Educative curricula and improving the science PCK of teachers in middle school settings in rural and remote Australia

Arthur Townsend
Edith Cowan University

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Educative Curricula and improving the science PCK of teachers in middle school settings in rural and remote Australia

This thesis is presented for the degree of

Doctor of Philosophy

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BEd, DipEd, MEd (Hons)

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Faculty of Education and Arts
School of Education
2015
The declaration page
is not included in this version of the thesis
Acknowledgements

I would like to acknowledge the leadership, assistance, and friendship of Professor David McKinnon. Without his ongoing support, I would not have completed this thesis.

I would like to acknowledge the help of Dr Geoff Lummis and Dr Julia Morris who provided critical comment on the structure of this thesis and provided detailed feedback on its structure and mode of expression. Any remaining limitations are entirely mine. I thank them.

I would also like to acknowledge the love and support of my wife Therese and younger children, Claire and Matthew, for allowing me some of their precious time to complete this work.

I would also like to thank the principals, teaching principals, teachers, consultants and the students in the schools in Western Australia and north-eastern Victoria who provided data for this thesis, who welcomed me into their classrooms and schools, and who honestly provided many insights into their human condition. For that honesty, I thank them.

Finally, I would like to acknowledge the professionalism and dedication of teachers and leaders in rural and remote areas of Australia who continue to do all they can to improve the educational outcomes for the students they serve. I would especially like to acknowledge those teachers and leaders I currently have the privilege of working with in the Northern Territory of Australia.

Please Note:

Photographs of individuals or groups of individuals that appear in Chapters 5 and 6 of this thesis have had their faces obscured so that they cannot be identified. Note also that the Appendices, which were supplied on a DVD for examination purposes, contains a large number images and videos of students, teachers and parents by which their schools might be identified. This DVD of files is not available for general distribution under the Ethics in Human Research guarantee of confidentiality. Please contact the author/university for advice on this matter should access be required.
Abstract

Science is one of seven-mandated Key Learning Areas (KLA) Foundation to Year 10 of the new Australian National Curriculum (ACARA, 2012). Not only, therefore, is science to be offered in every school as part of the curriculum, there is also the expectation that science is to be taught well to all students regardless of location, gender, cultural background or socio-economic status (ACARA, 2012). Studying science provides benefits to individuals by developing their scientific literacy skills (Goodrum, Hackling & Rennie, 2001; Hackling & Prain, 2008). Its study also benefits the national economy by equipping students with the innovative, inventive, and creative skills to generate and apply new ideas as knowledge workers in an interconnected and interdependent global economy (Marginson, Tytler, Freeman & Roberts, 2013; Productivity Commission, 2007).

A study of recent literature, including the national and international data on the middle years of school (ACARA, 2012; ACER, 2011, 2013; Goodrum et al., 2001; Goodrum, Druhan, & Abbs, 2012; Hackling & Prain, 2007; Marginson et al., 2013; Office of the Chief Scientist, 2012; Productivity Commission, 2007), could reasonably be expected to show rural and remote students doing well in science if not at least as well as their metropolitan counterparts. Sadly, this is not the case. Science performance in national and international assessments overall is flat-lining (ACARA, 2011; ACER, 2011, 2013) and the gap between metropolitan, rural and remote students in some assessment data indicates as much as 18 months of difference in schooling in favour of metropolitan students and with the gap increasing with increasing remoteness.

What are the causes of this inequity and how can it be addressed? Science teachers hold the key (Australian Council of Deans of Science, 2005; Dow, 2003a; Goodrum et al., 2001). Improving the effectiveness of science teachers helps improve science learning outcomes for students. One way to improve the effectiveness of science teachers is to improve their Pedagogical Content Knowledge (Kind, 2009b; Magnusson, Krajcik & Borko, 1999; Loughran, 2010; Loughran, Berry & Mulhall, 2006; Shulman, 1986) through professional learning experiences. However, improving teachers’ science PCK in the middle-school years in rural and remote settings through traditional face-to-face professional learning activities poses a number of challenges. These include lack of casual relief teachers, difficulties in attracting and retaining science teachers, the provision of experienced mentors and coaches and, the provision of fewer professional learning opportunities compared with metropolitan areas (Australian Council of Deans of Science, 2005; Australian Secondary Principal’s Association, 2006; National Centre of Science, Information and Communication Technology, and Mathematics Education for Rural and Regional Australia, 2006). Educative curricula designed to improve teachers’ science PCK as well as learning outcomes for students provide an alternative to traditional face-to-face professional learning for teachers in rural and remote locations (Davis & Krajcik, 2005). Can educative curricula help address the inequity in student science outcomes in rural and remote areas?

The Middle Years Astronomy Project (the Project) is an example of one educative curriculum currently in use in the middle years of some rural and remote schools (McKinnon, 2005). This educative curriculum is aligned with the Australian Science Curriculum. It comprises access to telescopes and digital cameras located in NSW (Australia) and Wyoming (USA) that students can
control remotely to take photographs of many astronomical phenomena, which can form the basis of further investigations. It also comprises a teachers’ guide designed to improve teachers’ science PCK by providing guidance on designing instructional strategies for science projects with knowledge of five factors in mind. These factors are knowledge of the science content, knowledge of students’ alternative conceptions, knowledge of instructional strategies and the most appropriate assessment strategies to employ, knowledge of the science curriculum, and knowledge of personal beliefs and orientations toward science teaching and learning.

This thesis explores the potential for this educative curriculum to improve the PCK of teachers of science in the middle school years in rural and remote settings. It does this by employing a Type IV multiple-case, embedded mixed-methods design (Yin, 2014) over two phases in two states of Australia collecting a range of data from four remote sites in Western Australia and four rural sites in Victoria. Participants comprised 12 teachers, four principals, four teaching principals, one Science KLA Consultant, one Cluster Coordinator and over 200 students. Data were gathered from interviews; archival records; researcher direct observations; an astronomy diagnostic test; student artifacts; and school based documents. A framework, developed from the works of Davis & Krajcik (2005), Kind (2009b) and Magnusson et al. (1999), is used to analyse the data for evidence of changes in teachers’ science PCK.

The results of this research indicate that the Project improved teachers’ science PCK for most teachers. Reasons for this are presented. An emerging phenomenon from the research was the ability of experienced science teachers to move holistically and fluidly between components of PCK to make in the moment pedagogical decisions to improve student learning. This has been referred to as ‘pinball pedagogical reasoning’ (Mitchell, Pannizon, Keast & Loughran, 2015). The findings of this research have implications for both current practice and future research, providing guidance to teachers and designers of professional learning experiences, including educative curriculum designers, on the areas to target when seeking to develop components of PCK for experienced teachers and on assisting less experienced teachers to acquire the ‘pinball pedagogical reasoning’ skills of experienced teachers. The findings also suggest that PCK development takes time and requires a planned and systematic approach to teacher career development with support from the employer.

This thesis suggests further areas for research and concludes by arguing that a poor science education, which results in poorer scientific literacy skills and a reduced ability to contribute to, and thrive in, the national and international knowledge economies, adds to the education disadvantage students in rural and remote locations experience relative to their metropolitan peers. It advocates a moral imperative to ensure this does not happen. It also suggests that using educative curricula to improve the PCK of rural and remote science teacher, as well as science student learning outcomes, is a strategy worthy of pursuit.
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CHAPTER 1: Overview and Purpose

The purpose of this thesis is to explore the potential for an educative curriculum known as the Middle Years’ Astronomy Project (the Project) (McKinnon, 2005) to develop the Pedagogical Content Knowledge (PCK) of teachers of science in rural and remote middle school science settings. Educative curricula provide an alternative to traditional face-to-face professional learning for teachers. Educative curricula are designed to improve teacher PCK by embedding professional learning within the curriculum materials while simultaneously using those curriculum materials to improve students’ learning outcomes (Davis & Krajcik, 2005; Schneider & Krajcik, 2002; Schneider, Krajcik, & Marx, 2000). Five key reasons emerge from a study of the literature for exploring the potential for an educative curriculum to develop the PCK of teachers of science in rural and remote middle school science settings.

First, the literature on students in rural and remote areas indicates they face educational disadvantages that adversely affects their ability to achieve the same level of performance as their metropolitan counterparts (Australian Curriculum and Reporting Authority (ACARA), 2011; ACARA, National Assessment Program, Scientific Literacy, 2003–2012; ACER, 2013; ACER-PISA, 2012; Alston & Kent, 2006; Australian Council of Deans of Science (ACDS), 2005; Council of Australian Governments (COAG), 2013; James, Baldwin, Hepworth, McInnis, & Stephanou, 1999; Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006; Mission Australia, 2006; OECD, 2013; Sidoti, 2000; TIMSS & PIRLS, 2013; VAGO, 2014). Redressing this disadvantage requires solutions that allow rural and remote students to achieve at the same levels as their metropolitan peers. An investigation of the potential for educative curricula to improve the science PCK of teachers in middle school settings in rural and remote areas and thereby improve teacher effectiveness to advance student-learning outcomes is worthwhile from an equity perspective as a means of addressing rural disadvantage.
Second, science teachers, who the literature indicates are critical to improving students’ learning outcomes in rural and remote areas (ACDS, 2005; Dow, 2003a; Goodrum et al., 2001; Marginson et al., 2013) face challenges to developing their PCK to improve their effectiveness using traditional face-to-face professional learning approaches. This is due to factors such as the lack of availability of casual-relief teachers to support teachers engaged in professional learning, as well as difficulties in attracting and retaining science teachers, which results in fewer experienced science teachers to mentor and coach less experienced colleagues to develop their PCK through activities such as analysing ‘360-degree’ data from their classrooms, and significantly fewer professional learning opportunities than their metropolitan counterparts (ACDS, 2005; Australian Secondary Principals Association (ASPA), 2006; VAGO, 2014). In addition, some teachers in rural and remote areas lack science content knowledge (Appleton, 2005) with some experiencing limited exposure to science PCK development in their teacher training (Loughran, 2010). This adversely affects their confidence to teach science (Appleton, 2005) with one consequence being a reduction in the frequency of science lessons offered (Goodrum et al., 2001; ACARA, 2011). Redressing this situation requires alternative solutions to face-to-face professional learning, which may allow teachers of science in rural and remote middle school settings to develop their PCK to improve both their effectiveness and students’ science learning outcomes. An investigation of the potential for educative curricula to improve the science PCK of teachers in middle school settings in rural and remote areas is worthwhile from the perspective of finding alternative solutions to traditional face-to-face professional learning experiences.

Third, science is one of seven mandated Key Learning Areas (KLAs) of the Australian Curriculum Foundation to Year 10. It plays a key role in achieving the goals of education expressed in the Melbourne Declaration, which “commits to supporting all young Australians to become successful, confident and creative individuals, and active and informed citizens” (ACARA, 2013, p. 8). The characteristics of ‘successful learners’ include being
... creative, innovative and resourceful, and able to solve problems in ways that draw upon a range of learning areas and disciplines, ... able to think deeply and logically, and obtain and evaluate evidence in a disciplined way as a result of studying fundamental disciplines and, ... are creative and productive users of technology (ACARA, 2013, p. 8).

The characteristics of confident and creative individuals include, “being well prepared for potential life roles as family, community, and workforce members” (ACARA, 2013, p. 8).

The characteristics of active and informed citizens include, “working for the common good to sustain and improve natural and social environments” and “... acting as global and responsible citizens” (ACARA, 2013, p. 8). The study of science contributes to the goals of the Australian Curriculum by developing scientific literacy skills (Goodrum et al., 2001; Hackling & Prain, 2007). The study of science also helps develop the innovative, creative, technological and problem-solving skills required of a national workforce of knowledge workers to generate and apply new ideas, the key factor of production in an interconnected and interdependent global economy (Australian Chamber of Commerce and Industry (ACCI), 2007; Marginson et al., 2013; OECD, 2002, 2006; Productivity Commission, 2007, 2010; Romer, 1995, 1998). Exploring the potential for educative curricula to improve the science PCK of teachers in middle school settings in rural and remote areas is therefore worthwhile from the perspective of ensuring the goals of the Australian Curriculum are met and that Australia has the workforce needed to thrive in a world economy that is increasingly dominated by globally competitive knowledge economies (ACCI, 2007; Drucker, 1995; Romer, 1995, 1996).

Fourth, there is a strong literature base indicating that the middle years are critical years for adolescents in building aspirations for the future (Chadbourne, 2001; Dinham & Rowe, 2009). This is particularly the case for building the students’ aspirations to study science and to provide a foundation for further study of the subject (Lyons & Quinn, 2010; Marginson et al., 2013). However, an examination of this literature reveals concern about the number of students electing to study the sciences at both senior high school and tertiary education levels (Lyons & Quinn, 2010; Office of the Chief Scientist (OCS), 2012). Further, poor student achievement data from national and international assessments may
reflect low student aspirations to study science. National and international middle-school science data reveal a flat-line trend in science performance in the National Assessment Program-Scientific Literacy (NAP-SL), Trends in International Mathematics and Science Study (TIMSS) and Program for International Assessment (PISA) for students in the middle years; significant variation in performance across states and territories in NAP-SL, TIMSS and PISA; a relatively large tail of lower performing students in NAP-SL, TIMSS and PISA; a low percentage of students in the higher performing bands in relative economic competitor countries in the TIMSS and PISA data; significant underperformance of identified equity cohorts in NAP-SL, TIMSS and PISA; a significant percentage of students in PISA classified as being at risk of having difficulty in working and living as productive citizens (ACARA, 2011; ACER, 2013); a decreasing percentage of students with positive attitudes to science from primary to middle years; and, a low frequency of science lessons being taught in Year 6 (ACER, 2013). None of this is suggestive of the ideal picture for science (Goodrum et al., 2001) being consistently achieved across the country in the middle years and could be indicative of low student aspiration for the study of science. An exploration of the potential for educative curricula to improve the science PCK of teachers in middle school settings in rural and remote areas is worthwhile from the perspective of building the aspirations of students for further study of science. Engendering a love for science in the middle years may also contribute to improved performance in the subject in national and national assessments.

Fifth, the literature concerning better practice principles for designing educative curricula is scant and comprises mainly of the works of Krajcik, usually in collaboration with other researchers. An exploration of implementing the Project to improve the science PCK of teachers in middle school settings in rural and remote settings will supplement the literature base on better practice design principles for educative curricula. It will inform designers and writers of educative curricula on the development of materials to improve simultaneously teacher PCK and student education outcomes.

This thesis, therefore, explores the potential for an educative curriculum (the Project) to improve the science PCK of teachers in rural and remote middle-school science settings
and comprises eight chapters. This first chapter introduces and provides both a rationale for the research and an overview of each of the other seven chapters. The second chapter presents a review of the literature, including middle school national and international science performance data, and develops an argument for researching the potential of the Project to improve science teacher PCK. The chapter begins with an examination of the benefits to the individual and national economy from the study of science and notes the compulsory intention of the Australian Curriculum to have science F–10 taught to all students regardless of location, gender, culture, and socio-economic status. The chapter explores how well science is being taught in the middle years by examining the national and international achievement data and school science literature and compares the findings with the ideal picture of science developed by Goodrum et al. (2001). An argument is presented that these findings indicate a clear deficit in outcomes for rural and remote students compared with their metropolitan counterparts. This questions a key aim of the Australian Curriculum: that all students, regardless of location, culture and socio-economic status, should have access to the Australian Science Curriculum taught well by skilled science teachers. Skilling teachers to teach science well, it is argued in Chapter 2, is assisted by continuously improving their PCK (Kind, 2009a; Magnusson, Krajcik, & Borko, 1999; Shulman, 1986) a construct that is defined and analysed in detail. A model identifying components of PCK is developed from the literature of Kind (2009a,b), Magnusson, et al. (1999) and Shulman (1986) to guide teacher professional learning for developing their PCK and noting that one component, ‘moving holistically and fluidly between the components of PCK’, requires time to develop and is a skill associated with experienced science teachers. Indicators of science teacher PCK growth are also developed from the literature to identify growing skill development of science teachers. A number of challenges for teachers of science in rural and remote settings in attempting to develop their science PCK using traditional face-to-face approaches are identified in this Chapter. These relate, for example, to a lack of capacity to provide casual teachers to release full-time teachers to undertake professional learning activities compared with metropolitan areas. Educativa curricula are presented as an alternative to face-to-face
professional development for developing the science PCK of rural and remote teachers and therefore as a means to address these challenges. Next, the design principles for improving PCK using educative curricula are examined. The chapter concludes by indicating that the focus of this research is to explore the potential for an educative curriculum, the Project (McKinnon, 2005), to improve the science PCK of teachers in middle school settings.

The third chapter presents the context of the study. The first part of the chapter describes the background to the study and provides a broad overview of the study conducted over two phases together with a detailed description of the Project. The fourth chapter presents a justification for employing a Type IV multiple-case embedded mixed-methods design (Yin, 2014) to explore the impact of the Project on the development of teachers’ science PCK in four sites in remote Western Australia and four rural sites in Victoria. The second part of Chapter 4 discusses the choice of sites and participants, access to the sites and ethical considerations. The final part of the chapter considers the role of the researcher, data-collection procedures, and the limitations of the reliability and validity of this study.

The fifth chapter presents the results obtained from analyses of the various sources of data derived from the four remote case studies sites in Western Australia. The organisational framework adopted in the chapter is to present the results from case study schools where implementation worked most successfully and conclude with sites where implementation worked least successfully. Data were gathered from interviews with teachers, principals, a middle manager, students, a Science KLA Consultant and a Cluster Coordinator; archival records; researcher direct observations; an astronomy diagnostic test; student artifacts and school-based documents. The first part of each case study is organised around a descriptive-analytic framework, describing each of the case study sites followed by an analysis of the data using the indicators of PCK growth developed in Section 2.5.1 of Chapter 2 to identify any changes that covary with implementing the Project. The final part of the chapter presents a summary of the data for all four remote case studies sites.
Following the same pattern as the previous one, Chapter 6 presents the results obtained from analyses of the various sources of data derived from the four rural case study sites in the state of Victoria. As with Chapter 5, the indicators of PCK growth developed in Section 2.5.1 of Chapter 2 are applied to each case study to identify any growth in teacher PCK that covary with implementing the Project. The final part of the chapter presents a summary of the data for all four rural case study sites.

Chapter 7 presents a summary and analysis of the data for phases one and two of the study; all case study sites in Western Australia and Victoria. The first part of chapter seven presents a summary of the data for each cluster of sites, that is to say remote sites in Western Australia and rural sites in Victoria and then summarises the data for all sites using the PCK indicators developed in Chapter 2. The second part of the chapter analyses the similarities and differences in the data for both the remote Western Australia and rural Victoria sites. Finally, the third part of the chapter attempts to account for the differences in PCK growth indicators between the remote and rural case study sites.

Chapter 8, the final chapter of this thesis, summarises, interprets and explains the findings of the research. The results suggest that the Project has the potential to improve the science PCK of teachers in middle school settings in rural and remote areas of Australia. The thesis argues this is due to the Project incorporating better practice design principles for educative curricula and having a well-developed implementation plan that includes a component of face-to-face professional learning coupled with ongoing support. The findings of this study illuminate differences between the science PCK of beginning and of experienced teachers, thereby providing guidance to teachers and professional learning experience designers, including educative curricula designers, on areas to target when seeking to develop components of PCK that are characteristic of experienced teachers. The findings suggest that PCK development cannot be left to chance. Rather, it requires a planned and systematic approach that is individualised for each teacher, and especially those in the middle years of schooling in rural and remote areas where there are a number of challenges to experiencing the more traditional face-to-face professional development offered to their peers in metropolitan locations. The findings also suggest
that the Project, and similar educative curricula, have an important role to play in developing teachers’ science PCK in rural and remote areas. Limitations of this research, implications for practice and areas for further research are also discussed in Chapter 8.

The thesis concludes that a poor science education, which results in poorer scientific literacy and a reduced ability to contribute to, and thrive in, the national and international knowledge economies adds to the education disadvantage that students in rural and remote locations experience relative to their metropolitan peers. It advocates a moral imperative to ensure this does not happen and suggests that using educative curricula to improve simultaneously rural and remote science teachers’ PCK and students’ science-learning outcomes is a strategy worth pursuing.
CHAPTER 2 Review of the Literature

This chapter presents an argument from a study of the literature for using educative curricula to improve the Pedagogical Content Knowledge (PCK) of teachers of science in middle schools in rural and remote settings in order to be able to improve student outcomes. The chapter has seven sections. Section 2.1 presents the case for studying science in the curriculum by pointing to the benefits to both the individual and nation from doing so. Given these benefits, Section 2.2 examines the international and national performance data as well as science education literature for the middle years of schooling (defined as Year 5 to Year 9), the focus of this study, to gain insights into how science education is ‘travelling’. It does this with two questions to the fore: Is science education meeting the aims of the Australian curriculum by being available to all students regardless of location, socio-economic status, and cultural background? And, Does the science being taught match the ideal picture of science education described by Goodrum et al. (2001)?

Given the integrated nature of planning in small schools, such as those discussed in Chapter 7, where teaching programs are presented to all students in the primary school years, Foundation to Year 6 (F–6), a brief analysis of national performance data for Primary Science in Year 4 is also discussed with the same questions in mind to see how it is ‘travelling’. From the analysis of the data and literature on science education in the middle years in Section 2.2, an area of interest emerges around science education in these years for rural and remote students. Section 2.2 also discusses the metropolitan-rural gap in performance from the international, national, and illustrative jurisdictional data as well as the science literature and provides reasons for these differences. Section 2.2 concludes by posing the question: What can be done to improve science education to ensure it is taught well to rural and remote students so that achievement data for rural and remote students equates to that of metropolitan students?

The case that science teachers are central to answering this question is made in Section 2.3, where the construct of Pedagogical Content Knowledge (PCK) is introduced to describe the work of teachers generally, and science teachers specifically, with a detailed
description of the PCK components being provided. A framework for developing science teachers’ PCK and their effectiveness is developed from the literature. Section 2.4 applies the framework for developing PCK outlined in Section 2.3 to improving the science PCK of teachers in rural and remote settings in the middle years of schooling, and develops from the literature a series of PCK indicators to provide evidence of growth. This framework is then applied specifically to improving the PCK of science teachers in Section 2.5. The many challenges rural and remote teachers face in accessing face-to-face professional learning experiences to develop their PCK are discussed in Section 2.6. An argument is presented that educative curricula provide an alternative (and supplement) to traditional face-to-face professional learning for developing the PCK of teachers of science in the middle years of schooling located in rural and remote areas. Educative curricula are defined and the design heuristics for educative curricula discussed. Section 2.7 provides a chapter summary culminating in a statement of purpose and outline of this study.

