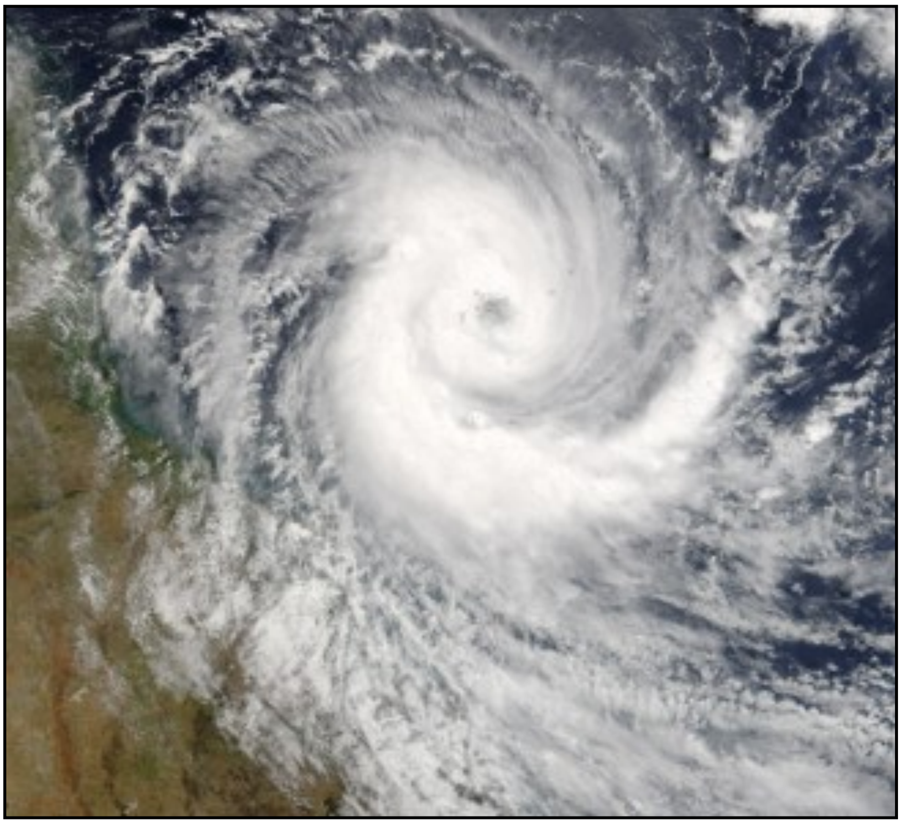
- *Shade in these areas on the map below.*
- *Why would you find them there? How do you know this?*



Question 5 refers to the colour image provided.

5. What is this a picture of?

6. What is happening here?



APPENDIX 8

PHASE 2 INTERVIEW PROTOCOL

Appendix 8 - Phase 2 Interview protocol

1. Introduction

Thank-you for volunteering to be involved in this study.

This part of the research focuses **- children's' ideas** and **the teaching of natural hazards**.
I am interested in discovering whether there is a **common set of beliefs that students/teachers have regarding natural hazards**.

This information will be used to **develop resources for addressing common student conceptions** in the classroom.

The interview has three main parts:

1. A **discussion** of your background and teaching practice
2. A **drawing task** and
3. A **questionnaire**

I will be **videotaping** parts of the interview

The purpose of the video is to make sure that I **represent your ideas accurately** and to **free me up** from making notes as we chat.

1. All contributions to the study remain **completely confidential** (only codes are used for ID). No individuals, schools or sectors will be identified. Please use code __________
2. **No ranking or grading** of either teachers or students will be conducted.
3. The purpose of the questionnaire and drawing task is to **identify commonalities in students/teachers ideas** and to **inform the development of resources/professional development** to assist teachers to identify and address misconceptions in the classroom.

This **sheet outlines the questions that I will be asking** so that you can read along with me.

2. Background information

- For how many years have you taught junior Geography?
- For how many years have you taught senior Geography?
- What Geography subjects did you study in your undergraduate degree (eg. both human and physical eg. geomorphology, geology, climatology/atmospheric sciences, resource and environmental management)?
- Which case studies do you teach in Natural Hazards?

3. Drawing Task

Please complete a **diagram of a cyclone** and include labels to identify the **cyclone's causes and processes.**

If you asked students the following questions, what sort of explanation would you expect from the students to indicate that they had a **thorough understanding?**

- What is a cyclone?
- What kinds of impacts do they have?
- Where do they form?
- How do they form?

4. Teaching practice

When did you last teach cyclone causes and processes in Geography?

I would like you to think about the way you taught this lesson.

Could you guide me through a step by step account of the lesson sequence?

- What were the **student activities**?
- What role did **you play** in the lesson?

5. Students' ideas

What **incorrect ideas** about cyclones would you expect students to have before they start the Natural Hazards topic? **Please be specific.**

6. Questionnaire

Questionnaire - please complete by indicating whether each statement is true or false. Place a cross on the line to indicate how sure or confident you are about your answer.

7. Where do we go to from here?

Student questionnaire
When is the best time to give your students the questionnaire? Date________ Time____________

Could you please provide me with a copy of the class list so that I can develop student codes?

Thank-you for being involved in the study.

Do you have anything that you would **like to add** to your **diagram or lesson outline**?
Did you want to **say anything about the questionnaire or research**?

Code:

Teaching practice - Lesson on cyclone causes and processes

Note: **it is <u>not expected</u> that you would have formalised plans for your lessons!** The purpose of this table is to help the researcher identify the stages of your lesson.

Lesson steps/stages	
Teacher activities/actions	**Student activities and resources**

APPENDIX 9

SUMMARY OF THE PHASE 1 DATA – FEEDBACK SHEET FOR TEACHERS

APPENDIX 9: Summary of Phase 1 student data – feedback sheet for teachers

Student Questionnaire Results (n = 339)

The table shows the proportion of students who responded correctly to each statement.*

Statements from the student questionnaire	% Correct
AIR PRESSURE	
Cold air applies a lower pressure on the ground than the same volume of warm air.	45
Air temperature increases from sea level to the base of the clouds	57
Cold air is denser than warm air.	59
Air is weightless.	63
Rising air applies less pressure on the earth's surface than falling air (of the same volume).	67
A body of air will rise if it is less dense than the air around it.	74
THE HEAT BUDGET AND CAUSES OF THE WIND	
The main reason that the tropics are hotter than the North and South Poles is because they are closer to the sun.	42
The weather is generally cold during a tropical cyclone.	55
Cold temperatures are the main cause of strong winds.	61
The eye or centre of a tropical cyclone is an area with light winds and frequently clear skies.	66
The molecules that make up water expand and float away when heated by the sun's energy.	32
When water evaporates from the ocean it is a boiling process.	55
Only a small proportion of the water that evaporates ever returns to the earth's surface as precipitation (rain, sleet, hail or snow).	67
Clouds are tiny water droplets suspended in the air.	73
FORMS OF TROPICAL STORMS	
The terms "hurricane", "typhoon" and "tropical cyclone" describe different types of storms that occur around the world.	27
CYCLONE IMPACT AND INTENSITY	
In a tropical cyclone, wind gusts of 280km/h will cause twice-as-much damage to the built environment as wind gusts of 140km/h.	32
Tropical cyclones increase in intensity when they move over land.	50
Tsunamis can be caused by tropical cyclones.	56
TORNADO CONFUSION	
A tropical cyclone is a rotating column of air that is in contact with the ground.	42
Tornadoes differ from tropical cyclones in that they are smaller and can form over land.	68

LOCATION AND MOVEMENT	
Tropical cyclones rotate in an anticlockwise direction in the Southern Hemisphere.	42
Tropical cyclones can form anywhere around the Australian coastline.	47
Tropical cyclones can form over land.	52
Tropical cyclones in Australia can move in any direction including sharp turns or loops.	61
THE ROLE OF TIDES AND SEA LEVELS	
The term 'storm surge' refers to a sudden burst in storm activity which creates problems in the supply of electricity.	30
TIME OF CYCLONE SEASON	
Australia's tropical cyclone season occurs between June and September.	58
*Note: Statements were excluded if 75% or more of the students responded correctly or if the performance difference between the top and the bottom quartile of the cohort was less than 10% (i.e. the item did not discriminate). **Misconceptions are in bold**	

APPENDIX 10

CODING PROTOCOL AND SAMPLE TRANSCRIPT FOR THE VIDEO STIMULATED RECALL INTERVIEWS

10A Coding protocol for VSR interviews
10B Sample VSR transcript

Appendix 10A: Coding protocol for VSR interviews

Reasons given for adopting particular strategies:
Diagnose preconceptions*
Address misconceptions by providing the scientifically accepted explanation*
Assessing existing understandings*
"Using students' experiences and ideas" as a part of the lesson
Linking and building on essential prior knowledge
Using probing questions to "build student understanding"
Engaging and motivating students
Involving students in group work learning
Need to use multiple strategies for diverse learners
The need to engage students in inquiry learning
Wanting students to integrate information from various sources
Helping students review and summarise learning
References to conceptual change strategies in the literature
Using simulations*
Analogies and models used to build understanding*
Provide a range of representations*
Promoting cognitive conflict*
Applying knowledge to authentic contexts and relating geographical concepts to students' personal experience*
Reflection in and on practice*
Other explanations
Classroom management – need to keep the class "under control"
Need to "stick to" the syllabus
Avoid unfamiliar concepts and questions (stick to the lesson plan)
Quickest way to "cover content" in the time available
Wanting to make use of an existing resource
Provide the "expert view" on a particular concept
Ensure that the lesson *appears to* model "best practice pedagogy"
Ensuring students have notes in their books/folders
"Covering" content to prepare for exams
Note: Teachers' responses were also coded for information regarding their *beliefs about knowledge, assessment and learning.* *A-priori codes are indicated with an asterisk The video stimulated recall sessions were video recorded and the above codes were applied using Studiocode software.

Appendix 10B: Sample transcript from the VSR interviews

FILE DETAILS T07 – Rachel

Audio Length: *38 minutes*

Number of Facilitators: *One*

Number of Interviewees: *One*

Other Comments: Prior to the commencement of the interview each teacher was given a demonstration of how to stop, pause and play video segments. The teachers were also given time to familiarise themselves with the technology. The teachers were informed that they would be watching extracts from the video of their lesson then discussing their goals and teaching approach with the researcher.