2.1 The case for studying science in the curriculum

In December 2010, the Council of State and Territory Education Ministers adopted the Melbourne Declaration on Education Goals for Young Australians. This declaration

...commits to supporting all young Australians to become successful, confident and creative individuals, and active and informed citizens (Australian Curriculum and Reporting Authority (ACARA) (2013, p. 8).

The characteristics of “successful learners” include being:

...creative, innovative and resourceful, and able to solve problems in ways that draw upon a range of learning areas and disciplines, ...are able to think deeply and logically, and obtain and evaluate evidence in a disciplined way as a result of studying fundamental disciplines and ...are creative and productive users of technology... (ACARA, 2013, p. 8).

The characteristics of confident and creative individuals include:

...being well prepared for potential life roles as family, community and workforce members. ... The characteristics of active and informed citizens include ...working for the common good to sustain and improve natural and social environments and ...acting as global and responsible citizens. (ACARA, 2013, p. 8).
The Melbourne Declaration provided the guiding principles for the development of a national curriculum titled *Australian Curriculum: Foundation to Year 10 (F–10)* with its overall purpose being to:

* ... describe what young Australians should learn as they progress through schooling. It is the foundation for their future learning, growth and active participation in the Australian community. It sets out essential knowledge, understanding, skills and capabilities and provides a national standard for student achievement in core learning areas. (ACARA, 2011a, p. 1)*

To achieve this overall purpose, the Australian Curriculum: F–10 describes the learning (knowledge, understanding and skills) required for each Australian student to provide the foundation necessary for successful, lifelong learning and participation in the Australian community, and makes available the education necessary for each young Australian to engage effectively with, and prosper in, a globalised (knowledge) economy, as well as making an important contribution to building the nation’s social, intellectual and creative capital.

To achieve this overall purpose, the Australian Curriculum supports students through the study of Key Learning Area content knowledge, Cross-Curriculum Priorities and General Capabilities, to acquire the skills, behaviours, and dispositions they require to become successful learners, creative and confident individuals, and active and informed citizens.

The overall purpose of the Australian Curriculum is achieved by establishing expectations for student achievement at points in their schooling through the specification of achievement standards. License is provided to schools to implement the Australian Curriculum in ways that best meet the local individual needs of their students. The Australian Curriculum recognises a need for continual updating of curriculum, pedagogy and assessment by forewarning teachers and schools that as more knowledge around effective teaching and learning becomes available, this will need to be applied to future curriculum, pedagogy and assessment practices. (ACARA, 2011a).

Seven KLAs are mandated for study in the compulsory years of schooling F–10 along with three cross-curriculum priorities and the development of seven general capabilities. Table 2.1 provides a summary of the organisation of the Australian Curriculum.
Table 2.1: Organisation of the Australian Curriculum for the mandatory years of schooling.

<table>
<thead>
<tr>
<th>Key Learning Areas</th>
<th>Cross-Curriculum Priorities</th>
<th>General Capabilities</th>
</tr>
</thead>
<tbody>
<tr>
<td>English</td>
<td>Aboriginal and Torres Strait Islander histories and cultures</td>
<td>Literacy</td>
</tr>
<tr>
<td>Mathematics</td>
<td>Asia and Australia’s engagement with Asia</td>
<td>Numeracy</td>
</tr>
<tr>
<td>Science</td>
<td>Sustainability</td>
<td>Information and Communication</td>
</tr>
<tr>
<td>Humanities and Social Sciences</td>
<td></td>
<td>Technology</td>
</tr>
<tr>
<td>The Arts</td>
<td></td>
<td>(ICT) competence</td>
</tr>
<tr>
<td>Technologies</td>
<td></td>
<td>Critical and creative thinking</td>
</tr>
<tr>
<td>Health and Physical Education</td>
<td></td>
<td>Ethical behaviour</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Personal and social competence</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Intercultural understanding</td>
</tr>
</tbody>
</table>

Table 2.1 shows the organisation of the Australian Curriculum by KLAs, cross-curriculum priorities and general capabilities with science being one of seven KLAs. It highlights that one of the KLAs to be studied in the compulsory years is Science. As one of seven mandated KLAs for the compulsory years of schooling F–10, the Australian Science Curriculum has been developed to provide an overview, rationale, aims, content and structure, overarching ideas, achievement standards, cross curriculum priorities and general capabilities for the study of science. The aims of the Australian Science Curriculum state:

*The Australian Curriculum: Science provides opportunities for students to develop an understanding of important science concepts and processes, the practices used to develop scientific knowledge, of science’s contribution to our culture and society, and its applications in our lives. The curriculum supports students to develop the scientific knowledge, understandings and skills to make informed decisions about local, national and global issues and to participate, if they so wish, in science-related careers.*

*In addition to its practical applications, learning science is a valuable pursuit in its own right. Students can experience the joy of scientific discovery and nurture their natural curiosity about the world around them. In doing this, they develop critical and creative thinking skills and challenge themselves to identify questions and draw evidence-based conclusions using scientific methods. The wider benefits of this “scientific literacy” are well established,*
including giving students the capability to investigate the natural world and changes made to it through human activity. (ACARA, 2012, p. 1)

Goodrum et al. (2001) illuminate the concept of ‘scientific literacy’ referred to above by defining it as:

...the capacity for persons to be interested in and understand the world around them, to engage in the discourses of and about science, to be skeptical and questioning of claims made by others about scientific matters, to be able to identify questions and draw evidence-based conclusions, and to make informed decisions about the environment and their own health and well-being. (p.15)

The Australian Curriculum helps students to develop scientific literacy skills (Fensham, 1997) and achieve the aims of the Australian Science Curriculum in a number of ways (ACARA, 2012). First, by developing student interest in science as a means of expanding their curiosity and willingness to explore, ask questions about and speculate on the changing world in which they live. Second, scientific literacy skill development occurs as students use the Australian Science Curriculum to develop an understanding of the vision that science provides of the nature of living things, of the Earth and its place in the cosmos, and of the physical and chemical processes that explain the behaviour of all material things. Third, the Australian Science Curriculum develops scientific literacy skills by developing an understanding of the nature of scientific inquiry through the use of a range of scientific inquiry methods, including questioning, planning and conducting experiments and investigations based on ethical principles, collecting and analysing data, evaluating results, and drawing critical, evidence-based conclusions. Fourth, the Science Curriculum develops scientific literacy skills by developing students’ abilities to communicate scientific understanding and findings to a range of audiences, to justify ideas based on evidence, and to evaluate and debate scientific arguments and claims. Fifth, the Australian Science Curriculum develops scientific literacy and achieves the aims of the curriculum by developing students’ abilities to solve problems and make informed, evidence-based decisions about current and future applications of science while taking into account ethical and social implications of decisions. Sixth, the Australian Science Curriculum develops scientific literacy and achieves the aims of the curriculum by helping
students to develop an understanding of historical and cultural contributions to science as well as contemporary science issues and activities along with an understanding of the diversity of careers related to science. Finally, scientific literacy skills are developed because of students obtaining a solid foundation of knowledge of the biological, chemical, physical, Earth and space sciences from the Australian Science Curriculum. Their study of the science curriculum allows them to select and integrate their scientific knowledge and methods needed to explain and predict phenomena, to apply that understanding to new situations and events, and to appreciate the dynamic nature of scientific knowledge (ACARA, 2012).

The study of science in the Australian Curriculum draws from three interrelated strands, Science for Understanding, Science as a Human Endeavour and Science Inquiry Skills. Science for Understanding is evident when:

...a person selects and integrates applied scientific knowledge to explain and predict phenomena, and applies that knowledge to new situations. Scientific knowledge refers to facts, concepts, principles, laws, theories and models that have been established by scientists over time. (ACARA, 2011, p. 3)

Developing Science for Understanding occurs through the study of four strands: Biological Sciences, Chemical Sciences, Earth and Space Sciences and Physical Sciences.

Science as a Human Endeavour seeks to improve student understanding and explanation of the natural world. This strand underscores the development of science as a unique way of knowing and doing as well as the role of science in everyday problem solving and decision making. Students study two sub strands: the nature and development of science and the use and influence of science.

Science Inquiry Skills involves engaging students in the act of inquiring to acquire such skills as identifying and posing questions, planning, conducting and reflecting on investigations and analysing and interpreting evidence. Students study five sub strands to develop science inquiry skills: questioning and predicting, planning and conducting, processing and analysing data and information, evaluating and, finally, communicating (ACARA, 2011).
It is evident from the outline of the Australian Science Curriculum presented above that much thought has gone into the design of the KLA (e.g., Ainsworth, 2010; Cooper, 2007; Hackling, Peers, & Prain 2007) to provide the learning experiences necessary for students to achieve the aims of Melbourne Declaration on Education Goals for Young Australians. In addition, the states and territories have made the conscious decision that the study of science is essential for all Australian school students F–10, regardless of location, gender and socio-economic status, as they progress through school. This requires, for example, teachers in rural and remote areas to teach science and to teach it well in order to meet the expectation expressed in the Australian Curriculum of setting high standards for student learning (ACARA, 2011a). By studying science, students obtain an individual benefit and also collectively provide benefits for the nation. These benefits are considered in the Section 2.1.1 and Section 2.1.2.

2.1.1 Benefits to the individual from studying science

At its most fundamental level, the study of science provides the knowledge, skills, values and attitudes individuals need to participate in their community and society. This is what, amongst others, Fensham (1997) and Goodrum et al. (2001) refer to as scientific literacy. Scientifically literate students are interested in and understand their world, engage in scientific discussion with a questioning approach of others and make evidence-based decisions on the best available scientific data particularly when it comes to controversial and topical areas of interest such as climate and health (Goodrum et al., 2001). Hackling and Prain (2007, p 3) argue that scientific literacy lies at the intersection of four factors. The first factor is positive attitudes towards and interest in scientific matters. The second factor involves broad scientific conceptual understandings that can be applied in real world contexts. The third involves applying the processes of science for formulating questions, planning investigations, and collecting and interpreting data from investigations, and the fourth requires knowledge of literacies of science, which are required to interpret science texts, to reason with science ideas, make and evaluate claims
and to construct texts that represent and communicate findings from science investigations.

Without scientific literacy skills developed through the study of science it is difficult to see how students can meaningfully contribute to debate on some of the current key issues facing societies. Such issues include: the development of genomics involving the application of recombinant DNA, DNA sequencing methods, and bioinformatics; phenomics involving the measurement the physical and biochemical traits of organisms; the media coverage given to climate change and its impact on the environment; or, advances in health care. Collectively, society also benefits from having a scientifically literate population with the skills necessary to lift the quality of debate and to arrive at well-formed solutions to these key issues.


The international literature reveals similar calls for national curricula to include the study of science to provide students with scientific literacy skills. For example, this theme emerges strongly in Organisation for Economic Cooperation and Development (OECD) publications such as *Learning for Tomorrow’s World*, (OECD, 2004) and *Knowledge and Skills for Life* (OECD, 2001). It is also a central theme of USA publications such as *Science for All Americans: Project 2061* (American Association for the Advancement of Science,

The study of science also helps produce a highly skilled workforce able to create knowledge products for export or to replace imports and to produce high quality products for the domestic economy more generally. This is vital to improving our productivity and prosperity and safeguarding our national competitiveness in a world economy increasingly defined by globally interconnected, competitive markets. This is examined in the next section.

### 2.1.2 Benefits to the economy from the study of science

*New Growth Theorists* such as Romer (1995) and Solow (1970, 1990) point to knowledge being the third factor of production in leading economies in the world and technology, including the knowledge on which technology is based, as an intrinsic part of the economic system. As Romer (1995) and Solow (1970, 1990) note, the centrepiece of New Growth Theory is the role knowledge plays in making growth continuously possible. For both economists, knowledge is broadly defined to include everything we know about the world; the ‘high tech’ as well as the ‘routine’. For New Growth Theorists, the education system plays a critical and ongoing role in providing the workforce with the skills to generate and exploit knowledge.

Leadbeater (2000) argues that the greatest source of wealth is new ideas, intellectual property and information, and that employers are seeking workers with the ability to generate new ideas, and to apply them to existing as well as future knowledge products. Spender (2002) supports this view when she asserts the education students receive needs to reflect that:

...we are now part of a global economy where our wealth is dependent on facilitating learning that acknowledges ideas as the substance, talk as the means of production, the embodiment of the idea/talk into commercial reality
The potential for a seemingly unlimited source of ideas to create new knowledge is far reaching for Romer (1992) who stresses the point that rather than everything useful being already invented, it is extremely unlikely that we will ever come close to discovering a fraction of all of the possible useful products, inventions and processes we might create from the resources available to the human race. He sees the quality of ideas as the limiting factor on what is possible. Romer (1995) and Solow (1970, 1990) argue that new investments built on new ideas and new technology is continuously possible. This leads to endogenously-created and sustained economic growth triggering continuous cycles of virtuous prosperity based on increasing returns at scale. This is in contrast to traditional economists such as Keynes, Friedman and Marshall, who saw technology as extrinsic to the economic system and all investment subject to the law of diminishing returns (e.g., Waks & Roy, 1987).

Drucker (1995) and Romer (1990, 1995) argue that special characteristics of knowledge make endogenously created sustained cycles of virtuous prosperity possible. These include:

1. Knowledge, ideas, and concepts are non-subtractive and independent of space. Their use by one person does not exclude their use by others;
2. The cost of knowledge is unaffected by the number of people who eventually use it, and production technology can replicate knowledge quickly and easily;
3. The value of knowledge is unrelated to the cost of creating it and there is little correlation between knowledge inputs and outputs;
4. Knowledge is time dependent and ever changing. Knowledge makes itself obsolete very quickly and competitive advantage based on knowledge will always be challenged; and,
5. Globalisation and the lowering of technical barriers to accessing information move knowledge across borders more quickly than ever before.

For New Growth Theorists, continuously increasing living standards by increasing returns associated with continuous new investment driven by the application of new ideas involves a strategic approach by national governments to all of the factors that help create knowledge. One important factor that helps create knowledge is the worker or labour,
and ensuring workers have the skills to create knowledge is dependent on a high quality education system (OECD, 2001, 2007) that focuses on the formal school education system responsible for educating students for 13 years. Australia requires a workforce capable of ensuring the country thrives in the global knowledge economy. As Marginson et al. (2013) argue, nations with leading and dynamic economies are those with the strongest performing education and/or research systems; for example, Finland; Hong Kong, China; Korea; Shanghai, China; Singapore; Switzerland and Taiwan. As the Australian Chamber of Commerce and Industry (2007), Johnson, (2005), the OECD, (2002, 2006b), the Productivity Commission, (2007, 2010) and Sen (1992, 2000) point out, one of the most important products of an educated population is knowledge and one of the most important indicators for measuring the successes of governments is their ability to develop knowledge as a key capability of their citizens.

Science, as a key component of the Australian Curriculum, plays an important role in developing the skills and abilities of Australia’s workforce to innovate, invent, create, problem solve and apply new ideas. Science requires students to think both convergently and divergently, to be analytical, and to evaluate possible solutions (e.g., Goodrum et al., 2001). In addition, the study of science, particularly through inquiry-based problem solving, plays a major role in generating new creative and innovative ideas as well as testing routine ideas as students engage with the concepts of science. Skills acquired through the study of science such as questioning and predicting, hypothesising, planning and conducting investigations, processing and analysing data and information, evaluating evidence and communicating help develop employability skills for knowledge workers. These skills, described by the Australian Chamber of Commerce and Industry (2007, p. 180), also include creative problem solving, planning and organising, using technology and learning to learn.

Acknowledging the importance of the study of science to Australia’s human capital agenda, the Australian Productivity Commission has devoted time and resources to suggesting improvements to science education in Advancing Australia’s Human Capital Agenda (2010) and Large Dividends from Science and Innovation Support (2007). More
recently, the Australian Council of Learned Academies (ACOLA) commissioned the report
*STEM: Country comparisons* (Marginson et al., 2013) to examine and learn from
international experiences in Science, Technology, Engineering and Mathematics (STEM)
education that contribute to the development of human capital. The report considered
STEM enrolments, access of STEM graduates to the labour market, and the relevance of
STEM to economic growth and wellbeing. The authors analysed policies put in place in a
number of countries, with a view to adopting nationally in Australia those policies that had
a high probability of success. The report argued that Australia is below a top tier of
countries in terms of promoting STEM subjects and lacks the national urgency found in
international competitor countries such as the USA and East Asian countries to advance
the study of these subjects. The study concluded that Australia is running the risk of being
left behind competitor countries if current STEM policies persist.

In the national business literature, the Australian Chamber of Commerce and Industry
summarised much of the thinking on the importance of science (and mathematics)
education to the development of Australia’s human capital agenda in its publication *Skills
when it argued:

> Science and Math skills are important to the continued wellbeing of Australia and its international competitiveness. ...demand for science and math skills in the workforce is increasing from a range of industries and in order to remain competitive and become world leaders this demand must be met. Australia can always meet a proportion of its demand for skills from international sources. However, all OECD countries are in a competitive bidding race for international talent. In the longer term, Australia must provide as high a proportion as possible of math and science graduates through our domestic education system. (p 177)

As a result, ACCI (2007) recommends that “... primary and secondary students are to be encouraged to study math and science as a career path” (p 177).

More recently, the Australian Chief Scientist (Chubb, 2015) has argued that the study of
science is a key building block to the nation’s prosperity contributing to the development
of an entrepreneurial culture and an internationally competitive economy. Australia’s
future, Chubb (2015) argues, lies in ensuring the education system provides students with a pathway from the classroom to a career in the STEM economy (p. 7).

2.1.3 Summary

The Council of State and Territory Education Ministers adopted the Melbourne Declaration on Education Goals for Young Australians, paving the way for the development of the Australian Curriculum. The Australian Curriculum describes what young Australians should learn as they progress through schooling in order to meet a number of national aims of schooling. These include providing the foundation necessary for successful, lifelong learning and participation in the Australian community and the education necessary for engaging effectively with and prospering in a globalised knowledge economy.

Science, as one of seven mandated Key Learning Areas (KLAs) in the compulsory years of schooling F–10, plays a key role in achieving the aims of the Australian Curriculum. In so doing, the study of science equips individuals with scientific literacy skills as well as the workforce skills necessary to improve productivity, prosperity, and safeguard our international competitiveness. The Australian Curriculum makes it clear that the study of science is mandated in the compulsory years of schooling for all students F–10 regardless of location, gender, cultural background, or socio-economic status. In addition, the expectation in the Australian Curriculum is that not only will science be taught to all students in the compulsory years but that it will be taught well (ACARA, 2012).

Given the importance of the study of science to both the individual and the national economy, the question that naturally arises is: Is science being taught well to all students regardless of location, gender or socio-economic status? This question is considered in the Section 2.2 using data from national and international science assessments together with a study of the literature on school science.
2.2 Is science being taught well to all students?

The focus of this study is the middle years of schooling. Thus, the question becomes *Is science being taught well to all students in the middle years regardless of location, gender and socio-economic status?* There is a strong literature base that indicates the middle years are critical years for adolescents (see e.g., Chadbourne, 2001; Dinham & Rowe, 2009; Western Australian DET, 2008) and so science education in the middle years is particularly important. Students in the middle years are usually defined as those aged between 10 and 15 years (Dinham & Rowe, 2009). For the purposes of this study, the middle years are defined as Year 5 to Year 8 in those jurisdictions in which Year 6 is the final year of primary school and Years 6 to Year 9 in those jurisdictions in which Year 7 is the final year of primary school. It should be noted, however, that Queensland and Western Australia have recently moved to include Year 7 as the first year of high school.

It is necessary to define *science being taught well* to facilitate an understanding of what it looks like. Goodrum et al. (2001) provide assistance by describing an *ideal picture for science education* using data from their review of the science education and from the research literature, an analysis of curriculum documentation, an analysis of the work on professional standards at that time (2000–2001), submissions from key science stakeholders and, through focus group meetings with a national sample of science teachers. Underpinning their ideal picture for science education is a belief that: *developing scientific literacy is a high priority for all citizens* (Goodrum et al., 2001, p. vii). Their *ideal picture* has the following nine elements:

1. The science curriculum is relevant to the needs, concerns and personal experiences of students;
2. Teaching and learning of science is centred on inquiry. Students investigate, construct and test ideas and explanations about the natural world;
3. Science assessment serves the purpose of learning and is consistent with and complementary to good teaching;
4. The science teaching and learning environment is characterised by enjoyment, fulfilment, ownership of and engagement in learning, and mutual respect between the teacher and the learner;
5. Science teachers are life-long learners who are supported, nurtured and resourced to build the understandings and competencies required of contemporary best practice;

6. Science teachers have a recognised career path based on sound professional standards endorsed by the profession;

7. Science teachers enjoy excellent facilities, equipment and resources support teaching and learning;

8. Class sizes make it possible to employ a range of teaching strategies and provide opportunities for the teacher to get to know each child as a learner and give feedback to individuals; and,

9. Science and science education are valued by the community, have high priority in the school curriculum, and science teaching is perceived as exciting an valuable, contributing significantly to the development of persons and the economic and social wellbeing of the nation. (p. vii)

In this study, science being ‘taught well’ is science education that conforms to this ideal picture of science. Conversely, science not being ‘taught well’ is science education that does not conform to the ideal picture of science (Goodrum et al., 2001). With this ideal picture of science education in mind, four main data sources are used in the following subsections to investigate whether or not science is being taught well in the middle years of schooling:

1. National assessment data for Year 6 science students;
2. International assessment comparative data for Year 8, 9 and 10 science students;
3. Science education literature on science teaching in the middle years; and,
4. Given the practice of whole school planning in small primary schools whereby curriculum such as that contained in the Project is taught to all students, International assessment data for Year 4 students is briefly examined.

A summary of these data is presented in Section 2.2.4. In each of these sections the approach used is to present the data followed by commentary on what that the data reveal in terms of the ideal picture of science developed.