Facilitator: What I want to do is just take you through some of the sections of your video. They're just parts of the lesson where different activities happened. I'll just get you to run through with me, what you were doing there and what you were trying achieve? What your aim was? So, the first one, it's over here.

[VIDEO STIMULUS]

Facilitator: You can cut these off whenever you like. So talk over the top of them. It's just a cue to get you…

Interviewee: All right. So you want me to talk about why I did that first activity.

Facilitator: Yes. What was happening and what your goal was?

Interviewee: Because I don't always teach this geography class. So I just wanted to know, roughly, where they were up to. I know that they've done natural disasters, so I just wanted to make sure that I know what sorts of natural disasters they've been made aware of. Which ones they've actually studied in class and I like to

[00:01:10.3]

look at things in terms of a global context first and then bring it back to say, Australia, because that's what they're doing.

Facilitator: You can see the timeline along the bottom here. This is only a couple of minutes later. Something happened.

[VIDEO STIMULUS]

Facilitator: You knew that was coming, didn't you? [Laughs] This was why I asked you to do the plan. So you can see the status.

[VIDEO STIMULUS]

Interviewee: This is an activity that I use in many of my classes to go with that brainstorming activity. It's a useful way of students just thinking by themselves and then switching or swapping ideas with other students. Then, it's a useful way of discussion as well. Incorporating all of the class, as you will see it. I tried to incorporate the whole class by getting their ideas and reading from the next activity. It's an important aspect of my teaching, making sure everyone's involved.

Facilitator: So it's a strategy of giving everyone a say?

Interviewee: Yes.

Facilitator: I'll just close these ones down. The third one, this is five minutes later, I think.

[VIDEO STIMULUS]

Facilitator: Okay, this is a shift?

Interviewee: Yes. So, again, at the end of that think, pair, share activity, this is the sharing part and I got Josh to write everyone's ideas up on the board, as if everyone would write down examples of disasters than you can have as well. So, again, it was a useful way of bringing [students' name] into the picture, rather than me standing there writing it and getting everyone involved, once again, as well.

Facilitator: Where are we up to? Number four. This will be 10 minutes later.

[00:03:06.5]

[VIDEO STIMULUS]

Interviewee: Yes. I found that story online. I was just looking through and I found out it was one of the, I don't know which school I got it from, but it was somebody's resource that they obviously made up or used the key things from the actual disaster. I just thought it brought - it gave the class something written down and it talked about different processes, not necessarily the processes, but different characteristics of cyclones right throughout the beginning.

But then it also concentrated on the impacts later on, as well. So, I think that they found it interesting. The fact that it occurred on Christmas and it gave them some, a hard copy of what we would actually look on with later. So it gave them the basics and, as you can see, a lot of them are only new, the types of characteristics already. So we were able to extend on that throughout the lesson as well.

Facilitator: So a bit of a platform for getting them to…

Interviewee: Yes. It's in the format of stories and I know a lot of students like stories, as well, so I thought that would be useful as well.

Facilitator: Now there will be a jump. Number five.

[VIDEO STIMULUS]

Interviewee: All right. I don't know if I wrote those up. I did, okay. Just the key - again, the geographical processes comes from the syllabus. So I thought it was important to include that because I wrote it up in my aim up there to say that, okay, this is what I want you to get out of the lesson and I hope that's that what they…

Facilitator: Your aim, as you wrote on your plan, was to link back to [outcomes] 5.6. It explains geographical processes that form and transform Australian environments. So what you're trying to do here?

Interviewee: I was trying to get them to, once they had read that excerpt from *Santa never made it to Darwin*, to identify any processes or characteristics that can form cyclones in Australia. So, again, there

[00:05:42.9]

were the wind, the strong winds, the low pressure system.

Facilitator: Was there a reason why you got them to come, derive themselves rather than giving it to them?

Interviewee: Well, in a way I did give it to them because I bolded key terms just to make it a little bit more - so they can see it easily rather than just skimming through. So, yes, I did bold it but I didn't tell them. I don't think I told them.

Facilitator: So you directed them?

Interviewee: Yes, I also directed them and the same with the second part so the impacts of cyclones, again, I bolded key ideas in that.

Facilitator: So your key aim here, was to link back to the processes in that outcome to make sure that they were, at least, recognising what those processes were?

Interviewee: Yes.

[VIDEO STIMULUS]

Facilitator: What do you think you meant by that?

Interviewee: I didn't hear what he said.

Facilitator: He [the student] was talking about mixtures of cold and warm winds, I think? You were asking them to come up processes?

[VIDEO STIMULUS]

Interviewee: That would have come from his story because I know he mentioned that but, also, his own knowledge as well. Most of the students know or recognise that, in order to form a storm, there needs to mixture, there needs to be warm rising air and cold sinking air as well, from the clouds. So, in order for a cyclone to form, they knew that there's that north at the top and bottom processes to that.

Facilitator: Connecting bits as the story goes?

Interviewee: Yes.

[00:07:50.2]

Facilitator: There's a few areas here where I've grabbed questions that the kids have asked?

[VIDEO STIMULUS]

Facilitator: This is a shift in the lesson again? A different strategy again?