2.2.1 Data from the National Assessment for Year 6 Students

The National Assessment Program-Scientific Literacy (NAP-SL) supports measurement and reporting on progress towards the achievement of objectives outlined in the Melbourne Declaration on Educational Goals for Young Australians (2008) in the study of science (ACARA, 2013). Conducted every three years since 2003 with a random sample of
approximately 5% of Year 6 students, the assessment provides national comparisons of achievement data against the science literacy scale, student survey data on interest in science, student survey data on engagement in science related activities, and student survey data on how science is relevant to their lives.

Key results from the NAP-SL national assessment for 2012 (ACARA, 2013) show no change in terms of mean achievement and the proportion of students performing at or above the Proficient Level in scientific literacy since 2003. The percentage of students at or above national proficiency levels is shown in Table 2.2.

**Table 2.2: The number of students at or above proficiency level in NAP-SL 2012**

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Percentage of Students at or above Proficiency Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACT</td>
<td>65.3</td>
</tr>
<tr>
<td>WA</td>
<td>56.4</td>
</tr>
<tr>
<td>VIC</td>
<td>51.3</td>
</tr>
<tr>
<td>TAS</td>
<td>51.3</td>
</tr>
<tr>
<td>SA</td>
<td>51.1</td>
</tr>
<tr>
<td>NSW</td>
<td>50.9</td>
</tr>
<tr>
<td>QLD</td>
<td>49.9</td>
</tr>
<tr>
<td>NT</td>
<td>31.0</td>
</tr>
<tr>
<td>AUSTRALIA</td>
<td>51.4</td>
</tr>
</tbody>
</table>

Table 2.2 shows that a national average of 51.4% of Year 6 students were at or marginally above the proficiency level in 2012. The results also show variability in the number of students at or above ‘Proficiency Level’ across states and territories with the range varying from 65.3% in the Australian Capital Territory (ACT) to 31% in the Northern Territory (NT).

The NAP-SL results for 2012 also show a ‘flat lining’ of students’ achievement between the years 2003 and 2012, and that Aboriginal\(^1\) students continued to perform below the level of non-Aboriginal students with means of respectively 303 and 399. In addition, students in ‘provincial’, ‘remote’, and ‘very remote’ areas in 2012 performed at lower levels than

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\(^1\)“Aboriginal” is the preferred term in Western Australia rather than “Indigenous” to denote the original inhabitants of the continent prior to the arrival of the Europeans who set up the first colony under British rule in 1788.
students in metropolitan areas with means respectively of 381, 349 and 400 (ACARA, 2013).

The emergence of the result for provincial students was a new phenomenon compared to previous results (ACARA, 2013). In addition, student survey data results showed that students’ self-concept in science had the highest correlation with self-performance on the student survey items and, that a positive attitude towards science existed with 80% of respondents indicating they would like to learn more about science. This is a positive result that teachers of science can build on with students expressing an interest in learning ‘new things in science’, ‘learning about science’ and ‘doing science based activities’ (ACARA, 2013).

A number of observations can be made when comparing the results of the 2012 Year 6 NAP-SL with the ideal picture for science education developed by Goodrum et al. (2001). There were a high number of students who indicated they ‘sometimes’ or ‘never’ worked in groups when carrying out scientific investigations (37%) and a surprisingly high proportion of students indicated that they ‘sometimes’ or ‘never’ used a computer for research or to present science ideas or findings (58%). In addition, a high proportion of students indicated that they ‘sometimes’ or ‘never’ got to carry out and plan their own investigations (72%). A high proportion also indicated that their teacher did not invite visitors to school to talk about science topics (69%) or did not go on excursions related to the science topic they were studying (63%). These results cast doubt on any notion that the ideal picture of science is operating consistently in Year 6 classrooms across the country.

In addition, survey results indicate a wide range in the frequency of science classes taught per week to Year 6 students. Twenty two per cent of students and teachers indicated a frequency of more than one lesson per week, 42% indicated a frequency of once per week, 18% less than one lesson per week, and a disappointing 18% ‘hardly ever’. This result indicates that 78% of students surveyed were taught science once per week or less. The finding that 18% (about one fifth) of Year 6 students in 2012 ‘hardly ever’ had science
lessons is particularly worrying and worthy of further investigation to ascertain the reasons for this with a view to redressing this situation. Similarly, the finding that only about half of Year 6 students surveyed (national average 51.4%) perform at or above Proficiency Level for NAP-SL is worrying.

Regrettably, this figure has ‘flat lined’ over the four surveys from 2003 to 2012 (ACARA, 2013). The poor performance of rural and remote students and the Aboriginal students compared with their metropolitan and non-Aboriginal peers are also areas of concern requiring further investigation to ensure the ideal picture for science education is achieved for all students regardless of gender, socio-economic status, cultural background and location. The NAP-SL data for Year 6 students in 2012 is suggestive that science is not being taught well to all middle school students.

2.2.2 Data from International Science Assessments

Australian students in the middle years participate in two international assessment programs: Trends in International Mathematics and Science Study (TIMSS) and, Program for International Student Assessment (PISA) Science. Data from each of these assessment programs are examined respectively in sections 2.2.2.1 and 2.2.2.2 to assess the extent to which science is being taught to all students regardless of location, gender and socio-economic status and how well that science is being taught.

A sample of Year 4 and Year 8 Australian students has participated at four yearly intervals in TIMSS since 1995 with the main goal being to assist participating countries to monitor and evaluate reading, mathematics and science achievement and teaching across time and across year levels (ACER, 2011). In the latest TIMSS survey (2011), 52 countries and 7 benchmarking jurisdictions participated in the Year 4 TIMSS assessment and 45 countries and 14 benchmarking jurisdictions participated in the Year 8 assessment. In Australia, a national stratified random sample of 6146 students participated, drawn from 280 primary schools and 290 secondary schools. In addition to a Student Questionnaire, data from a Home Questionnaire, a Teacher Questionnaire and a School Questionnaire are collected. These data help address concerns about the quantity, quality, and content of instruction.
In terms of the TIMSS assessment, there are three content domains in science at Year 4 and four at Year 8 level, and three cognitive domains in each curriculum area: knowing, applying and reasoning. The content domains define the specific subject matter covered by the assessment, and the cognitive domains define the sets of behaviours expected of students as they engage with the content.

2.2.2.1 TIMSS Year 8 Science Results for 2011

Key TIMSS results for Year 8 science students in 2011 indicated that Australia’s average achievement score of 519 was significantly higher than that of 26 countries including Italy and the Ukraine, and below that of nine countries, including high-performing Asian countries such as Chinese Taipei, Korea, Japan and Singapore as well as England, Finland, Hong Kong, Slovenia and the Russian Federation (ACER, 2011). The score for New Zealand and the United States was not significantly different to that of Australia.

Although Australia’s average achievement score of 519 was not significantly different to its score in TIMSS 1995, there have been some fluctuations over the 16 years between 1995 and 2011 prompting a view that Australia’s overall performance in TIMSS has ‘flat lined’ (ACER, 2011). Interestingly, science is the only curriculum area in which there has been a significant gender difference in Australia since 1995 in favour of males. The TIMSS results by jurisdiction summarised in Table 2.3 also show the range in scores by state and territory was 70 points between the ACT and NT.

<table>
<thead>
<tr>
<th>State/Territory</th>
<th>Mean Score</th>
</tr>
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<tbody>
<tr>
<td>ACT</td>
<td>551</td>
</tr>
<tr>
<td>NSW</td>
<td>532</td>
</tr>
<tr>
<td>QLD</td>
<td>516</td>
</tr>
<tr>
<td>WA</td>
<td>514</td>
</tr>
<tr>
<td>VIC</td>
<td>513</td>
</tr>
<tr>
<td>SA</td>
<td>506</td>
</tr>
<tr>
<td>TAS</td>
<td>496</td>
</tr>
<tr>
<td>NT</td>
<td>481</td>
</tr>
<tr>
<td>TIMSS all nations Year 8 Science</td>
<td>500 Average</td>
</tr>
</tbody>
</table>

Table 2.3: Mean scores by jurisdiction for TIMSS 2011
Table 2.3 shows that only two jurisdictions scored above the mean (broken line) and that the score for students in the ACT was not significantly different to that of students in NSW, but was significantly higher than that of students in all other states. Students in NSW significantly outperformed students in South Australia (SA), Tasmania (TAS) and the NT, and students in Queensland (QLD) also significantly outperformed students in TAS and the NT.

In terms of the achievement of key equity cohorts, TIMSS results for 2011 show gaps between the achievement data for Aboriginal and non-Aboriginal students, high and low SES students and rural and remote students. This difference is approximately the equivalent of two years in schooling (ACER, 2011).

There are four benchmarks in TIMSS for Year 4 and 8 science students:

1. Advanced International Benchmark  625 score points
2. High International Benchmark  550 score points
3. Intermediate International Benchmark  475 score points
4. Low International Benchmark  400 score points

Year 8 students at the Advanced International Benchmark demonstrate a grasp of some complex and abstract concepts in Biology, Chemistry, Physics, and Earth Science. In comparison, those at the Low International Benchmark simply recognise some basic facts from the life and physical sciences. Benchmark results for Year 8 students saw a continuing trend over the past four TIMSS surveys in the high performing Asian countries (Chinese Taipei, Japan, Korea and particularly Singapore) that achieved higher percentages of students in the Advanced Benchmark compared with Australia (ACER, 2011). Forty percent of students reached this Advanced Benchmark in Singapore and between 18% and 24% of students reached this level in Japan, Chinese Taipei, Korea compared with only 11% of students in Australia. At the lower ends of achievement, 8% of Australian students did not achieve the Low Benchmark, and a further 22% of students did not attain the Intermediate Benchmark.

In the states and territories, 19% of Year 8 students in the ACT and 16% of students in New South Wales (NSW) reached the Advanced Benchmark, but in all other states less
than 10% achieved at this level. Forty four per cent of students in the NT and 40% of students in Tasmania did not reach the Intermediate Benchmark. The range of students not achieving the Intermediate benchmark in other states varied from 32% in South Australia, Queensland, and Victoria, through to 18% in the Australian Capital Territory.

In other findings from TIMSS science results in 2011, students who indicated that they liked science scored higher on the cognitive assessments than students who indicated that they did not like the subject (ACER, 2011). Similarly, students who felt confident in the subject also scored higher. In the school Principal Survey, 52% of principals of Australian Year 8 students reported levels of resource shortages for science (ACER, 2011).

In terms of school-climate factors, Year 8 (and Year 4) science achievement was higher, on average, among students who liked school and felt that they belonged, were engaged during lessons, felt that they were safe and experienced low levels of bullying including cyber bullying (ACER, 2011). In addition, Year 8 (and Year 4) achievement was higher, on average, in schools in which principals and teachers reported a high emphasis on academic success, teachers reported they felt safe and the work environment was orderly and, where principals reported few problems with discipline or attendance. Furthermore, Year 8 achievement was higher where students had adequate prerequisite knowledge, disruptive or disinterested students did not affect learning and, and where lack of nutrition and sleep deprivation did not affect student learning (ACER, 2011).

The fact that Australia’s 2011 TIMSS results are above the average of participating countries is encouraging. However, the average results mask areas of concern that raise questions about the ideal picture of science teaching and learning being achieved in Year 8 classrooms across the country. For example, the fact that 8% of Australian students did not achieve the Low Benchmark and a further 22% of students did not attain the Intermediate Benchmark is an area that requires attention. In addition, the comparatively low 11% of students achieving the Advanced Benchmark compared with economic competitor countries is a further area that requires improvement. This is particularly the case in some East Asian countries where 40% to 50% of students perform at the Advanced
Benchmark level compared with only 10% to 15% of Australian students. The number of countries outperforming Australia is cause for concern from an internationally competitive human capital perspective and can lessen the benefits to the nation from studying science as more highly skilled workforces in competitor economies place these countries in a better position to exploit the global knowledge economy by producing superior knowledge products.

The findings that students performed better in countries where enjoyment and confidence with the subject were high resonate with the call from Goodrum et al. (2001) for the ideal picture of science education to be characterised by teaching-learning environments featuring enjoyment, fulfilment, ownership and engagement in learning science coupled with natural respect between teacher and student. The significantly increased performance of countries such as Chinese Hong Kong, Japan and Singapore relative to Australia may be indicative of science teaching-learning environments closer to the ideal picture. These countries may provide exemplars of science teaching and learning in the middle years from which Australia may learn.

The data on Year 8 TIMSS (2013) is suggestive that science is not being taught well to all students in the middle years regardless of location, gender, and socio-economic status. The relatively high number of students in the bottom two achievement bands and low numbers of students in higher bands may be improved by implementing the ideal picture for science education.

The range in the mean results across states and territories (70 marks) points to a lack of consistency in performance across the country. Calls from teachers for more resources and the fact Australia’s achievement is tending to ‘flat line’ are both suggestive of the ideal picture not yet operating consistently across the country for all Year 8 students. This may well be the case for the 8% of Australian students not achieving the Low Benchmark, and the 22% of students did not attain the Intermediate Benchmark. The differences in performance for equity cohorts such as those in rural and remote settings and the Aboriginal students compared with their metropolitan and non-Aboriginal peers, is
suggestive that more can be done to improve science education for these groups of students.

2.2.2 Program for International Student Assessment (PISA) results for 2012.

PISA is an assessment of the ability of a sample of 15-year olds who are near the end of the compulsory years of education to apply their knowledge and skills to real-life problems and situations (ACER, 2013). The emphasis is on assessing skills that will equip students to participate in adult society. In science, the areas assessed are:

1. Identifying scientific issues;
2. Explaining phenomena scientifically;
3. Using scientific evidence;
4. Scientific inquiry; and,
5. Attitudes to science, including interest in science, environmental responsibility and support for scientific inquiry.

The PISA assessment, repeated every three years, provides time series data to measure changes in performance over time. The latest survey (2012) had a sample size from participating countries of almost 510,000 students, representing 28 million 15-year olds from 65 countries. Australia contributed 14,481 students from 775 schools across all states and territories to this sample (ACER, 2013).

The major focus for the 2012 assessment was on mathematical literacy with a minor focus on reading and scientific literacy. Scientific literacy will be a major focus in 2015 to produce time series data incorporating 2006 data (i.e., the last year that science was the major focus of assessment). The 2012 PISA data for scientific literacy shows Australia achieved an average score of 521 points, which is significantly higher than the OECD average of 501 points (ACER, 2013). The data also show variation in performance across jurisdictions with Australian Capital Territory and Western Australia performing at a level greater than New South Wales followed by respectively South Australia, Queensland and Victoria, then Tasmania and the Northern Territory. The data also reveal 16 countries outperforming Australia (ACER, 2013) with an increasing trend in the number of countries outperforming Australia in PISA from 2000.
Table 2.4 shows an increasing number of countries outperforming Australia in PISA from 2000. This has implications for Australia’s international competitiveness. If knowledge workers in international competitor countries become more highly skilled relative to Australia’s workforce, then their productivity and ingenuity with knowledge products will increase, thereby making the products and services they deliver more competitive in international markets.

In PISA 2012, 14% of Australian students were top performers in scientific literacy reaching Proficiency Levels 5 and 6 compared to 8% across the OECD (ACER, 2013). At the other end of the scale, however, 14% of males and 13% of females failed to reach the International Proficiency Baseline (Level 2) compared with 18% of males and 17% of females across OECD countries. While males and females performed at a level not significantly different from each other, the scientific literacy performance by geographical location showed that metropolitan students outperformed students in provincial areas on average by around half a school year and by around one and a half years in remote areas. Expressed as the percentage of students in the top bands this represented respectively: 15% of metropolitan students; 10% of provincial students and 6% of remote students displaying a decrease in performance with increased remoteness. In addition, Aboriginal
students performed significantly lower in scientific literacy than non-Aboriginal students by an average difference of 84 score points or the equivalent of about 2.5 school years. Expressed as the percentage of top performers this was 2% for Aboriginal and 14% for non-Aboriginal students. In terms of low performers, 37% of Aboriginal students were in this category compared to only 13% of non-Aboriginal students (ACER, 2013).

In terms of the performance of students by socioeconomic status, the PISA 2012 results also reveal that students in the highest socioeconomic quartile performed at the equivalent of 2.5 school years higher than students in the lowest SES quartile. Compared with the 2006 PISA results, Australia's mean score for scientific literacy had not changed and further indicates a flat-lining in achievement (ACER, 2013). Within this national score there was a significant decline in mean scores for the Australian Capital Territory (15 points on average) and South Australia (19 points on average). It is important to note that within PISA, students performing below the baseline are judged to be “at serious risk of not achieving at levels sufficient to allow them to adequately participate in the 21st century workforce and to contribute as productive citizens” (ACER, 2013, p. 1). An analysis of 2012 PISA results for scientific literacy indicates that about 12% of Australian students are below this baseline.

This scientific-literacy figure is a concern. The OECD deems this student cohort to lack basic skills for effective participation in the workforce and society. Also of concern is the fact that within this 12%, representation of Aboriginal students is more than three times the representation of non-Aboriginal students; representation of remote students is more than twice that of metropolitan students; and, representation of low socio-economic status (SES) is more than seven times that of high SES students. The PISA results for the period 2003 to 2012 also indicate that Australia’s performance is not improving with the average scores for Mathematical Literacy and Reading Literacy significantly declining and for Scientific Literacy flat lining. The number of countries outperforming Australia on Scientific Literacy is increasing.
The fact that Australia’s PISA results are above the OECD average is encouraging. As with TIMSS assessment results, however, the ‘average’ performance of students in the middle years of schooling masks areas of concern for science education that indicate science is not being taught well to all students regardless of location, gender and SES. For example, as far as overall science achievement is concerned, TIMSS and PISA assessment results reveal that Australia’s science performance in both international assessments is flat lining. Additionally, there is diversity of performance across the country with the performance of students in Tasmania and the Northern Territory being below the OECD average. A reasonable expectation is that if all students studying science in the middle years regardless of location, gender, or SES were experiencing the ideal science picture then Australia’s performance should be improving and variations in state and territory performance would be minimal.

The data also indicate that students in remote locations are, on average, performing at significantly lower levels than metropolitan students and that they are over represented in the Below Proficiency Baseline for PISA (ACER, 2013). Aboriginal students are performing at significantly lower levels than non-Aboriginal students and are also over represented in the Below Proficiency Baseline set by the OECD. In addition, the performance gap between students of the same age from different SES backgrounds is stark. There is an over representation of low-SES students in the Below Proficiency level. A reasonable expectation is that if all students studying science in the middle years, regardless of location, gender, or SES were experiencing the ideal science picture for science education, then schools would be addressing the equity issues that produce disparities in student achievement data. It is worth noting that the ‘flat lining’ of performance, the variations in performance across the country and the equity outcomes for Aboriginal, rural and remote and low SES found in PISA results are also a feature of TIMSS results and NAP-SL results.

These data suggest that the ideal picture of science is not being achieved across the country.

Before leaving discussion of international performance data and turning to the literature on school science education to examine what it is saying about the ideal picture for
science education, it is necessary to provide brief comment on international assessment data for Year 4 science students. This is necessary because the small rural schools included in this study in rural Victoria jointly plan all curriculum activities on a Year F to Year 6 basis. This means that all students in the school participate in curriculum topics. A brief comment on Year 4 international assessment data is therefore provided in Section 2.2.2.3.

2.2.2.3 Brief Comment on Year 4 international assessment data.

Key results from TIMSS 2011 for Year 4 students (ACER, 2013) indicate a similar pattern to TIMSS Year 8 results. Australia’s achievement score of 516 was significantly higher than that of 23 countries, including Belgium and New Zealand, but below that of 18 countries, including most of the Asian countries, England and the United States. Korea and Singapore were the top-performing countries of TIMSS 2011 and scored well in excess of the High International Benchmark of 550. The scores for these countries were not significantly different to each other but were significantly higher than all other countries. The next highest performing country was Finland, which had higher achievement than all remaining countries. Australia’s average Year 4 science score of 516 in TIMSS 2011 was significantly lower than the score achieved in TIMSS 2007, but not significantly different to the score in TIMSS 1995. The range in scores across the states and territories was 56 points between the Australian Capital Territory at the top and the Northern Territory at the bottom representing just over half a standard deviation (ACER, 2013).

As far as achieving Year 4 TIMSS Science Benchmarks in 2011 is concerned, only 7% of Australian students achieved at the Advanced International Benchmark with a further 28% achieving at the High level and 36% at the Intermediate level. Twenty per cent of Australian Year 4 students achieved at the Low International Benchmark and 9% of Australian students did not achieve at this level (ACER, 2011). By comparison, Korea, Finland and Japan had between 14% and 30% of their Year 4 student’s proficient at the Advanced Benchmark and between 5% and 10% of their students reaching a Low Benchmark or not achieving this level at all.
The TIMSS data indicate that the Australian Capital Territory (ACT) was the highest performing jurisdiction with 13% of students reaching the Advanced International Benchmark and 84% achieving at least the Intermediate level. Victoria and New South Wales followed the ACT with 10% and 9% respectively achieving the Advanced International Benchmark and 77% of students and 74% students respectively achieving at least the Intermediate level. In each of the other states, fewer than 10% of students achieved at the Advanced International Benchmark noting that in the Northern Territory, 40% of students did not achieve the Intermediate level, while 34% of students in Queensland did not attain this standard of proficiency.

In terms of equity cohorts, the mean score of 458 for Aboriginal students was well below the mean score of 522 for non-Aboriginal students (ACER, 2013). The mean score by location decreased by remoteness with mean scores for Metropolitan, Regional and Remote Year 4 students being 520, 507 and 459 respectively (ACER, 2013). The mean score by SES ranged from 545 for those students who had many books in their homes to 459 for those students with a few books in their homes, the de facto measure of SES.

Other findings from TIMSS 2011 indicate that students who said they liked science scored higher on the cognitive assessments than students who indicated that they did not like the subject. Similarly, students who felt confident in the subject also scored higher in that area on the cognitive assessment. There were no significant gender differences at Year 4 TIMSS achievement scores. Interestingly, 68% of Year 4 teachers reported resource shortages that affected their teaching of science. Similar to results for Year 8 students, Year 4 science achievement was higher, on average, among students who liked school and felt that they belonged, were engaged during lessons, felt that they were safe and experienced low levels of bullying ‘almost never’ including cyber bullying.