Interviewee: So the use of a power point again, is to help out students who - I could have dictated it but I'd prefer it on the screen so the students can take their time and actually visualise it. There's a picture there just to help them out as well. But I wanted them to take their time to understand what they're writing down. As you can see, I didn't rush the whole lesson. I didn't want to rush. There was time for questions. There was time for discussion as well. So I think that's the key point and like I said, take your time when you're writing this down and I wanted to make sure everyone was roughly on the same track. If not, students looked on with the person next to them and they weren't very far off from finishing the slide.

Facilitator: So this bit was basically about delivering information?

Interviewee: Yes. I didn't tell them - you can see that most of the slides, they didn't have to write down. Perhaps, I could have gotten them to write down the slide where it talks about the actual formation of the cyclone but I thought that would take too much time to write down. So I gave it to them.

Facilitator: That's just their content in their books?

Interviewee: Yes, I looked at their text and their text didn't have very much about this as well.

Facilitator: This is true. Even the Heinemann text doesn't have much about cyclones in it.

[VIDEO STIMULUS]

Facilitator: Now, you shifted your questioning there. I was just interested there why you grabbed that?

[00:09:59.5]

Interviewee: Again, trying to just pull apart that definition and because there are two aspects of a definition with the rotation of the cyclone and the tropics as well. I wanted just to clarify that they know where the tropics are in Australia. In the later slides, you will see that I included a map there of the different - or where cyclones have moved right around Australia and most of them are located in the north of Australia. I just wanted to clarify the - which is one of my second outcomes. Demonstrate a sense of place about Australian environments.

Facilitator: So you're just making sure, because tropics, I think, is in the definition, that they actually know where that is? How did they go? Don't remember?

[VIDEO STIMULUS]

Interviewee: [Students' name] said, in Cairns.

Facilitator: The tropical places? So another 10 minutes later in the lesson....

[VIDEO STIMULUS]

Interviewee: What's the question?

Facilitator: I'm just wondering what - just talk me through what you were doing?

Interviewee: So with the map, I wanted to clarify that the students know that there are three different, well, three different names for cyclones but they all mean the same thing, they all have the same characteristics as well. It just depends on where they are located.

Facilitator: Is there a reason that you picked that concept to explain or it's just part of the location and processes?

Interviewee: Again, the research that I've done, a lot of them go into looking at where - the different words or names for cyclones. I think that some people tend to get confused about that name since it doesn't necessarily…

[00:12:18.3]

Facilitator: So you noticed when you were looking up resources that there was a bit of discussion about the confusion on the net?

Interviewee: Yes.

Facilitator: So you grabbed that diagram to, I guess, or were you assuming that the students would struggle with that too?

Interviewee: Well, not that they would struggle but if you go back to the brainstorming session, [students' name] mentioned typhoons when we already had cyclones there and I just made that link at the beginning to say, these are the same thing, you're right to say that, but they're the same things as well. I just wanted to, again, clarify that as well. But I thought I went through and we talked about the warm ocean characteristics and the wind that was needed for cyclones to form as well.

Facilitator: It was great. Here is another excerpt from the video. Number 10

[VIDEO STIMULUS]

Facilitator: So this was about explaining processes?

Interviewee: Yes, trying to explain the main processes that form a cyclone. I found the Bureau of Meteorology website and I thought that would be useful. A visual image, again, for students. They had a similar type of picture to that on piece of paper that I gave them along with these key ideas. But I thought it was useful, visually, for them. A lot of the kids, I think, found it useful to see the different movements as well as the writing next to it. I thought it was very useful and they got to see the movement.

Facilitator: Just so that their understanding was that they can actually move as opposed to reading about it?

Interviewee: Yes, and as opposed, yes, seeing the image that I gave them.

Facilitator: It was static?

Interviewee: Basically static, yes.

[00:14:17.8]

Facilitator: Now this is a big one because it's a whole heap of student questions. At the end of about 40 minutes in, they just launched into questions all of a sudden.

Interviewee: I don't think I noticed that.

[VIDEO STIMULUS]

Facilitator: Do you know what she [the student] was asking you?

Interviewee: I think she was talking about that there's a bit of information at the bottom there. Now, I got stuck on that so this is from what I read, I tried to put things together. I don't know how I could…

Facilitator: She was asking something about the air moving in different directions, at the top and the bottom and…

Interviewee: Eventually joining. I think I mentioned something about joining. Now that's the part of the lesson that I would have a problem with. That's one section I would want to improve on in answering those questions.

Facilitator: Or deflect it?

Interviewee: I could have but, yes, all right.

Facilitator: What do they ask next?

[VIDEO STIMULUS]

Facilitator: It's amazing how a diagram gets them?

Interviewee: Yes. When I was researching this, they tend to say it, talk about it in stages. I don't know if that's for the purpose of just the explanation but, definitely, it's all happening all at once. There's no way that it stops and shifts et cetera. Not at all. So, hopefully, I have explained her part correctly.

Facilitator: Yes, because you think, perhaps, because the explanation was in sections, they thought they happened discreetly and by themselves?

Interviewee: Yes.

Facilitator: There's another question, I think?

[00:16:19.0]

[VIDEO STIMULUS]

Facilitator: That's it. But that diagram really got them thinking? What's over here? Here is another extract from the lesson. This is number 12?

[VIDEO STIMULUS]

Facilitator: What was going on there?

Interviewee: So I just wanted to clarify, again, why do they think that the eye of the storm is calm and you see it in many - you see it in tornadoes as well, that nothing much happens in the centre of the storm because that's where you've got air just shifting, moving in and out and the majority of the storm or the destruction is caused by the clockwise movement which is occurring more so on the outside.

Facilitator: Was there a reason for asking a question there?

Interviewee: No, just to clarify that they know this. Because I know [students' name] knew about this already. I think he was the one that mentioned that it's a calm, nothing much happens there. It's where it moves in and out. Where air moves in and out.

Facilitator: Well, he showed he had a very good understanding because he just jumped straight on there, it's declining, therefore, it is clear. That's pretty impressive. So [lesson segment] 13? Here you use a map.

[VIDEO STIMULUS]

Facilitator: What was the strategy with that? With the map?

Interviewee: Again, just to clarify the tropics. But, also, to show them that - how far cyclones can move and to just talk about where we were, where Sydney's located, they can come quite far south with regards to the movement and how strong the winds are. Again, that was just to give them a global context.

Facilitator: Whether you were asking questions here or…

[VIDEO STIMULUS]

[00:18:56.8]

Facilitator: No, that's the explanation. Then, there's a big gap here? What happens in here? Let's have a look.

[VIDEO STIMULUS]

Facilitator: This is the categories. Do you want to talk me through what you were doing there?

Interviewee: Well, this was in the text as well, so I thought that it would be useful for them. I'm sure a lot of them appreciated me talking about this just to clarify that categories one and two, they don't - they're there, they don't cause that much destruction but where you need to get it right is, we'll also categorise three, four and five. I tried to find examples. You will see, there's not many examples for one, two and three that stick in our minds but for categories four and five, well, they were to find a few examples. Again, just to show them the level of destruction and, since they did earthquakes before, I linked it to the severity of earthquakes. So they already about how earthquakes severity were measured. Through the Richter scale and I just linked their knowledge to this.

Facilitator: Then, right up the end?

[VIDEO STIMULUS]

Facilitator: Can you talk me through that?

Interviewee: Just trying to, again, review the lesson and just to see what they've learnt in a quick and reasonable fashion. I said in no order because I just wanted them just to see what they got out of this lesson because we only a few months left [before the unit is formally assessed].

Facilitator: The verbal brainstorm type?

Interviewee: Yes.

Facilitator: Give me everything that's in your head approach?

Interviewee: That's right, yes.

Facilitator: In terms of the lessons outcomes that you set for yourself back at the

[00:21:05.5]

beginning there, those two syllabus outcomes, how do you think they went?

Interviewee: I think I met them. I think that the students will be able to explain how a cyclone is formed now. They definitely will be able to explain where cyclones are located around Australia. So, I'm pretty sure I met them. Like I said, if I was criticising myself on anything, I would go back and answer those questions a little bit better. That's where I would improve.

Facilitator: It was just a gap in your knowledge?

Interviewee: Yes. I've researched that, it's just left me.

Facilitator: You just didn't know what was going on there?

Interviewee: Yes.

Facilitator: That's fine. But their answers here, when you asked them what the processes are, you got three out of three, in terms of their responses and the three most important things? Yes? Hot water, yes?

Interviewee: Yes.

Facilitator: Strong winds and low-pressure systems, yes?

Interviewee: Yes.

Facilitator: So you were fairly happy with those responses?

Interviewee: Yes.

Facilitator: Did you get a chance to look at the data that I sent out with this?

Interviewee: I didn't. I'll just quickly move you into the class. I've got it on my desk

Facilitator: I just wanted to briefly ask you whether anything - well, first of all, whether you looked at it and whether anything on that had any influence on what you did here?

Interviewee: To be honest, I can't remember. I've skimmed over it, I just can't remember. I just wanted to make sure that I set it out in a clear and simple approach because I'm just remembering from some of those

[00:22:54.6]

questions that you asked me last year, it can get quite complicated. So an explanation is depending on, I guess, where you're coming from, what background you're coming from and so it can get quite complex. I just wanted to make sure I presented it in a clear and simple way.

Facilitator: So although the data didn't influence what you did here, your experience of the questionnaire did?

Interviewee: Yes.

Facilitator: Could you tell me more about how the questionnaire process influenced your lesson? You've clearly done a lot of research.

Interviewee: There are a lot scientific questions which I tried to steer away from and make it more geographical. Yes, I remember those definitely.

Facilitator: So your approach with the science stuff was to move towards the geography so that then you didn't have to harp on science?

Interviewee: Exactly, yes, because I'm not a scientist so I don't know the scientific approach to teaching this disaster.

Facilitator: Was there anything else in that process that influenced anything that you did here?

Interviewee: No, I just wanted to make sure I did a good job. I just wanted to make sure I did a good job and I hope I did.

Facilitator: I'll ask you a question about that, now that you've said that. What would be your criteria for the ultimate lesson on cyclones? What boxes were you trying to tick?