A similar pattern emerges from TIMSS results for Year 4 students to those of TIMSS results for Year 8 students, PISA results for Year 9/10 students and Year 6 NAPLAN-SL. This consistent pattern in performance shows a flat lining or deterioration in total achievement scores over the past 15 years, variability in performance across the country, over
representation of students from rural and remote locations, Aboriginal cohorts and low SES cohorts in the lower achievement bands, and teachers and principals indicating the need for more and better quality resources. A cause for concern in the data is the 29% of Year 4 students who achieved at the Low International Performance Benchmark or who were unable to achieve this benchmark (20% and 9% respectively). Further, relative to international competitors, the lower number of Year 4 students achieving the Advanced or High International Benchmarks (7% and 28% respectively) is an area for improvement (ACER, 2013). These data are suggestive that the ideal picture of science education in Year 4 classes is not being achieved consistently across the country for all Year 4 students.

In addition to the data from national and international assessments, it is helpful to examine the literature of science researchers and educators on science education in schools to understand what it is saying about achievement of the ideal picture of science education in the middle years of schooling. The views of a sample of key science researchers and educators on how well school science is travelling in the middle years are considered in the Section 2.2.3.

2.2.3 Views on science education: National and international literature

As indicated above, Goodrum et al. (2001) describe a variable picture for primary education across the country with some classrooms experiencing science education at, or close to, the ideal picture but also many where the actual picture was far from the ideal picture. As Goodrum et al. (2001) noted in their seminal study of the state of primary science across Australia:

*It would appear that where primary science is working well the teachers are enthusiastic, collegial and supported by the school administration. Despite the efforts of many enthusiastic teachers, there was concern among the focus groups across Australia that little or no science is taught in many primary classes. Where science is taught, it was pointed out that the teachers often lack confidence and have little understanding of science education, as one of the teachers commented: ‘Many teachers lack a science education background—science is not in their comfort zone’. (p. 87)*
The fact that Science is not in the comfort zone of some primary teachers is reflected in an average weekly figure for primary science teaching of 59 minutes (compared to an average of 200 minutes for secondary science) and which Goodrum et al. (2001) suggest is an overestimation given that the survey of over 500 primary teachers was conducted by telephone. However, a few years later, Angus et al. (2004) revised this estimate downwards to 41 minutes. In addition to this relatively low figure for student exposure to the science teaching, Goodrum et al. (2001) found that teachers taught on average only one topic from each of the biological, physical and Earth sciences each year further reducing student exposure to the breadth of the Science KLA.

In addition to the research of Goodrum et al. (2001), the national science literature paints a picture of concern not just for primary school education (e.g., Ainley, Caldwell, Burke, Selleck, Selleck, & Spinks, 2004; Angus, Olney & Ainley, 2007), but also for middle-school Science and senior high-school Science. The Federation of Australian Scientific and Technological Societies (2002), Harris, Jensz and Baldwin (2005), Lyons (2006) and Goodrum et al. (2001) all express concern regarding both the relevance of the science being taught to the lives of students and to the pedagogical approaches employed by science teachers to engage students. One conclusion reached is that student participation in school science will continue to decline if science educators do not ensure that science is relevant to students’ needs and interests. A concern that follows this conclusion is that it will lead to a further decline in numbers of students selecting Science subjects in higher education (Lyons & Quinn, 2010; Tytler, 2007). Another concern is for the need to develop more effective ways for creating engaging and exciting teaching and learning environments through improved resource rich pedagogical practices to help students improve their learning (e.g., Fitzgerald, Hollow, Rebull, Danaia, McKinnon, 2014; Tytler, 2008; Tytler & Hubber, 2005).

Federation of Australian Scientific and Technological Societies (2002), Harris, Jensz and Baldwin (2005), Lyons (2006), and Goodrum et al. (2001) all share the view that an inquiry-based approach to science, rather than presenting the subject to students as a body of knowledge for memorising, will help students make sense of their world. Other concerns
identified in the literature include students’ perceived difficulty with studying science, inadequate resources, facilities and preparation time for teachers, the use of summative assessment alone, rather than in combination with formative and ongoing assessment, to determine student learning, and the lack of discipline related professional learning to improve the quality of science teaching.

The themes of achieving the ideal picture for school science education by making science more relevant and making the science teaching and learning environment more conducive to learning by improving the quality of the science teaching commencing with pre-service training emerge from the literature of a number of science researchers and educators. These include Hickey (2007) on the art of teaching primary science, McKinnon (2001, 2005) on engaging students and teachers in the study of science and Tytler (2004, 2007), Hubber and Tytler (2004), Tytler and Symington (2006), on developing children’s knowledge, reasoning and literacies in science. Also included are Appleton (2003, 2005) on building teacher confidence to teach science, Hackling and Prain (2005, 2007) on developing pedagogical approaches to science based on inquiry learning and using assessment effectively to improve students’ scientific literacy with the more normal form of ‘literacy’ as a contributor (e.g., Norris, & Phillips, 2003), and, Hackling and Prain, (2007) on the need to improve the literacies of science.

Achieving the ideal picture for school science education by building the interest of students in science in the late primary and early high school years by engaging students more fully in pedagogical approaches that stimulate their interest in science are also themes pursued by the Chief Scientist in a study of the health of school science education (Chubb, 2012). In addition, there have been a number of national and jurisdictional parliamentary inquiries and reviews calling for improvements to science education. Such parliamentary inquiries include the Parliament of Victoria Education and Training Committee’s Inquiry into the Promotion of Mathematics and Science (2006) and the Prime Minister’s Science, Engineering and Innovation Council inquiry into Science Engagement and Education: Equipping Young Australians to Lead Us in The Future (2003). Reviews include the Commonwealth’s review of Teaching and Teacher Education: Australia’s
Teachers, Australia’s Future: Advancing Innovation, Science, Technology and Mathematics (Dow, 2003a,b) and a national Review of STEM literature (Tytler, Osborne, Williams, Tytler & Clark., 2008). These inquiries and reviews have all supported the notion that the ideal picture of science education is not being achieved and requires, among other things, investment in science teacher professional learning to do so.

Similarly, reports by national professional associations have provided support for the need to achieve the ideal picture for science education in the primary, middle and senior schools years. These reports include the Australian Council of Deans of Science (2005) report Who’s Teaching Science and the Federation of Australian Scientific and Technology Societies (2002) report Australian Science: Investing in the Future. Strategic plans at the jurisdictional and national levels addressing the concerns raised in the literature have been developed and implemented in an attempt to achieve the ideal picture of science. As an illustration, the Queensland Department of Education, Training and the Arts (2007) report, Towards a 10-Year Plan for Science, Technology, Engineering and Mathematics Education and Skills, promotes achievement of the ideal picture for science education by focusing actions on improving the quality of teachers as a means to improve scientific literacy through professional learning. At the national level, the Australian School Education National Action Plan 2008–2012 (Goodrum & Rennie, 2007) provided strategies to address the concerns raised in the literature regarding science education. Finally, the development of the Australian Science Curriculum built on the work conducted by Goodrum and Rennie (2007), and which promotes the achievement of the ideal picture of science education.

The national literature also recognises the importance of addressing concerns regarding science education early in the education of students. Tytler et al. (2008) suggest that by age 14 many students have made identity-related decisions about their future to the extent they have decided to pursue an interest in studying science or otherwise. This indicates the important role that the middle and primary school years play in nurturing students’ interest in science and the need to address any problems in science education to achieve the ideal picture for science education early. Also on the theme of addressing any
problems with school science education as early as possible, almost 50% of students
surveyed by Goodrum, Druhan and Abbs (2012) indicated that their interest in science was
stimulated in the junior years of secondary schooling and often by an inspirational science
teacher. This supports the view in the literature for ensuring science education is taught
well to students in the junior high school years. Lyons and Quinn (2010), for example,
found a key reason for Year 11 students not choosing to study science in the senior years
was that they found the subject uninteresting in their junior high school years. Tytler et al.
(2008) argue that the key to making science relevant and interesting to students in junior
high school and primary school lies in using pedagogies that are diametrically opposed to
the extant transmissive pedagogical approaches, viz., to focus on inquiry-based
methodologies. This is consistent with calls from Goodrum et al. (2012) for more
interactive, investigative pedagogical approaches with strong student input into practical
work.

The OECD (2006c) produced similar findings to those of Lyons and Quinn (2010) on
building student aspirations for science in the primary years. The OECD policy report,
*Evolution of Student Interest in Science and Technology Studies* (OECD, 2006c) found that
the impact on students of providing positive experiences in science and technology at an
early age could be long lasting. The report found that students whose experiences are
negative at school, due to uninteresting content or poor teaching, are far less likely to
pursue an interest in science and technology. The report also found that interest in
science and technology appears very early in the primary school. It recommended actions
to promote student contact with effective science teaching in early primary school as well
as raising the confidence of teachers to teach science in order to increase the
attractiveness of science and technology to students. Other recommendations included
teaching content using hands-on experience for students and providing pupils with
extracurricular science activities. The report also noted that while children in primary
school have a natural curiosity for science and technology, many of their teachers lack
initial training or are uncomfortable with science subjects and with hands-on
demonstrations due to heavy workloads leaving little time for experiments. This is
consistent with the finding by Appleton (2005) that primary teachers often lack confidence to teach the subject. Increased professional learning for primary teachers is viewed as the solution with the report recommending designing activities to assist primary teachers to:

1. Transmit the essence of the scientific method and to stimulate the interest and enthusiasm of their students in science and technology;
2. Update their knowledge on the latest science and technology developments;
3. Update their knowledge on how students learn; and,
4. Redesign curriculum to reflect better the reality of modern science and technology, emphasising their contributions to society.

The case for addressing any problems in science education early in school education was also a finding of the Australian Council of Learned Academies (ACOLA) STEM: Country Comparisons Report (Marginson et al., 2013). A key finding of this report was that laying the foundations of STEM competence occurs in the early childhood and primary years suggested the need for exposing primary and junior high school students to high quality primary science and mathematics teaching in the early childhood and primary years. One model recommended by ACOLA to achieve this was the placing of trained science and mathematics specialists in schools to develop teacher expertise in both subjects. In Australia, this approach is being trialled in Victoria as a national initiative of the Ministerial Council on Education, Employment, Training and Youth Affairs (MCEETYA) on behalf of all educational jurisdictions.

Concern over the teaching of school STEM subjects is a key theme in the ACOLA STEM: Country Comparisons Report (Marginson et al., 2013). This report provides a direct comparison between concerns over STEM in Australia and 23 other countries including Canada, China Yuan Gao, Finland, Japan, Korea, New Zealand, Singapore, Taiwan Yuan Gao, Russia, and the United States. Six key themes emerge from an analysis of STEM in the 23 countries studied. These themes are presented by ACOLA in the form of a series of conflicting policy choices requiring school policy makers to make choices firstly between designing curriculum to focus on core science and mathematics disciplinary concepts or on generic competencies (such as problem solving, creativity). The second policy choice
presented is between focusing on science for all students or streaming to encourage a STEM elite. The third policy choice is between promoting the study of science content discipline breadth and depth or broad science exposure based on a wide set of concepts. The fourth is between improving science and mathematics achievement through tight accountability processes or through supported local autonomy and innovation. The fifth is between employing an invigorated current science curriculum or to restructure the existing curriculum. The final policy choice is between employing traditional pedagogies focused on transmission of conceptual knowledge or employing student-centred pedagogies focused on developing creative and critical thinking.

Australian education policy makers, through the Ministerial Council on Education, Employment, Training and Youth Affairs, have responded to these policy choices in two key ways. First, they have adopted policy choices in the National Science Curriculum based on an inquiry-based pedagogical approaches to science rather than traditional transmissive pedagogical approaches. Second, they have implemented a curriculum relevant to the needs and concerns of students as opposed to a curriculum based on memorisation of scientific facts. In addition, science has been made compulsory, usually to Year 10, with student choice over subject selection operating in Years 11 and 12. Policy choices have also focused on developing scientific literacy for all rather than developing a STEM elite with an accompanying curriculum focused on preparing students for university.

While these approaches may help realise the ideal picture of science education (Goodrum et al., 2001), the ACOLA report identified five features in countries strong in STEM that it argued Australian school policy makers could adopt to strengthen STEM education.

The first involves ensuring that teachers enjoy high self-esteem, higher remuneration and a more meritocratic career structure. The report illustrates this by referring to Finland with its requirement for science teachers to have a Science Master’s Degree as a minimum and to agree to work in areas of challenge while in China teacher promotion is based on teachers demonstrating improvements in the standard of their work.
The second area involves having: ‘An unbreakable commitment to disciplinary content with a focus on improving students’ knowledge of the discipline’ (Marginson et al., 2013, p. 15). The report argued that in contrast to Australia, where science teacher qualifications can be less rigorous, where they can be teaching out of their field and where professional learning can be a mix of generic and discipline specific topics, teachers in ‘STEM-strong’ countries are fully qualified in their discipline and specialise in teaching in that field and no other (e.g., Deng, 2007; Eurydice, 2006; Gess-Newsome, 1999a,b,c). Therefore, in ‘STEM-strong’ countries, professional learning focuses on increasing teachers’ disciplinary knowledge of their subjects (Justi & van Driel, 2005).

The third area is to implement an active program in curriculum and pedagogical reform focused on making science and mathematics more engaging and practical through inquiry-based and problem-based learning with an emphasis on critical thinking and creativity. This policy approach is consistent with the approach used in the Australian Science Curriculum to achieve the ideal picture for school science education. In terms of developing creativity, the report contrasts Australia and South Korea where in the latter the arts have been incorporated into STEM (science, technology, engineering, arts and mathematics or STEAM) to promote creativity and design.

The fourth area is a focus on lifting the performance of identified equity cohorts. Finland’s focus on lifting the performance of low socio-economic status students and Canada’s focus on lifting the performance of Aboriginal students are used to illustrate this. As indicated in the discussion of national and international performance data, while Australia has national policy frameworks designed to lift the performance of equity cohorts, to date results have not been encouraging.

The fifth and final area is a strong strategic national STEM policy framework to create the preconditions for STEM success. The report points out that ‘STEM-strong’ countries have a strategic national framework that include curriculum reform and high teaching standards; world-class university science programs, recruitment of overseas science talent, and STEM partnerships linking schools with industry, business and the profession. To address this
theme, the Australian Chief Scientist (Chubb, 2014) released a strategic national framework for STEM that among other strategies proposes:

A core STEM education for all students—encompassing inspirational teaching, inquiry-based learning and critical thinking — placing science literacy alongside numeracy and language proficiency as a priority. (p. 20)

2.2.4 Summary of assessment data and science literature

In summary, the national and international science literature of educators and researchers presents similar themes to those emerging from an analysis of the national and international assessment data on the question of how well science being taught to all middle school students regardless of location, gender, Aboriginal culture and socio-economic status. The literature supports the conclusion that improvements in science education are needed to achieve the ideal picture of science education (Goodrum et al., 2001) for all students. Such improvements are required to address the following nine issues.

1. The flat-line trend in science performance in NAP-SL, TIMSS and PISA for students in Years 4, 6, 8, 9 and 10. This implies implementing strategies to raise continuously the achievement of these students in national and international assessments. (It should be noted that performance in PISA mathematics and reading also declined over the past three assessment cycles raising further concern as mathematics and reading are enablers for effective science education. Lifting achievement in these subjects too will require prioritisation.)

2. Eliminating the significant variation in performance across states and territories in NAP-SL, TIMSS and PISA. Achieving the ideal picture of science education would suggest little if any variation around an increasing mean.

3. Improving the performance of the relatively large tail of lower performing students in NAP-SL, TIMSS and PISA. Almost half of Year 6 students are not at the determined Proficiency Level for scientific literacy acquisition. Twenty per cent of Year 4 students and 8% of Year 8 students are at the Low Benchmark. Nine per cent of Year 4 students and 8% of Year 4 students have not achieved the TIMSS Low Benchmark.

4. Improving the percentage of students in the higher performing bands in TIMSS and PISA to match those of our economic competitor countries. This will reduce the number of these countries over time outperforming Australia so that our workforce remains competitive. In some of our Asian competitor countries 40% to 50% of students perform at the same level as the top 10% to 15% of Australian students.

5. Continuously lifting the performance of identified equity cohorts in NAP-SL, TIMSS and PISA. This involves continuously lifting the performance of rural and remote students,
Aboriginal students and students from low socio-economic backgrounds to that of, respectively, metropolitan students, non-Aboriginal students and the general student population measured by socio-economic status.

6. Decreasing the percentage of students in PISA classified as being at risk of having difficulty in working and living as productive citizens. The figure of 12% of students in this category is simply unacceptable.

7. Improving student attitudes to science in the primary and middle years of schooling in TIMSS. TIMSS (2011) data reveal that 55% of Year 4 students ‘like science’ but by Year 8 only 25% do so. This is against an international average decline from 53% to 35% indicating a much sharper decline in Australia in positive student attitudes toward science.

8. Addressing the low frequency of science lessons in Year 6. NAP-SL results identified that 18% of students received less than one lesson per week and 18% ‘hardly ever’ received science lessons. Science is a key component of the national curriculum and is compulsory for all students in Years F–10 so all students should be receiving science lessons at the same frequency as literacy and numeracy lessons (Chubb, 2014).

9. Taking action to close the gap between the actual and ideal pictures for school science education wherever the need is identified to do so, including by:
   a. Improving science curriculum, pedagogy and assessment to ensure students receive science curriculum relevant to their needs, concerns and personal experiences that promotes scientific literacy;
   b. Ensuring inquiry-based science teaching with high student engagement;
   c. Ensuring a teaching-learning environment characterised by student ownership, enjoyment, fulfilment and mutual respect between teacher and student rather than learning environments in which teacher choice of investigations, summative assessments and transmissive pedagogies dominate; and,
   d. Providing science teachers with better quality resources, facilities and more time to prepare lessons.

This last point receives strong support from the national and international science literature, which calls for action to close the gap between the actual and ideal pictures of science education. This literature calls for an inquiry-based approach to science education characterised by high student engagement, high curriculum relevance, and respectful, enjoyable and properly resourced learning environments build on effective instructional and assessment strategies (e.g., Abell & McDonald, 2006; Flick & Lederman, 2006; Lederman & Lederman, 2004; Lederman, 2006).

Each of these nine areas provides opportunity for researchers to conduct in-depth studies of the causes of the problems and to propose solutions. However, the breadth of work involved in investigating all nine areas is considerable and beyond the scope of the
present study. The view is taken therefore that it is beneficial to select one or two areas for intensive study. Two areas emerge from the data and literature that are of particular interest to the researcher. The first, as previously identified, is science education in the middle years of schooling and the second is the science education for the equity cohort ‘rural and remote’ students. Reasons for focusing this study on these two areas are discussed respectively in sections 2.2.5 and 2.2.5.1.

2.2.5 Science education in the middle years of schooling

The case for focusing this study on the middle years of schooling where primary and secondary education systems merge, stems from the literature indicating that these have long been considered to be the most important years of schooling (Chadbourne, 2001; Dinham & Rowe, 2009; Western Australian Department of Education and Training, 2008). As discussed in Section 2.4, there is a compelling argument in the literature for exposing students to the ideal picture of science before age 14 to ensure they are not ‘turned off’ science (Chubb, 2012, 2014; Goodrum et al., 2001; Goodrum, Druhan & Abbs, 2012; Lyons & Quinn, 2010; Marginson et al., 2013; OECD, 2006; The Regional Policy Advisory Committee of Victoria, 2013; Tytler, Osborne et al., 2008). This argument focuses the strategic ‘policy spotlight’ on science in the primary and junior secondary years to ensure that the aims of the Australian Curriculum are met, and that students and the nation acquire benefits from the study of science. In addition, TIMSS and PISA assessment data reveal that science performance in the middle years of schooling is ‘flat-lining’. A reasonable policy objective is to improve the performance of students by ensuring that the ideal science picture for science education is in place across all classrooms in the middle years of schooling in the country.

A further reason for exploring science in the middle years is TIMSS, PISA and NAP-SL assessment data showing wide-ranging performance across the country, with the performance of Tasmania and the Northern Territory below the OECD average in PISA and TIMSS. Reducing variation around an increasing mean would signal increasing student achievement in these assessments and reduced variation in science achievement. Yet
another reason for exploring science in the middle years is the literature and data on the variation in frequency of science being taught across the country that brings into question whether or not all students are being exposed to the compulsory Australian Science Curriculum.

Goodrum et al. (2001) revealed that science teaching is not in the ‘comfort zone’ of many primary teachers. This was reflected in an average figure for weekly primary science teaching of 59 minutes, which Goodrum et al. (2001) suggested is an overestimation, a caution later reinforced by Angus et al. (2004) who reported a figure of 41 minutes in schools in Western Australia. In addition, NAPL-SL (2012) data indicate that almost one in five students across the country ‘hardly ever’ receive science lessons. The Australian Curriculum makes it clear that all students are to receive science education in the compulsory years F–10. A low frequency of science lessons or no science lessons at all deny students the benefit of gaining scientific literacy skills, and also impacts the nation by denying the potential benefits of having a highly skilled knowledge workforce.

Finally, a further reason for exploring science education in the middle years is the literature that identifies primary teachers who have a low incidence of major studies in science compared with major comparator countries (Marginson et al., 2013; OECD, 2006). Appleton (2005) has shown that lack of science subject content knowledge affects primary teachers’ confidence to teach science and that many have not studied science during their senior school or in higher education courses. This affects the quality of science education delivered to students in the primary– and middle-school years and acts as a further barrier to teachers’ development of Pedagogical Content Knowledge (Kind, 2009a).

2.2.5.1 Science education for rural and remote students

The case for focusing this study on rural and remote students stems from the national and international assessment data indicating a long equity ‘tail’ in Australian international science assessment data, together with a strong personal interest drawn from the researcher’s work in rural and remote areas. In addition, there is a considerable body of national and international science assessment data and literature discussed in Sections
2.2.8 and 2.2.9, which indicate that rural and remote students experience major educational disadvantage. The long equity tail has an overrepresentation of rural and remote students, Aboriginal students and low socio-economic status students. Students in remote locations in particular are on average performing at a significantly lower level than their metropolitan peers and those located in remote areas are over represented in the Below Proficiency Baseline in national assessment data. Moreover, improving the performance of these equity cohorts provides one means of raising the Australian average in national and international assessments. Improving the performance of equity cohorts also achieves the education moral purpose espoused in the Australian Curriculum by ensuring that all students, regardless of gender, location, cultural background, and socio-economic status, have every opportunity to achieve the private benefits of science education as well as to contribute to national prosperity.

For the purposes of defining ‘rural’ and ‘remote’ students, this study uses the definitions provided by the Australian Statistical Geography Standard (Australian Bureau of Statistics, 2011) that divides Australia into six classes of geographical area based on access to services. These classifications are ‘Major Cities’, ‘Inner Regional’, ‘Outer Regional’, ‘Remote’, ‘Very Remote’ and ‘Migratory’.

When describing ‘Outer Regional’ areas the Australian Statistical Geography Standard (ASGS) indicates that typically these areas have small populations (Australian Bureau of Statistics, 2001), have variable accessibility to goods and services and limited opportunities for social interaction (DHAC & GISCA, 2001). In addition to small population size relative to metropolitan centres, students in these areas often have to move to larger centres to access further education and training. Often these areas experience high migration of families and youth to larger population centres. Information-Communication-Technology infrastructure is often lacking and the levels and breadth of employment and existence of key industries is lacking relative to metropolitan areas. There is usually limited access to a range of youth services often including the full range of education services (MCEETYA, 2015). This descriptor fits the sites in Phase 2 of this study and for ease of identification the term ‘rural’ rather than ‘Outer Regional’ is used.
As far as defining ‘remote’ is concerned, students in remote (and very remote) areas typically live in small communities of fewer than 999 people (ABS, 2001) and have limited accessibility to goods and services compared with their metropolitan and regional peers. Distances to larger centres are usually in excess of three hours travelling time on roads of variable condition and, on leaving, they have to move to larger centres to access further education and training. Such remote areas too often experience high migration of families and youth to larger population centres. The breadth of employment opportunities relative to metropolitan areas is much smaller and there is limited access to a range of youth services often including the full range of education services and curriculum offerings (MCEETYA, 2015).

This description of ‘remote’ fits the sites in Phase 1 of the study where the term is used to include both the ‘remote’ and ‘very remote’ categories of the Australian Statistical Geography Standard. An examination of science education in the middle years of schooling and the educational disadvantage experienced by students and teachers in these areas can coalesce in a study that explores ways of achieving the ideal picture of science for these groups.

The present study is thus focused in this way to investigate simultaneously both areas with a view to examining if improvements to science education can be made. It commences in Section 2.2.6 by developing an understanding of the issues involved in achieving the ideal picture for science education in rural and remote middle school settings by examining the dimensions of the general metropolitan-rural education achievement gap. A discussion of the general factors accounting for the differences in student achievement is presented in Section 2.2.7 and then specific factors that account for these differences in science education are considered in Section 2.2.8.

2.2.6 The performance gap: Metropolitan and Rural and Remote students

One obvious way to quantify the dimensions of the gap in performance between metropolitan and rural students is to measure the size of such gaps in key indicators such as national and international student achievement data. The data from national
assessments provided in Section 2.2.1 showed that students in ‘remote and very remote’ areas performed at lower levels than those in ‘provincial’ and metropolitan regions with means of 349, 381 and 400 respectively (Australian mean of 394) (ACARA, 2012). The gap in means for metropolitan and remote and very remote students is 51 points (ACARA, 2013b). Translated into years of schooling, where 30 points is equivalent to one year of schooling, metropolitan students on average outperformed students in provincial areas by around half a school year and those in remote schools by around one and two third years in the 2012 NAP-SL assessment.

A similar pattern existed in TIMSS data for 2011 where the gaps between metropolitan, remote, and very remote students were approximately the equivalent of two years in schooling. As far as PISA results are concerned, students from metropolitan, provincial, and rural and remote areas represented respectively 15%, 10% and 6% of students in the top band of PISA (ACER, 2013). The 2012 PISA results for scientific literacy indicate similar problems of distance from metropolitan centres. Representation of remote students in the lowest performing band levels is more than twice that of metropolitan students. The difference is not only reflected in science literacy but also in reading achievement.

At the national level, the COAG Reform Council’s report Education in Australia 2012: Five Years of Performance (COAG, 2013) provides an indication of the size of the performance gaps in reading achievement between metropolitan and rural students by producing a number of tables for Year 3, 5, 7 and 9 NAPLAN Reading Achievement for the years 2008–2012. As an illustrative example, Table 2.5 is a summary of these data for students meeting minimum reading standards in 2012:
Table 2.5: Performance gaps between Metropolitan, Remote and Very Remote students: Percentage of students meeting minimum reading standards (2012) by Year Group.

<table>
<thead>
<tr>
<th>Reading Standards of:</th>
<th>Year 3</th>
<th>Year 5</th>
<th>Year 7</th>
<th>Year 9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metropolitan</td>
<td>96%</td>
<td>93%</td>
<td>97%</td>
<td>92%</td>
</tr>
<tr>
<td>Remote</td>
<td>85%</td>
<td>80%</td>
<td>85%</td>
<td>80%</td>
</tr>
<tr>
<td>Very Remote</td>
<td>59%</td>
<td>41%</td>
<td>55%</td>
<td>57%</td>
</tr>
<tr>
<td>Gap (Metropolitan-Remote)</td>
<td>11%</td>
<td>13%</td>
<td>12%</td>
<td>12%</td>
</tr>
<tr>
<td>Gap (Metropolitan-Very Remote)</td>
<td>37%</td>
<td>52%</td>
<td>42%</td>
<td>35%</td>
</tr>
</tbody>
</table>

Table 2.5 demonstrates that there are significant achievement gaps in the percentage of students meeting minimum NAPLAN reading standards for students in metropolitan, remote and very remote areas. The table shows that gaps in performance increase as remoteness increases and that there are gaps for each year level of approximately one and a half years’ schooling between metropolitan and very remote students.

Decreasing achievement with increasing remoteness is a highly significant feature of the NAPLAN assessment results. For example, in Year 7 NAPLAN data for 2012 for Grammar and Punctuation there are four categories of geographical location: metropolitan, provincial, remote and very remote. The percentage of students not meeting minimum national standards for this measure is 4%, 6.6%, 16.4% and 54.3% respectively. The gap between metropolitan and remote students for Year 7 NAPLAN data for Grammar and Punctuation is significant. For very remote students the gap is highly significant at 50.3%. For Year 9 Persuasive Writing, as a further illustration, the data show a similar pattern with the percentages of students not meeting minimum national standards being 13.8% (metropolitan), 22.2% (provincial), 35.2% (rural) and 65.6% (very remote). As a final illustration, the data for Year 7 Numeracy mirror this pattern with the percentages of students for each category not meeting national minimum standards being respectively 2.3%, 3.8%, 9.8% and 37.2% (ACARA, 2014). These figures starkly illustrate the increasing performance gaps with remoteness of location.
National data can give an ‘average’ picture for student achievement that may not be present in individual jurisdictional data. For this reason, data from an illustrative jurisdiction, Victoria, is presented in Section 2.2.6.1 with the range of education data broadened to see if the same national pattern of results holds true. Victoria is selected because of its links to the Phase 2 case studies discussed in Chapter 6.

2.2.6.1 Victoria: Metropolitan and Rural and Remote performance data gaps

In Australia, Victoria does not usually spring to mind when thinking about jurisdictions with large pockets of rural, remote, and very remote populations. This usually occurs when thinking of jurisdictions such as New South Wales, Western Australia, Queensland, and the Northern Territory. One could be forgiven, therefore, for thinking that differences in the performance of students by geolocation are not significant or perhaps do not exist in Victoria. However, *The State of Victoria’s Children Report* (Department of Education Training and the Arts, 2011) highlights the differences between ‘rural and remote’ and ‘metropolitan’ children and their performance on a range of education achievement measures. For example, rural children are more developmentally vulnerable than metropolitan children are on six of seven Australian Early Development Index domains and there is increased reporting by parents of their child’s difficulty with speech and language in rural areas compared with metropolitan ones (17% compared with 12.9% in metropolitan areas). In addition, the report shows there is a higher average absence from school rate for rural areas compared with metropolitan Victoria with the most notable differences observable in Years 7 to 12.

The Victorian report also shows lower school connectedness scores for rural students than for metropolitan students. School enjoyment is lower for young people in rural Victoria compared to young people in metropolitan areas. Moreover, school retention rates are consistently higher in Years 10 to 12 for metropolitan students compared with those in rural areas (the 2011 figures were 87% retention for metropolitan students compared with 74%).
The report also highlighted a higher percentage of students in metropolitan Victoria achieving at or above the National Minimum Standard for reading, writing, and numeracy compared with those in rural and remote areas on 2011 NAPLAN attainment data for Years 3, 5, 7, and 9. Consistently lower completion rates for Years 11 and 12 rural students from 2006 to 2010 compared with their metropolitan peers were also highlighted in the report (2010 figures: 82.8% completion for metropolitan students compared with 73.1%). Young people in rural Victoria were shown to be more likely to express a preference for trade apprenticeships and Technical and Further Education (TAFE) compared with metropolitan students with consequent negative impacts on overall earning ability and productivity.

Disappointingly for rural students in Victoria, a recent report by the Victorian Auditor General’s Office (VAGO, 2014) into rural education stated:

*The audit assessed the effectiveness of the Department of Education and Early Childhood Development’s (DEECD) activities to ensure that Victorians in rural areas have access to a high-quality education ... [While] DEECD supports schools, vocational education, and training providers to assist them in delivering education in rural settings ... it has not developed a targeted and comprehensive strategy to overcome commonly understood barriers to rural students participating and achieving in education.* (pp. 3–4. My emphasis)

The general data presented in Sections 2.2.6–2.2.8 and the illustrative data presented in this section provide an indication of the gaps in general school performance between rural and remote students and metropolitan students. They show that rural and remote students perform significantly below their metropolitan peers on a range of general school and early childhood national indicators. These data also show that performance gaps increase with increasing remoteness.

An understanding of factors accounting for this situation is necessary to be able to examine actions to close the gaps in performance between metropolitan, and rural and remote students. Section 2.2.7 examines general factors accounting for performance gaps between metropolitan, and rural and remote students as the basis for developing gap-closing strategies. It does this by first examining the general context in which rural and
remote education occurs before turning to specific factors affecting science education in Section 2.2.8. A section summary is presented in Section 2.2.9, which concludes by asking the question: “What can be done to close and ideally eliminate the performance gap between metropolitan and rural and remote science student performance in middle school settings?”

2.2.7 General factors accounting for these performance differences

There are a number of factors of a general nature that impact adversely on rural and remote education. Alston and Kent (2006), Mission Australia (2006) and Sidoti (2000) all report that school students in rural, remote, and isolated areas of Australia are disadvantaged. The various authors attributed this to restricted access to rich learning environments available to their counterparts in metropolitan schools. These authors also attributed this disadvantage to the lower value placed on education and its relevance by rural families relative to their metropolitan counterparts. Restricted access to information and communication technologies and the greater impact of the most recent droughts and natural disasters such as bushfires and flooding on social, economic, and environmental change in rural areas compared with metropolitan areas were also identified as causes.

Alston and Kent (2006), James et al. (1999), Mission Australia (2006) and Sidoti (2000) all argue that this disadvantage has a number of negative impacts on rural students relative to their metropolitan counterparts. These include rural students being less likely to finish school, especially if they are Aboriginal students, less likely to enrol in tertiary education after completing school, less likely to participate in schooling, more likely to be absent from school and less likely to complete Year 11 and Year 12.

Inquiries into aspects of rural disadvantage have identified other factors termed ‘barriers’ impacting on the education of rural and remote students. For example, the Commonwealth Senate Standing Committee on Rural Affairs and Transport—Inquiry into Rural and Regional Access to Secondary and Tertiary Education Opportunities (2009) found that tertiary education for rural students typically means moving away from home and incurring considerable financial costs. As a result, higher percentages of rural students
who have completed year 12 defer the offer of a tertiary education place at a rate two and a half times that of metropolitan students and often do not go on to study at university (VAGO, 2014). The Victorian Auditor General’s Office (VAGO, 2014), reported the following on gaps in performance and barriers that rural students face in accessing education:

*I found that there is a persistent gap in achievement and outcomes between rural and metropolitan students ... Students in rural areas have, for a long time, not performed as well as their metropolitan peers. They face barriers to accessing education that the (Victorian) Department of Education and Early Childhood Development (DEECD) has not managed to overcome, and there is no sign that the gap in performance is likely to narrow. Indeed, in some areas of performance, the gap is getting wider* (p. 1–4).

Section 2.2.8 examines the challenges that science education faces with this context of general rural and remote school education disadvantage.

### 2.2.8 Specific factors accounting for differences in Science performance

Within the general context of rural and remote educational disadvantage, science education in rural and remote areas is facing some difficult and, in some cases, unique challenges in achieving the ideal picture for science education that, if not addressed, could compound the general educational disadvantages rural and remote students face and which will likely perpetuate inequity. What follows is a description of these difficult and somewhat unique challenges facing science teachers in rural and remote schools drawn from survey data from the National Centre of Science, Information and Communication Technology, and Mathematics Education for Rural and Regional Australia (Lyons et al., 2006) as well as data from the Australian Secondary Principals’ Association (2006) together with a study of the literature. The description of specific factors is presented as three themes. The challenges identify where energy is required to increase the performance of middle years’ rural and remote science.

#### 2.2.8.1 Theme 1

*Science Education and Teachers are not immune to general factors affecting education in rural and remote areas discussed in Section 2.3.2*
The Australian Council of Deans of Science (2005), The Australian Productivity Commission (2010), The Federation of Australian Scientific and Technology Societies (2002), The NSW Inquiry into Public Education (2002) and Sidoti (2000) reported issues of ‘general’ disadvantage and inequality in relation to science teachers and teaching in rural and remote Australia. This ‘general’ disadvantage and inequity affect all teachers in rural and remote areas and result in a lack of professional learning opportunities for rural and remote teachers as well as a lack of specialist science staff. Difficulties in retaining qualified teachers and a lack of adequately qualified casual replacement staff to support science teachers engaging in a range of necessary activities, including professional learning, and poor access to ICTs are further effects of this disadvantage.

2.2.8.2 Theme 2

Recruiting, retaining, and professionally developing science staff, in addition to ‘out-of-field’ teaching, lack of science resources, student access to outside learning area experiences and combined classes.

The national survey Science, ICT and Mathematics Education in Rural and Regional Australia (SiMERR) conducted by Tytler, Mousley, MacMillan, Marks, and Tobias (2006) had a particular emphasis on rural and remote teacher supply and demand for Science, ICT and Mathematics (see e.g., Lyons, 2006). Rural and remote school staff and parents were surveyed (almost 3000 teachers and 928 parent/caregivers) and detailed interviews took place in 37 rural schools. Key findings for science teaching included that teachers in provincial areas were twice as likely, and those in remote areas about six times as likely as their metropolitan colleagues to report high annual staff turnover rates (> 20% per year) in their schools. In addition, primary teachers in provincial areas were more than twice as likely, and those in remote areas up to six times as likely as those in metropolitan areas to report that it was ‘very difficult’ to fill vacant teaching positions in their schools.

In relation to filling positions in secondary Science, ICT and Mathematics, teachers in provincial areas were about twice as likely, and those in remote areas about four times as likely than those in metropolitan areas to report that it was ‘very difficult’ to fill teaching vacancies in these subjects. A further finding was that teachers of Science, ICT and
Mathematics in provincial areas indicated they were about twice as likely and those in remote areas more than three times as likely as colleagues in metropolitan areas to be required to teach a subject for which they were not qualified, including Science.

In addition, findings from this survey indicated that primary teachers in remote areas reported a significantly higher unmet need for professional growth opportunities such as mentoring, release time for professional development and collaboration with colleagues than did teachers in metropolitan areas. Moreover, primary teachers outside of the metropolitan areas indicated a substantially greater unmet need for subject specific professional learning in Science and Mathematics than did their metropolitan counterparts. The findings also indicated that primary science teachers in non-metropolitan areas indicated a significantly higher unmet need for a range of resources and assistance including ICT support and maintenance, learning support, and resources to cater for student diversity, than did their metropolitan colleagues. The report also indicated that primary teachers and secondary Science and ICT teachers in non-metropolitan schools identified a significantly higher unmet need for their students to have access to a broad range of learning experiences including opportunities to visit educational sites, than did their metropolitan colleagues. Primary teachers and secondary Science and Mathematics teachers in schools with higher proportions of Aboriginal students in rural and remote areas also indicated that their needs for alternative and extension activities to cater for the diversity of student backgrounds and ability levels in their classes were not being met. Finally, the findings indicated that the practice of combining secondary classes (e.g., Year 11 and Year 12 physics) was significantly more common in rural and remote schools than in metropolitan schools. Only 11% of Metropolitan Area respondents reported that composite classes in Science, ICT or Mathematics were operating in their schools. By contrast, 36% of those in Provincial Areas and 58% of those in remote areas reported this arrangement.
2.2.8.3 Theme 3

*Rural and remote parents share teacher concerns about science teacher attraction and retentions issues, teacher experience, and student achievement and student access to good learning experiences*

From the SiMERR National Survey (Tytler, et al., 2006) insights into rural parent/caregivers perceptions and views on Science, ICT and Mathematics education indicate that the confidence they have in the capacity of their children’s primary schools to attract and retain qualified teachers declined substantially with the size and remoteness of school location. However, this was not perceived with secondary school staffing. The survey also indicated that although parents/caregivers in remote areas were generally appreciative of their children’s teachers, there were concerns about the inexperience and capabilities of the teachers commonly recruited to these schools, and the long-term effects on the education of their children, which were perceived to be negative.

The perceptions of parents/caregivers about levels of achievement in Science, ICT and Mathematics in their children’s schools varied substantially with geographic location. Those with children in metropolitan schools were more inclined to agree that children in these schools achieved to a high standard in these subjects compared with those in non-metropolitan schools. Those with children attending schools in remote areas were least inclined to agree. Finally, the survey revealed that the greatest concern of parents/caregivers related to their children having adequate access to a good range of learning experiences and opportunities, including excursions, visits by experts, and a variety of senior courses from which to choose. Parents/caregivers expressed a belief that student access to these experiences and opportunities is considerably greater in larger population centres than in rural and remote centres. Those outside the larger centres were concerned that their children were at an educational disadvantage.

The Australian Secondary Principal’s Association Teacher Survey of secondary schools in 2005 (25% response rate comprised of 386 responses) added weight to the findings from SiMERR (Tytler et.al., 2006) concerning the increased difficulty in finding qualified science relief staff. Trend data showed increasing difficulty in finding qualified science staff, with
43% of responding schools in 2003 reporting this problem and rising to 52% of responding schools in 2006. Both the 2003 and 2006 surveys reported that rural and remote schools had double the degree of difficulty of metropolitan ones in finding Science relief staff and Science was the fourth largest of ten subjects in terms of the number of teachers indicating retirement within the next five years.

2.2.9 Summary of factors accounting for differences in science performance.

School-science education faces significant challenges within the general context of educational disadvantage for students and teachers in rural and remote areas resulting in lower levels of performance, school completion, enrolment in tertiary education, and school participation than in metropolitan areas. These challenges include lifting student achievement data for science students to levels comparable with those in metropolitan areas, attracting and retaining science teachers and especially those with experience, and improving the quality of science teachers through professional learning programs tailored to meet the needs of teachers in rural and remote areas. This involves offering professional learning courses and ensuring a pool of casual relief teachers to support teacher attendance at such events. The challenges also include supporting teachers to teach science ‘out of field’ to teaching combined year groups, and providing a range of quality science learning experiences including through the provision of quality resources and access to effective ICTs.

These factors make achieving the ideal picture for science education for rural and remote students difficult. For example, providing relevant, inquiry-centred science curriculum is challenging if science teachers cannot be attracted to, or retained in, rural and remote schools. Creating enjoyable, fulfilling, engaging science teaching and learning environments modeling best practice assessment techniques where mutual respect between the teacher and students is the norm is a major challenge in the absence of skilled, confident science teachers continually improving their science teaching skills, including through access to appropriate professional learning. Creating the teaching and learning environment characterised by enjoyment and fulfilment is also a challenge in the
absence of excellent science facilities, equipment, and resources. Ensuring that Science is valued by the whole school community and has a high priority in the school curriculum is challenging if effective science teachers are not in place to champion the cause. Subject and mentoring arrangements between more and less experienced teachers is difficult if experienced science teachers cannot be attracted and retained in rural and remote areas.

Understanding the challenges to achieving the ideal picture for science in the middle school years in rural and remote settings provides insights into strategies to address those challenges. The focus of the strategies is to ensure that rural and remote students achieve at the same level as metropolitan students, and that they both derive personal benefit and contribute to the national benefit through the study of science to the same extent as their peers in metropolitan areas. Addressing these challenges will also reduce the effect of rural educational disadvantage on student performance. At the national and international assessment level, addressing the challenges will improve Australia’s flat line science performance by increasing the performance of this equity cohort.

One key question is: ‘Where do we start to address these challenges?’ A logical starting point would appear to be with science teachers. The effective science teacher creates the ideal picture for science teaching, learning, and assessment in each classroom. The effective science teacher also lifts student achievement. The effective science teacher supports the professional learning of colleagues while reflecting on their own practice to improve their own teaching effectiveness. The effective science teacher also champions the role of the science curriculum to the school community and lobbies the school leadership team to garner effective resources and facilities to ensure students receive effective science teaching and learning. Attracting and retaining science teachers to rural and remote areas may be easier if newly appointed teachers know they have highly effective colleagues willing to support them. The centrality of the effective science teacher to achieving the ideal picture of science education in the middle years in rural and remote middle areas (and all other years) is discussed in the next section, Section 2.3 together with strategies for ensuring the effectiveness of science teachers improves over time.
2.3 The centrality of the science teacher to achieving the ideal picture

As Goodrum et al. (2001) declared over a decade ago:

*Teacher change is the basis of educational innovation, reform and improvement. The research findings presented in this report emphasise repeatedly that the most important factor in improving learning is the teacher. Efforts to close the gap must focus on helping teachers recognise the gap between students’ real needs in science and what is offered in the actual curriculum.* (p. 15)

Similarly, more recently, Goodrum et al. (2012) emphasised the centrality of the teacher:

*The research outlined in this study clearly shows teachers are the key to educational improvement. While new teachers entering the system will assist, the real momentum for change will come from those experienced teachers already in the system. For this reason, an extensive professional learning effort is required to help teachers work together with relevant quality resources to bring about the change that is needed.* (p iv)

The notion of the centrality of the science teacher to improving science education finds support throughout the school science and science research literature. For example, Dow (2003a) made this point in the report for DEST titled *Australia’s Teachers, Australia’s Future: Advancing Innovation, Science, Technology and Mathematics*. It is a key theme of Goodrum et al. (2001) and Goodrum et al. (2012), and the Productivity Commission reports large dividends from science and innovation support (2007, 2010). Marginson et al. (2013) stress the key role that science teachers play in improving STEM performance in their study involving 23 countries. This literature stresses the importance of ensuring that all science students have access to highly effective science teachers.