Interviewee: So to make sure that I clearly explained the processes and that's because that's what the outcome states, the processes that transform and form Australian environments and also at the end, just the impacts as well. We didn't get a chance to go through that but I did set it for homework for them.

Facilitator: To make sure that their explanation of that is clear?

[00:25:04.3]

Interviewee: Yes and to come up with examples of impacts of cyclones.

Facilitator: Anything else that you would see as being the criteria for an effective lesson?

Interviewee: To make sure that everyone's involved. To make sure that there's a level of preparation, if necessary. Images are good as well. Again, like you said that visual of the cyclones that I got from the Bureau, I think that helped them and like you said, it stimulated questions which was good as well. So, yes, visual images, that's why I chose the power point method so they could have everything in front of them.

Facilitator: Just watching it as an observer, the things that I particularly notice is that you went to a particular effort to make sure that the students had a say before you said anything? Was there a reason for that?

Interviewee: I just enjoy listening to their responses. I think it's important that students have a say in my lessons, rather than me talking. It's about getting them actively involved and not just sitting there. Yes, I tend to listen to their ideas and thoughts before I put forward my own or if they say everything, I don't necessarily need to say anything and I can just praise them and give them encouragement.

Facilitator: Because you didn't pick up on some things later in the lesson that had been said at the beginning of the lesson like the typhoon and you came back to the typhoon on that map?

Interviewee: That's right. So, again, and you can draw on people's name. [Students' name] said that and it's important to acknowledge what they've said and bring it back.

Facilitator: Back in the last interview that we had, I asked you about the sorts of things that students might misunderstand about cyclones. If I asked you the same question again, would your answer change? Sorts of things…

Interviewee: What did I say [laughs]? I can't remember. Let's see.

[00:27:16.7]

Facilitator: Off the top of your head now, what would you say the key things are that - say, misconceptions that they might have?

Interviewee: The rotation. I think I had to clarify that because [students' name] said anticlockwise.

Facilitator: Direction?

Interviewee: Yes, the direction of that the way the cyclones moved. I thought they might ask a question - I did some research with the coriolis effect and I thought that was interesting, just looking at it. I guess that's a scientific thing as well, the coriolis.

Facilitator: You thought they might ask you, why does it spin?

Interviewee: Why does it spin as well as…

Facilitator: They had all sorts of crazy ideas about that?

Interviewee: Yes. So I just thought I'd back myself up with that.

Facilitator: Anything else, because you deliberately targeted certain things? I'm just wondering whether there was a reason for targeting. Is there any other common idea that you think they might have? You've already mentioned the names, the different names?

Interviewee: I guess just the warm air and cold air, just to clarify that hot air rises and cold air sinks, so just to clarify it.

Facilitator: They seem to like this explanation that it's a mixture - a smashing together of hot and cold air but that's where the explanation stops? They don't know what else is going on in there?

Interviewee: Yes.

Facilitator: Did you want to say anything else about the process?

[00:29:22.3]

Interviewee: About this whole process?

Facilitator: Yes, what was the research process like?

Interviewee: It was good. I think that was definitely a useful process for me to just read different sorts of material and to come up with a simple way of teaching this lesson to students so they would understand it. Yes, I enjoyed it. I didn't have a problem with it.

Facilitator: Did going through the process yourself make you teach it to students in a way that you would, otherwise, not have?

Interviewee: Yes.

Facilitator: Can you just tell me about that, just quickly?

Interviewee: So I just…

Facilitator: You wanted it to be really clear?

Interviewee: …and straightforward and everything needed to be explained. Well, not necessarily explained, but just written there for their - I wrote most of those things there for their own notes. So if they needed to go back and look at it in the future, they've got this clear explanation, whereas their text book doesn't have a clear explanation.

Facilitator: One other question. Was there a particular reason why you didn't look at the data when you were planning the lesson?

Interviewee: I forgot to look at it, honestly.

[Laughter]

Facilitator: That's a good answer.

Interviewee: But, going back, probably that would have helped me clarify a few ideas as to what students' preconceptions would have been. Maybe that would have been a good starting point as well, thinking about, okay, how do they think a cyclone is formed? So that would be, yes, thinking about it now, that would be useful.

[00:31:11.9]

Facilitator: Just one of the things that I'm interested in with the project is, that the first part, the last year part, that feeds a whole heap of data into this part and I'm interested in seeing what people do with it and the reasons. Your decision making about the lesson was last year driven and, tell me if I'm wrong, I'm just trying to summarise what you were saying. It was last year driven by your experience of the questionnaire and how you felt with the different parts of the questionnaire and then, for how you wanted to present it to the kids?

Interviewee: Yes.

Facilitator: Whereas, other people have picked up the data and they've rearranged the data by, which were the most difficult through to the least difficult things and they've hit them one - explicitly, bang, bang, bang, bang. Do you think this, it's not this, it goes like this. Do you think that, it's not this, it goes like this. Just different approaches. I'm interested in why some people take one approach and other people take another approach and whether that's got something to do with your beliefs about kids' ideas? Your lesson was interesting in that, although you didn't use - explicitly use the ideas from the first phase…

Interviewee: Could you see them slightly in there?

Facilitator: Yes and that's why I was wondering whether you'd looked at that data because the reason that I tagged the map because that was one of the statements on that sheet. The reason that that mixing of hot and cold air was another statement on that sheet. I was wondering whether you deliberately targeted - no?