Ensuring science students in rural and remote settings have access to highly effective science teachers requires a conscious effort to ensure that they have the skills through teacher training, on-site professional learning and off-site professional learning to become highly effective (Fishman, Marx, Best & Tal, 2003). It also requires an understanding of the specific skills that highly effective science teachers possess so these skills can be nurtured and continually improved (Birman, Desimone, Porter & Garet, 2000; Tinoca, 2004). Finally, it requires an understanding of the challenges, described above, facing rural and remote
science teachers as they nurture, maintain and grow their professional skills to become highly effective, so that the challenges can be addressed (Sheffield, 2004).

In order to understand the skills required by highly effective science teachers, Section 2.3.1 introduces the construct of Pedagogical Content Knowledge (PCK) and develops a framework from the literature for understanding the construct in greater detail. Some challenges in applying PCK are discussed in Section 2.3.2. The PCK framework developed earlier in that section is applied in Section 2.3.4 to understand the work of science teachers. Each element of PCK development is described in detail as it relates to the professional learning of science teachers.

2.3.1 Pedagogical Content Knowledge’ (PCK): Making teachers’ work explicit

How can we make the work of teachers, and what they need to know to do this work, more explicit? A useful starting point is to understand clearly the terms ‘teaching’ and ‘learning’ when applied to the work of teachers. Loughran (2010) reminds us that while the term ‘pedagogy’ is used synonymously for ‘teaching’ in countries like Australia, Canada, the USA and UK; in European countries it is used to describe the relationship between teaching and learning (e.g., Saari, 2004).

Viewed from this latter perspective, Loughran (2010, pp. 36–40) argues that the focus of our understanding of the work of teachers as ‘teaching alone’ needs to shift to thinking of that work as the interplay between teaching and learning, and learning and teaching. Thinking of teachers’ work in this way challenges notions of teaching as ‘telling’ and learning as ‘listening’ because this implies that teaching is a one way process, counter to the meaning of pedagogy as an inquiry process involving interaction between teaching and learning, and learning and teaching. This further implies that the way teachers ‘teach’ is a reflection of their pedagogical reasoning designed to achieve a particular learning response from a specific cohort of students for a specific purpose and usually at a specific time. Teaching is therefore interrelated with, and dependent on, student learning (Fishman et al., 2003).
Similarly, student learning is interrelated with, and dependent on, teaching. In this view, building the pedagogical reasoning skills of teachers to respond to specific students for specific purposes in specific teaching and learning environments at specific times becomes critical to achieving effective teaching and learning (Abell, 2008; Kahle, 1999). Adapting, transferring, and applying pedagogical reasoning skills to new teaching and learning environments with new students to achieve effective learning signifies growth in teacher knowledge of practice (Angell, Ryder & Scott, 2005; Cochran-Smith & Lytle, 1999; Davis, Petish & Smith, 2006; Grimmett & MacKinnon, 1992).

To help understand the work of teachers and pedagogical reasoning skills, Shulman (1986, p. 8) proposed a framework for describing and understanding the work of teachers comprised of the following seven areas:

1. General pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organisation that appear to transcend subject matter;
2. Knowledge of learners and their characteristics;
3. Knowledge of educational contexts, ranging from workings of the group or classroom, the governance and financing of school districts, to the character of communities and cultures;
4. Knowledge of educational ends, purposes, and values, and their philosophical and historical grounds;
5. Content knowledge;
6. Curriculum knowledge, with particular grasp of the materials and programs that serve as “tools of the trade” for teachers; and,
7. Pedagogical Content Knowledge.

Shulman (1986) defined the last dot point, Pedagogical Content Knowledge (PCK), as:

... the most useful forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations — in a word, the most useful ways of representing and formulating the subject that make it comprehensible to others ... Pedagogical content knowledge also includes an understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those most frequently taught topics and lessons ... that special amalgam of content and pedagogy that is uniquely the province of teachers, their own special form of professional understanding. (p. 9)
For Shulman (1986) PCK has three important interdependent components. The first, involves selecting the most powerful teaching approaches based on knowledge of the students being taught. The second requires an understanding of what makes learning specific topics easy or difficult for students to learn. The final one requires an understanding of students’ alternative conceptions. Shulman (1986) argued that research into teaching and learning up to 1986 had largely ignored questions concerning the content of lessons taught. To ensure this did not continue, he presented a strong argument for PCK as a specific form of knowledge required by teachers to transform subject matter knowledge to facilitate student learning. It was the ability to do this, Shulman (1986) argued, that gave teachers the status of professionals as opposed to skilled workers.

Building on the work of Shulman (1986, 1986a), Magnusson, Krajcik and Borko (1999) argue that PCK comprises five interdependent components. The first is orientation towards teaching. This includes teachers’ knowledge and beliefs about the purposes and goals for teaching a subject at a particular grade level and refers to the general way in which a teacher views the teaching of a subject together with the objectives of instruction (Fetters, Czerniak, Fish, & Shawberry, 2002; Odgers, 2003). Examples of orientations for science that are attached to beliefs about the teaching and learning of science include academic rigor, didactic or transmissive approaches, conceptual change, activity driven, discovery, project-based science, inquiry and guided inquiry (Magnusson et al., 1999).

The second component is knowledge of curriculum. While Shulman (1986) considered curriculum knowledge separate from PCK, Magnusson et al. (1999) argue for its inclusion claiming that it is knowledge of the curricular materials that divide the content specialist from the pedagogue and is one essential factor of PCK. For Magnusson et al. (1999) knowledge about science curriculum is divided into two subgroups. The first is Goals and Objectives, which include knowledge of relevant standards as well as knowledge of the learning continuum progression of students within a subject. The second is Specific Curricular Programs and Materials and knowledge of the programs and materials for
teaching that are specific to a domain, including knowledge of the learning goals of these programs (Magnusson et al., 1999).

The third component is knowledge of students’ understanding of the subject. There are two sub-domains involved. The first sub-domain is Knowledge of Requirements for Learning. This includes teachers’ knowledge of the prerequisite ideas and skills that students will need to learn a topic. It also includes teachers’ knowledge of varying approaches that students will use to learn the specific content depending on the developmental level and learning style of an individual student. The second sub-domain is Knowledge of Areas of Student Difficulty. This sub-domain includes teachers’ knowledge of content areas that student will find difficult to learn. For example, student difficulties may arise from direct alternative conceptions that they hold, which will hamper their ability to learn the new concepts that may seem counterintuitive. Knowledge of common student alternative conceptions requires accompanying knowledge of strategies to assist students to address their alternative conceptions. Teachers too may hold some of the same alternative conceptions as their students. Teachers need to be aware of this because lack of awareness risks students continuing to hold these common alternative conceptions after instruction (Magnusson et al., 1999).

The fourth component is knowledge of assessment. Knowledge of assessment itself comprises two elements. The first is Knowledge of Dimensions of Subject Learning to Assess. This refers to teacher knowledge of which parts of student learning are the most important to assess in a specific content area. The second is Knowledge of Methods of Assessment. This refers to the way in which a teacher will assess certain aspects of student learning specific to a topic area and includes both the knowledge of certain specific tools for assessment and their associated advantages and disadvantages (Magnusson et al., 1999).

The fifth and final component is knowledge of instructional strategies, which again has two elements. The first is Knowledge of Subject Specific Strategies. This element refers to strategies for teaching the specific subject and is closely linked to ‘orientations for
teaching the subject’ in that teachers’ use of particular strategies is influenced by their beliefs about the teacher’s role in student learning. The second is *Knowledge of Topic Specific Strategies* and has two further sub-elements:

a. *Topic Specific Representations* refer to employing illustrations, models, examples and analogies with students to represent specific content. Magnusson et al. (1999) argue that *Topic Specific Representations* are reliant on deep knowledge of the subject matter content to prevent them from presenting analogies with inaccuracies or to assist them with constructing meaningful analogies when responding to students’ questions. Magnusson et al. (1999) warn, however, that having strong content knowledge is not sufficient on its own. Teachers will still need to transfer this content knowledge into topic specific representations and decide which instructional strategy is appropriate when using topic specific representations.

b. *Topic Specific Activities* refer to teacher’s knowledge of problems, simulations, demonstrations, investigations, and experiments and how these activities will affect students’ understanding (Magnusson et al., 1999).

For Magnusson et al. (1999), these five elements of PCK represent an *integrated knowledge system* required for effective teaching and learning. That is to say, the five elements define what is required by teachers to be *effective* in their work and the implicit assumption is that those teachers who have high levels of PCK are more effective than those teachers who have lower levels of PCK. In addition, for Magnusson et al. (1999) PCK is not just the sum of the five components but rather the ‘value-add’ teachers obtain from moving fluidly amongst these components. This fluidity requires teachers to move continually amongst the five components while making ‘in-the-moment’ decisions in the classroom to achieve effective learning for each student. This requires the teacher who has devised an instructional strategy for students based on sound knowledge of the other four components of PCK and to alter that instructional strategy in response to in-the-moment decisions if changes occur in one or more of the other four components of PCK during the course of the lesson. For example, the teacher who has developed an inquiry-based approach to teaching a unit on Day and Night using appropriate models and resources will have to change tack if it is discovered that students have an emerging alternative conception during the lesson, which the teacher had not factored into her/his planning or if there are student content-knowledge gaps that require further teaching.
This requires continuous teacher scanning of the learning environment to assess and reassess the effectiveness of the chosen instructional strategies to achieve the desired learning outcomes in response to changes in all PCK components. For this reason, teaching to achieve effective learning requires continually monitoring the impact each component of PCK has on the teaching and learning environment and making the necessary adjustments due to changes in any of these components to ensure the ‘value-add’ is realised in terms of continuous student learning. This is a complex process requiring great skill with Kind (2009a) and Magnusson et al. (1999) indicating that it takes time to develop (see also e.g., van Driel, de Jong & Verloop, 2002).

Applying their refined definition of PCK, Magnusson et al. (1999) present four recommendations for enhancing PCK development. First, they propose helping teachers to examine their pre-existing ideas and beliefs. This allows teachers to understand both their orientations toward the subject as well as any alternative conceptions they may hold. Second, they advocate that teachers should address the relationship between their subject matter knowledge and their PCK. This allows teachers to understand how best to design instructional approaches with full knowledge of any areas that students are likely to find difficult and why this is likely to be the case. Third, situating learning experiences for teachers in meaningful contexts is advocated. This refers to ensuring teacher learning experiences in developing their PCK occur in the classroom or its simulation so that the process of developing PCK can occur and is refined in the real world of teaching and learning. Finally, Magnusson et al. (1999) advocate using a model comprised of the components of PCK to guide learning-to-teach experiences. This refers to breaking PCK into its five components and using each to build teacher effectiveness but importantly guiding these learning to teach experiences to obtain a ‘value-add’ component by applying the components holistically and fluidly in the classroom context.

There are further implications for developing teacher PCK emerging from the literature of other science educators and researchers. One implication is that teacher development of sophisticated levels of PCK is both possible and desirable (Angell, Ryder & Scott, 2005;
Clermont, Borko & Krajcik, 1994; Loughran, Berry & Mulhall, 2006; Loughran, Berry, Mulhall & Woolnough, 2006). Existing PCK can be refined and improved and new PCK acquired (Kind, 2009a). One approach to developing PCK that has promise focuses on developing folios of content representations (CoRes) and pedagogical and professional experience repertoires (PAP-eRs) for topics (Hume & Berry, 2011, 2013; Loughran, Berry, & Mulhall, 2004, 2006).

A CoRe derives from linking the main content ideas or big scientific idea associated with a specific topic, teaching procedures and purposes and knowledge about students’ alternative conceptions and thinking. PAP-eRs are short narratives based on teachers’ decisions of teaching topics intended to make the different dimensions of, and links between, knowledge of content, teaching, and learning about a particular topic explicit. Assisting pre-service teachers as well as novice teachers to design CoRes and PAP-eRs, with the assistance of expert teachers, has proven a useful means of building teachers’ PCK by making the pedagogical decision making processes explicit (Hume & Berry, 2011; Loughran, Berry, & Mulhall, 2006). A similar approach to building science teacher PCK is put forward by Bybee (2014) using the Next Generation Science Standards for Today’s Students and Tomorrow’s Workforce (NGSS Lead States, 2013). This approach focuses on linking interconnecting science and engineering practices, disciplinary core ideas, crosscutting concepts, and recognised learning progressions to develop undergraduate science teachers.

Another implication for developing teachers’ PCK involves recognising that teaching and learning is a partnership between students and teachers. This partnership requires both teacher and student to be learners; students to be learners of subject knowledge, skills, values and attitudes, and teachers to be learners of PCK. Teachers can, therefore, view teaching and learning as a form of inquiry where the findings and ‘lessons learned’ from each inquiry can be written up as case studies and referred to as a means of continuously build their stock of PCK (Cochran-Smith & Lytle, 1999).
As Kind (2009a), Mason, (2002) and Rohaan, Taconis, and Jochems (2010) point out, another implication is that the development of teachers with expert PCK takes time. In support of this notion, Kind and Taber (2005) argue that PCK is a collection of pedagogical approaches that teachers acquire from repeatedly teaching a certain topic. This is both reassuring and sobering for novice teachers who need to understand that it takes time to acquire the PCK needed to become highly effective expert professional teachers.

While the PCK construct provides a useful way of making teachers’ work explicit, providing insights into how to improve that work or its effectiveness, applying the concept in practice is not without its challenges. These are considered in Section 2.3.2.

2.3.2 Challenges in applying the PCK construct

As Ball, Thames and Phelps (2008) note:

*The continuing appeal of the notion of pedagogical content knowledge is that it bridges content knowledge and the practice of teaching, assuring that discussions of content are relevant to teaching and that discussions of teaching retain attention to content. As such, it is the unique province of teachers — a content-based form of professional knowledge. However, after two decades of work, the nature of this bridge remains inadequately understood and the “coherent theoretical framework,” called for by Shulman (1986, p. 9) remains underdeveloped.*

(p. 3)

They, and others such as Abell (2008), attribute the reasons for this lack of sufficient understanding of PCK to two factors. First, they argue, researchers have failed to establish precise or agreed-upon definitions of PCK using the term to refer to a wide range of aspects of subject-matter knowledge and aspects of the teaching of that subject matter. This, Ball et al. (2008) argue, has led to lack of clarity on how ideas in one subject area relate to those in another subject area, or even whether research findings within the same subject take similar or different views of teacher subject-matter knowledge (e.g., Abell, 2007). Second, Ball et al. (2008) argue that too few studies test whether there are, indeed, distinct bodies of identifiable content knowledge that matter for teaching and too few studies that develop measures for PCK and use these measures to test definitions and our understanding of the nature and the effects of content knowledge on teaching and learning (e.g., Banks, Leach & Moon, 2005). These issues leads Ball et al. (2008) to argue
that an absence both of agreed definitions and of empirical testing pose limitations on the
degree to which the concept of PCK is likely to further our understanding of the
relationships between teacher knowledge, teaching and student learning. However,
despite these criticisms, Ball et al. (2008) argue that PCK is a valuable framework requiring
further work and understanding. Without this work and understanding, they contend,
ideas on teacher knowledge, teaching, and student learning remain constant, and are
comprised only of promising hypotheses and ad hoc arguments about the content people
think teachers need to undertake their work effectively.

Kind (2009b) argues that while PCK is a valuable construct for understanding the work of
teachers and therefore the knowledge they require for performing this work effectively, it
comprises ‘tacit knowledge’ on how to devise good teaching practice and as such is often
‘hidden knowledge’. As Kind (2009b) points out:

...when preparing lessons, for example, teachers think pragmatically, ‘I am
preparing a lesson’ not, ‘I am using my PCK’. As a result, PCK is not (yet) an
explicit tool used consciously by teachers. Investigating PCK requires
researchers to understand processes underlying lesson preparation, and an
analysis of how and why a teacher teaches as s/he does. (p. 171)

However, while Kind (2009b) argues that understanding the nature of teacher tacit
knowledge has it challenges, she acknowledges the construct is a useful tool for
understanding teachers’ work when pointing out that the attraction of PCK lies in its
ability to “… tell us something of the unique professional experience that constitutes
effective teaching” (p. 198).

Williams and Lockley (2012), like Kind (2009b), argue that more research is needed to
understand PCK. These researchers point out that while much has been written about the
nature of PCK since Shulman first introduced the concept in 1986, including aspects of its
defining characteristics; there is still much debate about the nature of PCK and how to go
about developing teachers’ PCK. Williams and Lockley (2012) agree with Kind (2009b) that
the work of Loughran, Mulhall and Berry (2006) on the use of CoRes and PAP-eRs will
assist in promoting PCK development in novice teachers, particularly if expert teachers
work with novice teachers during the process to develop relevant CoRes and PAP-eRs.
van Driel and Berry (2012) argue that one of the pre-eminent issues in the education research literature is the ongoing debate on the nature of PCK, what it is, and how it can be represented. Van Driel, Verloop and de Vos (1998) point out that while the research community generally embraces the concept of PCK, few topic-specific examples are available in the literature to illuminate PCK. They suggest reasons for the lack of concrete examples include the tacit nature of teachers’ knowledge, the absence of a shared language permitting discussion of teacher knowledge, and teachers being unaware of the knowledge they possess. Like Loughran, Berry, and Mulhall, (2006), van Driel and Berry (2012) see work with CoRes and PAP-eRs as providing useful insights and solutions into developing teachers’ PCK, and particularly with novice and trainee teachers. However, van Driel and Berry (2012) see a ‘fuzziness’ around the concept of PCK due to lack of common definitions cautioning that in the absence of such definitions it is unclear whether teachers should see PCK as very specific for each topic they teach or whether PCK should be viewed as generic. They argue there may be a tendency by researchers conducting further empirical and analytical studies into PCK to segment teacher professional knowledge into discrete units and run the danger of presenting too simplistic a picture of PCK in the absence of agreed definitions. Van Driel and Berry (2012) argue that this ‘fuzziness’ represents a challenge to ensure the concept of PCK is made relevant to the work of teachers and teacher educators by, for example, using approaches based on CoRes and PAP-eRs (Loughran, Berry, & Mulhall, 2006).

Kind (2009b) emphasises that the evidence from the research literature indicates that PCK is more complex than Shulman proposed. She argues that part of this complexity derives from how researchers represent subject matter knowledge (SMK) and PCK. Marks (1990), Fernandez-Balboa and Stiehl (1995) and Koballa, Gräber, Coleman and Kemp (1999), for example, include SMK in their definitions of PCK. Kind (2009b) refers to this as an ‘integrative model’. Others, such as Childs and McNicholl (2007), Gess-Newsome and Lederman (1990), Grossman (1990), Magnusson et al. (1999) and Sanders, Borko and Lockard (1993) retain SMK as a separate knowledge component. Kind (2009b) terms this a ‘transformative model’ of PCK and suggests an emerging preference in the literature for
more integrative rather than transformative types of models. She attributes this to two factors. The first factor is because integrative models tend to offer a wide-ranging general picture of teachers’ skills and knowledge while transformative models tend to focus on subject-specific PCK. Second, the trend towards integrative models may reflect the ‘known’ current practice in teacher education, viz., initial training, rather than the unknown. Gess-Newsome and Lederman (1990), in arguing for a transformative approach to developing PCK, make the case that adopting integrative models with trainees and novice teachers can limit their ability to move from the transmission style of teaching in which a teacher simply lectures, or delivers subject knowledge, to other styles of teaching. Transformative PCK models, by contrast, they argue, have more explanatory power and provide clearer guidance for developing PCK.

Marks (1990) and Appleton (2005) argue that PCK may differ for experienced, expert teachers working within their preferred specialism. They argue that expert teachers tend not to articulate SMK as a distinct component of their knowledge base, but roll SMK into PCK. The novice, by contrast, treats SMK as a separate component of teacher knowledge focusing on re-shaping SMK and adapting it to a school setting and, in effect, replaces the modified SMK with a version suitable for school use (Mortimer & Scott, 2003). Kind and Taber (2004) and Kind & Wallace (2008) illustrate this modification process by novice teachers using science. They distinguish between Science as an academic subject and science as school-science, clearly different subjects. Two points emerge from this latter point. The first is that when training to be a teacher, adjustment of SMK must take place and assisting novices through this adjustment process forms a critical component of teacher training courses. The second is that integrative models may provide a more appropriate theoretical background for understanding the PCK of experienced teachers, as these models reflect more closely the fluid process that happens in practice for this group of teachers.

Kind (2009b) thus argues for a transformative model of PCK at least for initial teacher trainees and novices, with SMK as a separate knowledge component. For Kind (2009b), academic training provides the basis for possessing good SMK. Other factors identified by
as important for developing PCK include good levels of self-confidence, a belief system that encourages and benefits from constructive feedback on practice, resilience to handle setbacks and the ability to adapt to school (Kind, 2009b).

2.4 Discussion

In spite of the challenges identified above and the debates on whether PCK should be thought of as an integrated construct or as a transformative construct, there is broad agreement among researchers and educators that PCK provides a useful construct for understanding the work of teachers and for making explicit the knowledge that is required to do that work effectively. This is despite Shulman discarding the concept of PCK because in his view it was not a fruitful concept when using his definition to describe teachers’ knowledge and skills. In addition, PCK appears more complex than Shulman (1986) initially envisaged and following more than a quarter of a century since Shulman introduced the term, it is evident that researchers are still debating the construct. This is understandable given the difficulty in defining precisely all of the work of teachers and the tendency for the profession to treat that work as ‘tacit’ (Kind, 2009b). It is also helpful to have different viewpoints from researchers on such issues as whether SMK is separate to or a part of PCK, whether PCK is comprised of subject specific skills or generic skills that apply across subjects and on whether agreement can be reached on definitions of terms associated with PCK. These debates can help clarify positions leading to agreement on these issues.

Magnusson et al. (1999), building on the work of Shulman (1986), offer a useful definition of PCK comprised of five elements. Combining these elements with those proposed by Kind (2009b) indicates that PCK comprises the following seven elements, which provide a framework for understanding, and therefore developing, PCK:

1. Knowledge of how to holistically and fluidly apply PCK in the classroom settings and includes ensuring PCK is developed in the context of the classroom (Kind, 2009; Magnusson et al., 1999);
2. Knowledge of instructional strategies;
3. Knowledge of subject matter (and of the curriculum, which features that subject matter);
4. Knowledge of assessment;
5. Knowledge of students’ understanding of the subject (including alternative conceptions);
6. Knowledge of orientations towards teaching (teacher knowledge of and about their subject, beliefs about it, and how to teach it); and,
7. Well-adjusted emotional attributes.

The preceding sections have provided a general means for understanding the work of teachers using the construct of PCK. In Section 2.4.1 the PCK construct is applied to understand the specific work of science teachers including by providing a rich description of each of the seven elements listed above and derived from the combined works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986).

2.4.1 Applying the PCK construct to understand the work of science teachers

As discussed in the previous section, Kind (2009b) argues that transformative PCK models appear to be most useful for developing science teacher PCK as they focus on subject-specific issues, including how to teach difficult and abstract ideas that are common in science. A key reason for this is that transformative models offer the opportunity to help novice teachers internalise expert teachers’ explanations, analogies, and instructional strategies (Kind, 2009b). Accordingly, Kind (2009b) argues that the transformational model suggested by Magnusson et al. (1999) and built on Shulman’s (1986a) original definitions of teacher knowledge outlined in Section 2.3.1 above is a useful starting point for conceptualising the PCK of science teachers.

Before discussing each of these elements to obtain greater understanding of their contribution to the work of effective science teachers, two points are worthy of note. The first is that applying this framework to improve science teacher effectiveness implicitly assumes that science teachers will improve their PCK by improving any single or combination of the seven elements listed above. Helping science teachers to move holistically and fluidly between these elements as they make ‘in the moment decisions’ involves helping them to acquire and apply the skills of experienced science teachers (Kind, 2009a; Mason, 2002; Rohaan et al., 2010; Shulman 1986). The second point to note is that while there is some alignment between the process for developing science teacher effectiveness through improving their PCK and developing it using the Australian National
Professional Standards for Teachers, these alone do not provide a coherent and integrated process for its improvement. The Standards, therefore, provide less guidance on how to develop science teacher effectiveness and do so from the perspective of a fragmented as opposed to a coherent and interdependent framework. However, this is not to say that the PCK framework is completely unrelated to the National Professional Standards for Teachers. This relationship between elements of teacher knowledge described in the Standards (AITSIL, 2011) and those described by Kind (2009a) and Magnusson et al. (1999) is shown in Table 2.6.

Table 2.6: Relationship between the National Professional Standards for Teachers and Elements of PCK described by Magnusson et al. (1999).

<table>
<thead>
<tr>
<th>National Professional Standards for Teachers</th>
<th>Elements of PCK (Magnusson et al., 1999; Kind, 2009b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Know the students and how they learn</td>
<td>Knowledge of students’ difficulties; Knowledge of science instructional strategies; Orientations towards teaching, beliefs about science.</td>
</tr>
<tr>
<td>Know the content and how to teach it</td>
<td>Knowledge of science curriculum; Orientations towards teaching, beliefs about it; Knowledge of science instructional strategies</td>
</tr>
<tr>
<td>Plan for and implement effective teaching and learning</td>
<td>Knowledge of science instructional strategies; Knowledge of science curriculum; Knowledge of students’ difficulties; Orientations towards teaching, beliefs about it.</td>
</tr>
<tr>
<td>Create and maintain supportive and safe learning environments</td>
<td>Knowledge of instructional strategies; Knowledge of students’ difficulties; Orientations towards teaching, beliefs about it.</td>
</tr>
<tr>
<td>Assess, provide feedback and report on student learning</td>
<td>Knowledge of science assessment; Knowledge of science curriculum; Knowledge of students’ difficulties.</td>
</tr>
<tr>
<td>Engage in professional learning</td>
<td>Levels of teacher proficiency increase as PCK improves and seeks to provide professional learning experiences, including coaching and mentoring, to improve PCK.</td>
</tr>
<tr>
<td>Engage professionally with colleagues, parents/carers and the community</td>
<td>PCK will grow through professional engagement with colleagues, parents/carers and community. Well-developed emotional attributes. Implicitly assumes teachers have personal attributes, such as receptiveness to feedback, reflective</td>
</tr>
</tbody>
</table>
Table 2.6 shows some alignment between the National Professional Standards for Teachers and elements of PCK described by Kind (2009b) and Magnusson et al. (1999). For example, The National Professional Standard ‘Know the students and how they learn’ aligns with some of the components of the PCK elements ‘Knowledge of students’ difficulties’, ‘Knowledge of science instructional strategies’ and ‘Orientations towards teaching, beliefs about science’ but seems to infer the focus is on knowing students from a relationship perspective and understanding how student learning occurs. It does not specify the components of content knowledge students find difficult to learn as well as alternative conceptions they hold implicit, as is the case with ‘Knowledge of students’ difficulties’. ‘Know the students and how they learn’ does not make explicit that the design of instructional teaching strategies must take account not only of the content students find difficult to learn as well as the alternative conceptions they hold, but also beliefs the teacher has about science and how to teach the subject as well as any alternative conceptions they bring to the learning environment.

For these reasons, it is argued that the PCK framework discussed above provides a more holistic and a more useful construct for developing teacher effectiveness than the Australian National Professional Standards by providing an integrated and explicit knowledge system for teachers. This knowledge system indicates that teachers could potentially improve their PCK by improving each individual element of PCK and, over time, develop the skill of moving holistically and fluidly among the elements of PCK. That is to say, using the approach of improving science teacher effectiveness by developing teachers’ PCK requires teachers to design instructional strategies taking into account four elements.

The first is their knowledge of students’ alternative conceptions and areas of the curriculum they find difficult to learn. The second is their knowledge of the subject content and curriculum students need to learn. The third is their knowledge of assessment strategies that work best for students including providing feedback and which are applied
throughout the whole period of teaching and learning and not just at the end of the unit of work. The fourth is their beliefs and orientation to teaching science that may impact on the instructional strategies they select. Over time, teachers should develop the skill of holistically and fluidly moving between the components of PCK (Kind, 2009b; Mason, 2002; Rohaan et al., 2010; Shulman, 1986) and improve their effectiveness by using personal qualities such as receptiveness to receiving and providing constructive feedback and continually reflecting on their practice to improve further their PCK. Bybee (2014) has also identified additional personal qualities teachers need to possess to be effective. Bybee (2014) found that adequacy of personal relations with students and consistent enthusiasm for science teaching were important personal qualities science teachers needed to possess to be effective.

In contrast, an integrated approach is not evident in the National Professional Standards. Rather, a checklist of actions against criteria that imply effective teaching occurs separately from establishing the linkages amongst the various standards. That is to say, the linkages are not drawn between ‘Plan for and implement effective learning’ and ‘Assessment, content and knowledge of students and how they learn’. This gives the impression of a punctuated and truncated approach to developing teacher effectiveness that may work against developing the higher levels of teacher competence through combining elements of PCK in an integrated, holistic, fluid approach.

Returning to an understanding of science teacher PCK, each of the elements of PCK from the literature of Kind (2009b), Magnusson et al. (1999) and Shulman (1986) is described in detail in Sections 2.4.1.1 through 2.4.1.7.

2.4.1.1 Holistically and fluidly applying in-the-moment pedagogical decisions

As discussed in Section 3.1 there is a ‘value-add’ component associated with applying PCK holistically and fluidly in the teaching and learning environment. The sporting analogy is ‘the sum of the team is greater than the sum of the team’s individual players’. Something ‘extra’ is obtained by moving fluidly and holistically between the elements of PCK as in-the-moment decisions are made in the learning environment to improve student learning.
Kind (2009b) and Magnusson et al. (1999) find it hard to describe the ‘extra’, but suggest that it can be observed in the highly effective science teacher’s ability to continuously scan the teaching and learning environment to assess the effectiveness of their chosen instructional strategies to achieve the desired learning outcomes. Where the chosen instructional strategy is not achieving the desired student-learning outcome, in-the-moment responses are made to teaching strategies in response to changes to any or all of the other elements of PCK. Mitchell et al. (2015) describe this as ‘pinball pedagogical reasoning’. This conjures up images of a nonlinear activity of making high-speed pedagogical decisions in response to responding continuously to changes in observed elements of PCK within the learning environment, for example, changes in students or teachers’ alternative conceptions, changes in teacher subject matter knowledge, changes in the diagnostic and summative assessment and so on.

Kind (2009b), Mason (2002), Rohaan et al. (2010) and Shulman (1986a) point out that PCK development takes time and development of this ‘value-add’ component is therefore likely associated with experience and experienced teachers. One way to illustrate this is to consider a PCK continuum from trainee to expert teacher. This continuum may be represented by a horizontal axis for career stage descriptors (Teacher Trainee, Graduate; Proficient; Highly Proficient; Accomplished and Lead or Expert Teacher) and a vertical axis comprised of the elements of PCK from combining those elements identified by Kind (2009b), Magnusson et al. (1999) and Shulman (1986a). It could reasonably be expected from the research literature on PCK that at one end of the continuum would be placed trainee and novice teachers who would show some growth in PCK during their careers due to improvement in one or more of the single elements of PCK identified by Kind (2009b), Magnusson et al. (1999) and Shulman (1986). These could include knowledge of instructional strategies, knowledge of content, and knowledge of assessment, ability to provide and receive constructive feedback and to show resilience while developing classroom management practices early in their careers. At the other end of the continuum could be placed experienced/lead teachers showing high levels of proficiency in all elements of PCK, but importantly, high proficiency in the skill of being able to move
holistically and fluidly amongst the five elements listed by Magnusson et al. (1999) when assessing and reassessing instructional strategies to ensure they are achieving their desired aims. This process of continuously scanning the learning environment and making required adjustments to instructional strategies requires a sophisticated development and implementation of PCK in the teaching and learning environment.

2.4.1.2 Knowledge of science instructional strategies

This component of PCK refers to strategies for teaching science designed to elicit effective science learning and accepts Loughran’s (2010) premise that the focus of our understanding of the work of teachers as ‘teaching alone’ needs to shift to thinking of teachers’ work as the interplay between teaching and learning, and learning and teaching. In this view, teaching is a strategy to achieve effective learning. Understanding of subject matter, assessment, students’ alternative conceptions, and teacher orientations to the subject all help teachers to design or implement instructional strategies that achieve effective learning. There is also a considerable body of knowledge on how students learn to assist teachers to select instructional strategies, content, assessment strategies, to deal with students’ alternative conceptions and to understand their teaching orientations. It is important to discuss briefly this knowledge to understand its contribution to both PCK implementation and development.


Brandt and Perkins (2000) contend that various conceptions of the mind have influenced the practice of learning. In particular, they argue that there has been an evolving science of learning beginning with behaviourism and moving to cognitive science that has influenced the practices of schooling in recent decades. Duit and Treagust (2003) argue
that learning should not be viewed as a form of implanting concepts but rather an interplay between students’ existing ideas that they bring to the learning environment and the experiences and knowledge they are exposed to in that learning environment. Marzano (2000) presents a similar argument when stating that theories from cognitive psychology have given rise to two basic principles guiding teaching and learning in the latter decades of the 20th century to the present. The first is that learners construct their own meaning, and the second is that learning and thinking involve interactive systems (cognitive, meta-cognitive, and executive).

The view of knowledge underpinning pedagogy, curriculum, and assessment in Marzano’s first point, that learners construct their own meaning, is that knowledge is obtained and understanding is enhanced through active construction and reconstruction of mental frameworks (Brooks & Brooks, 1993; Campbell & Tytler, 2007; Piaget, 1974, 1987). This view contrasts with behaviourist views of students as ‘empty vessels’ requiring regular ‘topping up’ with knowledge, usually factual, by acknowledging from the outset that students come to the learning environment with prior knowledge, which may or may not represent accepted subject knowledge at that time. A study by Zahorik (1995) provides a useful summary of the constructivist view of learning. In Zahorik’s view, knowledge is constructed by humans and is not a set of laws or facts waiting to be discovered or independent of the ‘knower’, but is created as learners attempt to bring meaning to their experiences. Created knowledge is conjectural and fallible as the understandings we invent are subject to human failings, and are always tentative and incomplete.

The literature identifies three main strands of constructivism; cognitive constructivism associated with ‘personal constructivism’ based on the work of Piaget (1970, 1974, 1987), social constructivism based on the works of Vygotsky (1962), and radical constructivism based mainly on the works of van Glassersfeld (1981). A summary of the shared core beliefs described in the literature that bind each view of constructivism together include firstly, that knowledge is not passively received through the senses or by way of communication but is actively constructed (Bruner, 1968; Piaget; 1970,1973). A second binding feature is that the learner is central to the creation of knowledge (Biggs, 1991;
Piaget, 1987) because such knowledge is constructed in the minds of each learner and learning is situated or anchored and is context-dependent (Brooks & Brooks, 1993). A third core belief is that learning occurs in social contexts allowing learners to test their constructs through dialogue and presentation (Vygotsky, 1962). A fourth binding belief is that the function of cognition is adaptive, serving the learners’ organisation of the experimental world, not the discovery of an objective ontological reality (von Glasersfeld, 1981). Collaboration facilitates the social interaction necessary to test knowledge (Vygotsky, 1962) and, through scaffolding, the teacher can assist students to understand concepts that initially prove difficult to comprehend (Bonk & Dennan, 1999; Vygotsky, 1962).

In the construction of such personal knowledge, or cognitive frameworks, each individual builds a unique replica of reality that fits that reality in that it must function to their satisfaction in the appropriate context (Piaget, 1970, 1974). Individuals have knowledge structures that have unique meanings for each individual. Accordingly, new experiences are seen as they relate to existing knowledge structures (Piaget, 1970). There are two means of acquiring knowledge structures: assimilation or accommodation. Assimilation refers to creating new knowledge structures by building on, or going through, previously made knowledge structures. Accommodation refers to the reshaping of old knowledge structures to accommodate new experiences (Piaget, 1970, 1974). Since, in the constructivist view, learners do not simply accept the knowledge given but rather search for knowledge that fits their unique perception of reality, each learner’s personal constructions about their world manifest themselves in individual ideas, beliefs and attitudes (Piaget, 1970, 1974). Personal constructs, therefore, act as filters through which learners interpret concepts and ideas to be learned and through which they apply these to what is already known (Duffy & Jonassen, 1992). This means that in the process of mental construction (learning), students fit new information together with what they already know, and they learn best when they actively construct their own understanding.

In addition to treating learning as an individual approach occurring within the student, constructivism embraces the notion of knowledge creation as a social process of learning.
(social constructivism). In this process, students construct and acquire knowledge through interaction with their learning environment that includes their peers, their teachers and resources, which include those found in the classroom as well as the wider world (Vygotsky, 1962, 1978). The important point to emphasise here is that in their social learning environment students do not rely simply on their teacher’s knowledge. In the social constructivist approach, interest has centred on the more fundamental roles that language and culture play in the acquisition of knowledge and in the way students think (Vygotsky 1962, 1978). Rather than simple social discussion among students in the classroom, this approach advocates thoughtful, planned verbal interactions (discourse) between teachers and learners in the learning environment as part of the discourse of a community of learners to help students acquire knowledge. This view sees learning as increasing students’ access to and competence with the ways of talking and acting within the community of learners (Vygotsky, 1978).

A further perspective on social constructivism is the notion that learning should include learners replicating authentic practices, and to achieve this, the boundaries between the classroom and rest of the world should be broken down so that students solve ‘real world problems’ and experience active interactions in solving those problems (Rogoff & Lave, 1984). This authentic replication involves presenting and representing knowledge in the literacies of the discipline usually with the aid of ICTs.

Constructivism, therefore, suggests that learners construct knowledge by developing mental schemas allowing them to add new information to existing knowledge resulting in the development of increasingly complex cognitive structures culminating in personal understanding. As a theory of learning, constructivism comprises a ‘broad church’ embracing both the personal construction of knowledge (Piaget, 1970, 1973) and social construction of knowledge (Vygotsky, 1962, 1986) with the latter focusing on the social processes to co-construct knowledge within a community of learners. The pattern of teacher-student talk or classroom discourse becomes critical to assist students as individuals and groups to develop knowledge (von Glasersfeld, 2005; Vygotsky, 1986). The situational context in which understanding occurs becomes critical to the process of
understanding, requiring the community of learners to work on authentic problems and issues. Finally, demonstrating acquired knowledge and understandings requires re-representing these understandings in modes of written and spoken language attached to the science discipline and community of learners at large.

The implications of the constructivist viewpoint for pedagogy, curriculum and assessment are profound in that it is essential from this viewpoint to structure learning environments to assist students to actively construct knowledge rather than simply absorb it by initially taking account any prior student learning especially if alternative conceptions and preconceptions exist. As the community of learners includes the teacher, it is also necessary that the teacher examine any alternative conceptions they hold. The implications of the constructivist view for the design of instructional strategies, as well as curriculum and assessment strategies are summarised by Brooks and Brooks (1993), Fosnot (1998), Hyerle (1996) and Zahorik (1995) as follows. The practical application of applying the eight principles described briefly to design instructional strategies can be found in the works of Bybee’s 5Es Teaching Model (2006) and Hackling and Prain (2005).

First, the role of the teacher changes from ‘sage on stage’ to ‘guide on the side’ to help students master ideas they cannot understand on their own. Supporting students’ learning through scaffolding, especially when they experience difficulty in acquiring new knowledge becomes important. Scaffolding refers to providing students with enough support to complete the required learning then withdrawing that support gradually to allow the student to become an independent learner.

Second, the teacher needs to begin the teaching and learning design process by ascertaining the prior learning of students especially to perceive and correct any alternative conceptions or preconceptions. Additionally, the teacher needs to check continually for any alternative conceptions or preconceptions they may hold that differ from accepted scientific knowledge. Taking account of the prior knowledge possessed by students and teachers becomes an important step in designing teaching approaches. This refers to teachers needing to appreciate and build on students’ and their own
preconceived ideas so that the current state of knowledge is assessed and strategies developed to help both acquire new understandings through assimilation, accommodation, and social interaction. Having taken account of prior knowledge, Zahorik (1995) lists five elements to guide the teacher in designing learning experiences when implementing constructivist-teaching practice. These are activating knowledge; acquiring knowledge; understanding knowledge; using knowledge; and reflecting on knowledge.

Third, greater emphasis is placed on the teaching of ‘higher order’ thinking skills such as problem solving, reasoning and reflection and making greater use of cognitive terms such as predict, create and analyse to get students to try out their own ideas and hypotheses. Ensuring students achieve ‘deep knowledge’ or understanding by, for example, employing an approach based on the elicitation, comparison, resolution and application becomes important when designing teaching approaches (Dykstra, 2005).

Fourth, a greater emphasis is placed on teaching learners ‘how to learn’ or to develop the necessary metacognitive skills.

Fifth, assessment is formative, summative, and continuous. Assessment is also focused on collaborative tasks, authentic role performance, portfolio assessment, and more open-ended evaluation of learning outcomes.

Sixth, learning occurs best in collaboration and cooperation with other learners in order to test ideas and the newly acquired knowledge. Providing opportunities for students to acquire and test their new knowledge especially in social contexts becomes important as does providing realistic (authentic) learning contexts. This refers to using real world learning contexts that mirror the types of problems needing to be resolved thereby extending the classroom into the real world.

Seventh, student learning is enhanced by using technology to augment teaching and learning. This refers to using ICTs to research, to manipulate information, to explore ideas, to re-present information and to construct personal meaning.
Lastly, designing instructional strategies needs to take account of providing opportunities for student demonstration of learning through the employment of specific subject literacies aided by ICTs (to allow students to acquire subject literacies and provide feedback on progress).

Beare (1998), Brooks and Brooks (1993), Hargreaves (1999), and Senge (1994) argue that applying pedagogical techniques based on the constructivist view leads to the notion of school as a ‘learning organisation’ concerned with knowledge creation, learning networks and individual, as well as social learning. This is a view shared by Hargreaves and Fullan (2012) and Fullan (2013) who see a key role for teachers in designing learning experiences cooperatively with students that lead to ‘knowledge creation’. However, in the design of teaching responses to assist student learning, it is important to recognise that while constructivism as a theory of learning carries with it the above eight well-established implications for teaching practice; it does not preclude teachers using other teaching approaches. These include direct or explicit teaching approaches. As Campbell and Tytler (2007) state:

We must emphasise that constructivism is a theory of learning and does not necessarily imply a teaching program. It is possible, for example, to talk of students constructing meaning from lectures or explanatory passages in a book. (p. 29)

Therefore, a teacher can select from a range of teaching approaches to facilitate students’ personal and social learning to implement effective constructivist teaching and this may include substantial teacher input. As Hattie (2009) points out, all too often more direct teaching approaches are contrasted in the literature with more child centred approaches with direct approaches portrayed as ‘bad’ and constructivist (child-centred) approaches as ‘good’ when what is required is an inclusive approach that combines teacher-centred and student-centred learning and knowing. As indicated above, Campbell and Tytler (2007) support this view indicating it is possible to apply both approaches to help students acquire knowledge.
2.4.1.3 Knowledge of students’ difficulties with learning science

As discussed in the previous section, constructivism acknowledges that students (and teachers) come to the science-learning environment with knowledge formed from previous experiences. This knowledge may or may not be consistent with accepted scientific knowledge at that time and the teacher must design learning experiences that allow students to make explicit their beliefs ready for testing, ideally in a secure and safe learning environment and in a non-confrontational manner. This is particularly important if the alternative conceptions are not consistent with accepted scientific knowledge and which are needed to be the ‘building blocks’ of later science knowledge creation. Science teachers facilitate students’ testing their alternative conceptions in a safe learning environment by acquiring and employing knowledge of how students understand and learn science and by pretesting for diagnostic purposes. This requires knowledge of the prerequisite ideas and skills that students will need to learn a topic as well as the differing approaches they will use to learn specific science content depending on their developmental level and learning style. Science teachers also need to acquire knowledge of areas of science that students are likely to find difficult to learn. These can be identified by using diagnostic tests and addressed as early as possible in the teaching and learning cycle. In the process, any alternative conceptions they themselves may hold can be identified and addressed.