Interviewee: No.

Facilitator: So that was just your hunch based on your experience of the questionnaire and your research?

Interviewee: Yes.

Facilitator: That's interesting. Do you see where I'm coming from now?

Interviewee: I do.

[00:33:05.2]

Facilitator: I deliberately didn't tell you that before because I wanted to see how people use the data or whether it made any sense to them. But what I'm generally finding is that [teachers] tend not to look at it for a couple of reasons. One, they don't have the time to do anything with it. They don't necessarily have an idea what to do with it and they want to stick to the syllabus [material]. Would that be right?

Interviewee: Yes, that too.

Facilitator: They want to do the dots on the sheet?

Interviewee: That too, yes.

Facilitator: Rather than go astray and go into what kids think?

Interviewee: Well, look, if I had more time, I'd go back now and think about, okay, what did I do and I actually look on the sheet now to see, did I talk about this or did students mention in the lesson. I think it would be a useful exercise.

Facilitator: There were about 10 things in the lesson that linked back to that sheet [the Phase 1 data]. The movement of the air, the causes, the locations, the names. One of the students actually mentioned as a major impact, the ripping up of sewerage pipes and things. That came up in the research last year. Out of 400 students, students think that, there's something happening underground with cyclones that rips ups sewerage pipes and that cropped up in these kids' ideas too. So it's just interesting.

Interviewee: I wondering where that - where would he have come up with that.

Facilitator: It's in here. One of the students said it.

Interviewee: I remember that. I remember it was the impacts.

Facilitator: It's very common.

Interviewee: Yes, okay. I probably didn't pick that up, it probably just went way over my head. [Laughs]

[00:34:51.8]

Facilitator: The idea that didn't come up in your lesson that comes up in many of the lessons, is the confusion between tornadoes and cyclones. There was that brief in there and I've got it down here where you asked a question about it. Let's have a look.

[VIDEO STIMULUS]

Facilitator: That was on the data sheet too.

Interviewee: Yes, okay.

Facilitator: I was wondering whether your reason for targeting that was because of the data sheet, but it clearly wasn't, it was because they said tornadoes on the brainstorm on the board, they say...

Interviewee: I didn't even realise that was on the sheet [Phase 1 data].

Facilitator: So you're collecting these ideas anyway but via a different approach - yes?

Interviewee: Okay.

Facilitator: What's this one?

[VIDEO STIMULUS]

Facilitator: This confirms how common the beliefs are and I think what kids are doing is they go - they think about natural hazards, they go, well, they're all awful and negative things, therefore, they're all connected.

Interviewee: Okay.

Facilitator: So all the things that happen in an earthquake will also happen in a cyclone and they just jumble them all up and that's an example.

Interviewee: That's really useful. That's good.

Facilitator: Do you see what I mean?

[00:36:21.4]

Interviewee: Yes.

Facilitator: So these are the kinds of things I am looking a together with the professional development implications of giving people data about what students think.

Interviewee: I can see that now.

Facilitator: Yes?

Interviewee: Definitely, yes.

Facilitator: The reason for testing the kids was to find out what the common kids' thoughts were. The reason for interviewing you was to look at the relationship between your ideas and their ideas and then, I gave you their ideas and I was interested in seeing what happened between there and then. Your response was fairly typical of what teachers do with data about kids' ideas. Thank you so much for your time and willingness to be involved in the project.

APPENDIX 11

EXTRACTS FROM TEACHER INTERVIEWS INDICATING POSSIBLE ALTERNATIVE CONCEPTIONS

Appendix 11: Extracts from teacher interviews indicating possible alternative conceptions

Source: Teacher interview 1 (Phase 2, Steps 1-2)

Note: the numbers in brackets indicate the individual teachers in the study

1. Evaporation and precipitation

"Normally when we heat up something it expands. Molecules I expect are no different . . ."(3) (14)
"Molecules do expand when they are heated" (7)
"I know that hot water has a greater volume than cold water as a result of molecules expanding" (3)
"I don't know what percentage of evaporated water returns to the earths' surface. Certainly not all of it" (3)
"Rain does occur when clouds are shaken by the wind but this is not the only reason why rain occurs . . ." (7) (3)
"The heating causes the water molecules to expand and become less dense and turn into water vapour. Heating does not give them more energy." (10)
"Evaporation is kind of a boiling process" (13)

2. Differences in temperature with latitude/altitude

Heat budget

"Yes I think the main reason the tropics are hotter than the poles is their closeness to the sun"(3)
"The sun's rays are more direct and travel shorter distance because they are closer to the Sun" (10)
"The earth is heated unevenly by the sun because there are trees and vegetation. The heat can't get through the foliage level and therefore the ground is heated unevenly"
"The tropics are closer to the sun and therefore hotter. That's what I tell the kids" (15)

Altitude

"Air temperature increases from sea level to the base of the clouds" (13)

3. Air pressure (low pressure = cold air was common)

"Cold air creates low pressure systems"
"Air is weightless I am pretty sure" (7)
"I'm not sure if air has mass" (10)
"If air does not weigh anything it can not exert pressure on the Earths' surface" (7)
Contradiction – "air is weightless but has mass" (6)
"I am unsure about density. Denser air stays down and has less pressure usually" (13)
"Yes, cold temperatures are the main cause of strong winds because they are associated with a low pressure system and low pressure systems have stronger wind intensity because the isobars are closer together" (14)

"Low pressure systems have cooler, denser air which applies greater pressure on the earth's surface" (this contradicts the same teacher's belief that tropical cyclones are low pressure systems containing warm rising air).

4. The conditions in a tropical cyclone

"Tropical cyclones form when a body of warm air meets a body of cold air over the ocean forming a front" (14)
"Yes, conditions are generally cold in a cyclone which brings cool air and rain" (7)
"Weather is generally cold in a cylone because it is a low pressure system – cool dense air (14)
"In low pressure areas there is cooler air than in high pressure areas" (12)
"It is generally cold when it is windy" (12)

5. Tropical cyclone movement, location and timing

"All tropical cyclones move in a predictable pattern from east to west" (9)
"Tropical cyclones always move in the direction of an arc" (14)
"Tropical cyclones always track in a predictable and linear fashion" (16)
"I would expect students to be able to account for the location of tropical cyclones in terms of the environments that are up there, the situation of the temperatures and the plates and so on" (12)
"I am fairly sure that tropical cyclones in the southern hemisphere rotate anticlockwise" (13)
"Students do not generally understand why we get tropical cyclones in Sydney" (14)
"June to September is cyclone season in Australia because it is winter so there are cooler temperatures. Cool temperatures are associated with low pressure systems and tropical cyclones" (14)

6. Biophysical interactions and consequences for human activity

Different types of storms

"hurricanes and typhoons are strong winds not spinning storms like tropical cyclones"(3)
"Cyclones become hurricanes when they cross the coast"(3)
"Hurricanes and tropical cyclones are different but I am unsure about typhoons" (13)

Cyclone/Tornado confusion

"I do not think there is a difference in size between tropical cyclones and tornadoes"(3) (5)
"Australia does not experience tornadoes" (3)
"Tornadoes are not necessarily smaller than tropical cyclones" (7)
"Tropical cyclones are a rotating column of air in contact with the land" (13)

Cyclones and Tsunamis

"If you classify tsunamis as large ocean waves then they can be caused by tropical cyclones" (3)
"Cyclones can cause tsunamis. Especially if the wind is strong enough and the waves generated by the cyclone have enough of a path to travel across . . ." (3) (12)
"Storm surge is just like a tsunami, the water will recede away…like with the creation of cyclonic swell and stuff" (3)
"Tropical cyclones increase the sea level and can cause tsunamis" (13)

Impacts

"Contradictory views were expressed by four of the teachers who indicated that both "objects flying in the air" and "rising sea levels" were the main cause of death and injury in tropical cyclone events." (3)
"I am aware of storm surge but I think wind causes most of the deaths globally" (3)
"100, 200 and 700km/h winds all cause the same degree of damage" (7)
"The cyclone builds as it moves over the ocean and intensity increases when it hits the land" (14)

Scientific foundations

"When you refer to air being less dense what do you mean?"(7)

Misleading Analogies

"It is like a washing machine or like a whirlwind to create a tropical cyclone" (7)
Understands that twisters are different but uses them in classroom explanations of cyclones (2) (8)

APPENDIX 12

CONCEPTUAL CHANGE STRATEGIES ADDRESSING THE EPISTEMOLOGICAL, ONTOLOGICAL AND AFFECTIVE DIMENSIONS OF LEARNING

Appendix 12: Conceptual change strategies addressing the epistemological, ontological and affective dimensions of learning

Strategies addressing the epistemological, ontological and affective dimensions of learning include the following:

- regularly assessing and monitoring the validity of students' conceptions (Ozturk & Alkis, 2010);
- engaging students in variety of rich tasks where they are encouraged explore and evaluate a range of explanations for geographical phenomena including their personal beliefs and theories;
- promoting the expression of "naive" conceptions in class and using students' ideas as the starting point for instruction;
- encouraging students to identify the key characteristics of concepts and to differentiate between related ideas (Carey, 1991);
- designing curricula so that students from early years onwards are exposed to learning experiences that help them build the required prior knowledge for understanding more complex concepts in the curriculum (Vosniadou et al., 2008);
- building students' reflective and metacognitive skills so they are more aware of their beliefs and assumptions and are able to identify and monitor inconsistencies in these beliefs (Inagaki & Hatano, 2003);
- promoting substantive discussions in class where students feel comfortable expressing their beliefs and are given the opportunity to identify and reflect upon inconsistencies in their explanations (e.g. using Thinking Through Geography and other similar approaches);
- promote argument and debate rather than consensus in the classroom (Dove, 1999);
- modelling the application of processes and principles in real world contexts (e.g. through the use of simulations and hypotheticals);
- breaking down complex phenomena (e.g. the processes of a tropical cyclone) and providing opportunities for students to explore the individual processes and principles in a range of contexts; and
- building students' critical literacy skills so they can question the accuracy of representations of scientific processes depicted in of popular culture and differentiate these ideas from the established scientific understandings (Luke, 1999). An awareness of the multiple purposes of "texts" can also assist students to decipher scientific fact from entertainment.