2.4.1.4 Knowledge of science content (science subject matter knowledge)

Kind (2009a) is quite definite that science teachers require high levels of science subject matter knowledge but that this alone does not guarantee effectiveness as a teacher. What is apparent from other literature is that when designing learning experiences science teachers require a level of knowledge of science that goes beyond the level of understanding they want their students to attain. Not having this knowledge limits teacher effectiveness in two main ways. First, it limits the level of accurate and detailed explanations provided to students at their appropriate cognitive level (Jacobbe, 2008). At its extreme, this may mean not being able to answer students’ questions. Second, it limits
the ability of teachers to judge accurately students’ current levels of understanding including the nature of any alternative conceptions they may have. At its extreme, this may mean they cannot recognise any alternative conceptions their students may hold and are not being able to design appropriate learning experiences to move student science knowledge towards the accepted scientific knowledge.

Tytler (2007) contends that teacher knowledge of science directly relates to four factors with the first being the study of science at school and in further education. A common theme running through the literature of science researchers and educators is that lack of exposure to science in primary school leads to fewer students selecting the subject in high school beyond the compulsory years of schooling. It is then argued that fewer students studying science in turn leads to fewer student studying the subject in higher education settings (see for example, Chubb, 2012; Goodrum et al., 2001; Lyons & Quinn, 2010). Not having studied science at senior high school, university or other higher education institutions impacts negatively on orientations toward science, knowledge of science disciplines generally and knowledge of the science curriculum specifically. As indicated above, lack of science subject knowledge can result in not being able to answer students’ questions or not to be able to predict which parts of the curriculum students will find difficult to learn both of which hinder the effective design of instructional strategies to improve student learning. This challenges science teachers to develop this element of PCK, as well as to combine it holistically with other elements of PCK to grow their effectiveness.

The second factor associated with the acquisition of science subject knowledge is the study of science during teacher education (Tytler, 2007). A scan of the literature on pre-service teacher training, including AITSIL (2011), Craven (2015), Dinham (2013) and the Victorian Inquiry into the Suitability of Pre-Service Training (Parliament of Victoria, 2005), indicates that pre-service teacher training is currently in a state of flux, and is attracting interest at the national and jurisdictional levels to improve the quality of teacher graduates from teacher training institutions. Four key themes emerge from scanning the literature, each relevant to science teacher education and the development of this element of science PCK. These themes are:
Theme 1: Attracting better quality candidates, tightening entry level and selection requirements and expanding regulatory tools for setting standards for graduate teachers’ capabilities and the program quality they experience with the aim of gaining greater assurance on the quality of trainee teachers by controlling the ‘inputs’ into the profession (Dinham, 2013).

Theme 2: Improving the quality of delivery models, redesigning course content and establishing university and school partnerships with the aim of bridging the gap between theory and practice by giving trainee teachers strong clinical skills and more hands on experience (AITSIL, 2011; Productivity Commission, 2012; Victorian Inquiry into the Suitability of Pre-Service Training, 2005).

Theme 3: Monitoring the quality of outcomes and outputs from teacher-training courses with the aim of placing a greater emphasis on assessment practices in pre-service training and through monitoring the quality of pre-service teacher courses (Australian Council of Deans of Education Survey of Final Year Teacher Education Students, 2006; Victorian Inquiry into the Suitability of Pre-Service Training, 2005).

Theme 4: Changing the structure of teaching and teaching support in schools by, for example, providing more support to teachers through teachers’ aides and increasing the number of primary specialist teachers (Craven, 2015; Dinham, 2013).

Drawing from these themes, the literature suggests an approach to pre-service teacher education based on four principles. The first involves ensuring high standards for entry to teaching, to courses within teacher training, for fulfilling the requirements of the practical experience and for the capabilities of teachers entering employment. The second is ensuring pre-service teacher training is founded on evidence-based instructional models, skilled classroom-management models, tools for diagnosing assessment of learning and for researching all aspects of pre-service training. The third is increasing collaboration in the preparation of teachers between universities and schools in authentic school learning situations, and the fourth involves increasing the professionalism of pre-service teachers through explicit preparation for professional practice by developing skills in observation, analysis and reflection.

Interestingly, absent from these themes is explicit discussion on commencing the development of science (and all) teacher PCK during teacher training by, for example, using the approach to CoREs and PAP-eRs suggested by Kind (2009b) and Loughran, Berry, and Mulhall (2006). Providing teachers with such tools early in their profession will skill them to focus on developing their PCK during their career. Exceptions to this are to be
found in the works of Bybee (2014) and McKinnon, Danaia and Deehan (2015) who describe an effective approach to science teacher education focused on developing PCK from the commencement of teacher training.

The third of Tytler’s (2007) themes relating to obtaining science content knowledge is through experience teaching science. Teacher training and study of the subject prior to that are not the only ways to acquire science content knowledge and pedagogical content knowledge. Experience in teaching science allows the acquisition of both. However, the proportion of primary teachers in Staff in Australia’s Schools (ACER, 2010) survey, a national survey of science teacher supply, demand and quality, who have five or more years teaching experience in general classroom teaching (68%) was lower than the proportion teaching science at that time (78%). This suggests a lack of experience (greater than five years) for a significant number of general science teachers. In addition, the ACER (2010) survey reveals that in most secondary science curriculum areas, the proportion of teachers with more than five years teaching experience is lower than the proportion currently teaching in the science subject. This is again suggestive of a number of science teachers teaching the subject with fewer than five years teaching experience. In the primary school teacher sample, 24.8% had been teaching for five years or less. Among secondary school teachers, 20.1% were in this category. Within these figures, at the primary level, about 30% of all teachers in remote schools had been teaching for five or fewer years while for secondary teachers the proportion was 24%. Science teachers with five or fewer years teaching experience, nearly one quarter of primary science teachers and one fifth of secondary science teachers are likely to need continuing support to develop their science content knowledge. This applies particularly to the nearly one third of secondary and one quarter of primary science teachers working in rural and remote areas. The data suggest that significant percentages of primary and secondary teachers are still building their content knowledge of science through teaching experience. These percentages increased with remoteness.

Further, the experience of science teachers teaching the subject was an area of interest for the Australian Council of Deans of Science (2005) who expressed concern over the
issue of the qualifications of Australian Science Teachers and their lack of science content knowledge. The Deans conducted a national survey of science teachers and heads of secondary school science departments covering four science disciplines: Biology, Chemistry, Physics and Geology/Earth Science. The survey’s findings relating to science teaching in the middle years indicated there was a relatively high percentage of Year 7 and Year 8 teachers with no university exposure to the content of any of these four science disciplines. The survey found that there was agreement among heads of secondary school science departments that future teachers of senior science should have at least a major in the appropriate discipline area.

Concern around the content knowledge on science teachers as well as the qualifications of science teachers was also a key finding from the Australian Secondary Principals Association Teacher Survey (2006). The survey indicated that 40% of science classes were being taken by teachers without subject expertise (defined as no method training) or who did not pass the subject at second year university level (and therefore had limited science content knowledge). The survey also indicated there was a 1% national reduction in offering of science subjects due to lack of science teacher supply, which was most pronounced in rural and remote areas. In addition, the survey found there was an increase in difficulty in finding qualified science relief staff that was most pronounced in rural and remote schools. Such schools, the survey found, experienced double the degree of difficulty of urban schools in finding science relief staff. Moreover, science was the fourth largest of 10 subject areas in terms of the number of teachers indicating they would retire within the next five years.

The evidence from ACER (2010), the Australian Secondary Principals Association [ASPA] (2006) and the Australian Council of Deans of Science (2005) surveys indicate that some science teachers entering the profession have an inadequate preparation from their teacher training to develop the content knowledge required by the science curriculum. There is also evidence of out-of-field teaching of science, particularly in rural and remote schools (ASPA, 2006), and evidence of significant percentages of teachers with fewer than
five years teaching experience. This suggests a continuing need to develop the science content knowledge of science teachers.

The fourth area identified by Tytler (2007) through which science teachers can build their science content knowledge is through professional learning. The ACER (2010) survey indicated that around three-quarters of primary teachers (74.7%) had engaged in organised professional learning activities focused on ‘knowledge of content’ or ‘subject matter I am expected to teach’. This could be indicative of high demand for such courses because primary teachers lack the relevant science knowledge in addition to a need for continuing professional learning experiences in this area, with 34.6% of primary teachers and 32.8% of secondary teachers indicating they would like further professional learning opportunities. Viewed in this way, these data suggest that about one third of primary and secondary science teachers desire further professional learning to improve their knowledge of science subject matter. The ACER (2010) survey also revealed that the average professional learning activities attended by science teachers over the previous 12 months was only 8–9 days, which is well below the OECD Teaching and Learning International Survey average of 16 days for lower secondary and primary science teachers (OECD, 2009). Indeed, these activities were not of ongoing duration. In fact, 20% of primary and 30% of secondary science teachers reported spending three days or less on science professional learning activities during the previous 12 months. This would suggest for these groups in particular, investment in developing science teacher PCK was too low. Supporting the notion that the number of professional learning days was relatively low, between 15% and 30% of primary and secondary science teachers signaled they needed more opportunities for professional learning. The area of greatest need for primary teachers was ‘methods for assessing student learning and development’ (45%) followed by ‘effective teaching methods for the subject matter’ (38%), which was also the greatest area of need for secondary teachers (45%). All of these areas comprise elements of PCK and teachers are signaling they require more assistance to improve their PCK in these. Of all 18 areas identified in the ACER (2010) for professional learning, the percentages of teachers indicating that they would like more professional support varied from between
15% and 40%, which suggests a need for further targeted professional learning experiences.

Similar findings were evident in the SiMERR (2006) survey, which reported that primary teachers in remote areas indicated a significantly higher unmet need for professional development opportunities such as mentoring, release time, and collaboration with colleagues than did teachers elsewhere. In addition, primary teachers in non-metropolitan areas indicated a substantially greater unmet need for professional learning in Science and Mathematics than did their metropolitan counterparts. Primary teachers who taught science in non-metropolitan areas also indicated a significantly higher unmet need for a range of resources and assistance including ICT support and maintenance, learning support, and resources to cater for student diversity, than did their metropolitan colleagues. Finally, primary teachers and secondary science and mathematics teachers in schools with higher proportions of Aboriginal students indicated greater need for alternative and extension activities to cater for the diversity of student backgrounds and ability levels in their classes. The ASPA (2005) and ACDS (2006) survey results also revealed a desire among primary and secondary science teachers for greater professional support, especially in the form of mentoring for early-career teachers. They also pointed to difficulties in releasing staff to attend professional learning activities due to the lack of casual supply teachers.

In summary, the literature, including an analysis of data from SiAS (2010), SiMERR (2006), ACDS (2006) and ASPA (2005) paint an intriguing and somewhat confused picture of science teacher knowledge of science curriculum content. Four key points emerge from this picture. First, as far as deriving science content knowledge from the study of science at school is concerned, the literature show decreasing time devoted to science in primary schools. This impacts negatively on developing students’ aspirations to continue the study of science (and technology) in their later years of schooling and in higher education (OECD, 2006). Some science teachers do not possess the relevant science content knowledge from the study of the subject at school or higher education. The prevalence of these teachers is higher in rural and remote areas than in metropolitan areas suggesting
the need for greater support to build the science curriculum and science content knowledge of rural and remote teachers. Second, as far as gaining knowledge of Science during teacher training is concerned, for those science teachers with at least one term of Science content knowledge in a three year teacher training course, there are significant numbers who did not received methods support through their teacher training (ACER, 2010). Whether or not one semester of Science in a three-year degree is sufficient preparation for teaching the subject to primary or secondary students is an area for further consideration and discussion. Third, while it can be argued science classroom teaching experience may make up for some of the lack of science content knowledge and methods training, approximately 20% of both primary and secondary teachers had less than five years teaching experience in 2010 (ACER, 2010). These figures point to a need to support these teachers to develop their PCK. Once again, the prevalence of teachers with five or fewer years teaching experience is higher in rural and remote areas. Finally, as far as professional learning is concerned, the picture is one of too few professional development opportunities with an ongoing focus explicitly on the development of science PCK. This situation is more pronounced in rural than metropolitan areas (SiMERR, 2006). In addition, both the ACDS (2006) and the ASPA (2005) surveys identify ‘out of field’ teaching in science as well as difficulty in obtaining qualified casual relief teachers to allow science teachers to engage in professional learning activities. This suggests that more needs to be done to improve science teacher content knowledge particularly for teachers in rural and remote areas.

In addition to science content knowledge, when designing science experiences to achieve effective student learning, it is critical that science teachers know the science curriculum they are teaching including the curriculum content, the curriculum learning goals and their curriculum beliefs. As discussed in Section 2.1, Science is a Key Learning Area (KLA) within the Australian Curriculum. The Australian Science Curriculum provides a rationale for teaching science including science content, science knowledge, skills, attitudes, and values. It is essential that science teachers know and understand the science curriculum and its scope and sequence from Years F to 10 and similarly any Science KLA they teach in
Years 11 and 12. For the purposes of this study, science subject matter refers to Science Content, the curriculum in which that content is nested and the expectation is that science teachers know both the Science Content they are teaching and the presentation of that content within the curriculum.

2.4.1.5 Orientations towards science teaching

Orientations towards teaching science refer to the general way in which a teacher views the teaching of science. Shaping orientations are teacher beliefs about the purposes and goals of science as well as their beliefs concerning the teaching and learning of science. For example, it has been shown in Section 2.4.1.2 that those teachers who believe constructivism represents a common sense way of describing students’ learning employ instructional strategies that support student learning based on that view. Similarly, those teachers who believe that student learning occurs best in situations where students receive and internalise information directly are likely to employ didactic instructional approaches. It is important, therefore, that teachers understand their beliefs about the purposes of science together with their beliefs about student learning. Having a reflective approach to clarifying and challenging their beliefs, in a non-threatening and professional way, helps teachers to adopt additional evidence-based practices. Kind (2009a) points out that having well-adjusted emotional attributes, including the ability to take and apply constructive criticism, allows teachers to self-reflect and to challenge their practices to ensure they are continually improving. Presenting science teachers with opportunities to discuss their beliefs about science as well as to discuss alternative theories of student learning and associated evidence-based instructional practices will help teachers to reflect on their science orientations and selection of instructional practices thus improving their PCK.

2.4.1.6 Knowledge of Science Assessment

Knowledge of science assessment includes teacher knowledge of specific tools for science assessment, including their advantages and disadvantages, as well as identifying which parts of the subject are most important to assess. Also included is diagnosing those parts
of the curriculum students are most likely to have difficulty in understanding so that instructional strategies can be developed to assist students’ learning. In addition, science teachers are required to assess their own as well as their students’ alternative conceptions in the diagnostic phase. Goodrum et al. (2001) and Goodrum and Rennie (2007) argue that in line with constructivist approaches to teaching and learning, effective assessment is required to take two further forms during and after learning. The first is formative assessment to assist students and the teacher to identify/diagnose current understandings and plan teaching approaches to account for these. The second is summative assessment, which is used to monitor students’ learning and measure learning growth, so that feedback can be provided to assist students to monitor their own progress with the aim that they take charge of setting their own goals for learning growth (Hattie, 2009).

2.4.1.7 Well-adjusted personal attributes

In order to become an experienced and effective science teacher with the sophisticated PCK skills described in the previous sections, perseverance, professionalism and an ability to receive and act on well-constructed teaching performance feedback drawn from the teacher’s classroom (Kind, 2009b) are also required. Willingness to help develop the PCK of colleagues as well as to engage with colleagues to develop one’s own PCK requires a professional and reflective approach to developing professional growth. ‘Rebounding’ following periods of intense work and pressure in the teaching and learning environment require resilience. These personal attributes all enable PCK development.

Having developed an understanding of the PCK construct as it applies to science teachers, the next section, Section 2.5, discusses the implications of using the PCK framework developed in Section 2.4.1 from the work of Shulman (1886), Magnusson et al. (1999) and Kind (2009b) to improve the effectiveness of science teacher PCK in the middle school years of rural and remote settings. It does so by slightly augmenting the framework and suggesting indicators to show whether or not PCK is developing.
Since improving the PCK of science teachers improves their effectiveness, it is critical to focus on teacher learning experiences that allow this to occur. Improving teachers’ science PCK is discussed in Section 2.5.

### 2.5 Improving teachers’ science PCK

Section 2.3 established that science teachers are central to achieving the ideal picture of science education (Goodrum et al., 2001; Goodrum et al., 2012; Dow, 2003a, ACDS, 2005). Section 2.4 demonstrated that science teacher’s PCK is a useful construct for both developing and measuring teacher effectiveness in terms of achieving the ideal picture of science education (Goodrum et al., 2001). Therefore, continuously developing science-teacher PCK becomes critical to ensuring that the effectiveness of science teachers is continuously improving. This is what Goodrum et al. (2001) meant when they indicated that in their ideal picture of science education, “Teachers are lifelong learners who are supported, nurtured and resourced to build the understandings and competencies required of contemporary best practice” (p. 85). Before turning to the issue of improving PCK for teachers of science in the middle school years located in rural and remote schools, it is important to first consider how we will we know that any processes designed to improve science teachers’ PCK are achieving their intention. What are the indicators that will signify science teacher PCK is improving? These indicators are discussed in the next section, Section 2.5.1.

#### 2.5.1 Science PCK improvement indicators

Combining the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986) on PCK allows development of the PCK framework based on the elements defined in Section 2.4. By using this framework, it is possible to provide indicators that describe improvements in teachers’ science PCK. What follows is a list of the elements of PCK with indicators that signify improvements in PCK are occurring.
2.5.1.1 Ability to scan holistically the teaching and learning environment
This includes improvements in assessing and reassessing the effectiveness of teaching and learning approaches to be able to make in-the-moment modifications in response to changes occurring in any of the five components of PCK described by Magnusson et al. (1999). As previously discussed, this occurs in a holistic and fluid manner so that the observer would see the teachers continually scanning the teaching and learning environment, and making in-the-moment decisions in relation to instructional strategies to amend them where necessary in response to changes in any of the other elements of PCK.

2.5.1.2 Knowledge of science instructional strategies and their implementation
Indicators of improvements in science instructional strategies and their implementation includes improvements in constructivist teaching strategies as well as teachers employing illustrations, models, examples and analogies to represent specific content. Improvements in teachers’ knowledge of problems, simulations, demonstrations, investigations and experiments, and how these activities will affect student understanding are also indicative of improvements in knowledge of science instructional strategies.

2.5.1.3 Knowledge of areas that students find difficult to understand
Indicators of improvement in this element include improvements in teachers’ knowledge of the prerequisite ideas and skills that students will need to learn a topic, and of the varying approaches students will use to learn specific content, depending on the developmental level and learning style of each individual student. It also includes improvements in teachers’ knowledge of content, areas students will find difficult to learn particularly due to their alternative conceptions, and improvements in teacher knowledge of strategies to assist students’ address their alternative conceptions. The use of diagnostic pretesting to determine any student alternative conceptions is another indicator.
2.5.1.4  Knowledge of personal orientations to teaching science
Indicators of improvement in this element will include recognition of one’s own beliefs and orientations toward teaching the subject and any consequent effects on selecting instructional strategies as well as any teacher alternative conceptions that may arise because of orientations towards teaching science.

2.5.1.5  Knowledge of science content
Indicators of improvement in this element include improvements in knowledge of science content, knowledge of student standards on a learning continuum and knowledge of specific science teaching programs and support materials. Also included are knowledge of student skills, attitudes and values the curriculum sets out to develop.

2.5.1.6  Knowledge of science assessment
This includes improvement in teacher knowledge of certain specific tools for assessment and their associated advantages and disadvantages as well as improvements in diagnosing which parts of the subject are most important to assess. Also included is the teacher’s use of assessment tools to determine students’ alternative conceptions.

2.5.1.7  Improved teacher confidence to teach science
This has been added to the PCK framework developed in Section 2.4 on the grounds that it is reasonable to assume that improvements in teachers’ PCK will result in improved teacher confidence to teach science (Appleton, 2005).

2.5.1.8  Improved student science learning outcomes
This has also been added to the PCK framework in Section 2.4 on the grounds that student learning outcomes represent a measure of the effectiveness of the teachers’ teaching and of the learning approaches adopted to achieve student-learning growth and are therefore, an indication of improved teacher PCK. It is reasonable to expect that improved teacher PCK will lead to improved student learning outcomes.
2.5.1.9 Improved personal attributes

This includes improvements in resilience, receptiveness to constructive criticism and ability to assist colleagues by providing constructive criticism (Kind, 2009a). Bybee (2014) also found adequacy of personal relations with students and enthusiasm for science teaching consistently to be important personal qualities science teachers need to possess.

Having developed a framework with indicators to show if improvements in PCK are occurring, Section 2.6 examines a means of developing the PCK of teachers of science in rural and remote middle school settings given the unique challenges these teachers face.

2.6 Educative Curricula and developing teachers’ science PCK

Sections 2.2.7 and 2.2.8 showed that developing PCK for rural and remote science teachers through traditional face-to-face professional learning means is challenging due to unique factors associated with teaching in these isolated areas. These challenges arise due to such factors as limited development of science content knowledge, lack of experience in teaching science, lack of professional learning opportunities including mentoring by experienced teachers and lack of exposure to specific science PCK development in pre-service teacher training and during in-service teaching (e.g., Fetters et al., 2002; Kind, 2009a; Odgers, 2003; Tytler, Osborne et al., 2008; VAGO, 2014). Exacerbating these challenges are factors common to education in rural and remote areas. These include a lack of availability of casual relief teachers, a higher incidence of out-of-subject field teaching, difficulties in attracting and retaining science teachers, and greater incidences of combining science classes compared to schools in metropolitan areas. Can these challenges in rural and remote areas to providing face-to-face professional learning to improve science teacher PCK be addressed? One alternative to using a face-to-face professional learning to develop the science PCK of teachers in middle school settings in rural and remote Australia is to use ‘educative curricula materials’ to do so.

Curricula designed with the aim of simultaneously achieving teacher and student learning are known as ‘educative curricula’ (Davis & Krajcik, 2005; Schneider et al., 2000; Schneider & Krajcik, 2002; Schneider & Rivet, 2000). Educative curricula for science usually consist of
‘ready-to-go’ packages that guide teachers to improve their PCK by providing advice on the selection of instructional strategies, the selection of assessment tools and methods and through the provision of correct science content knowledge within the curriculum materials. In addition, educative curricula for science provide teachers with: advice on common student alternative conceptions and how to devise interventions to challenge these; a scope and sequence of appropriate instructional strategies to deal with them, as well as the impact of science orientations on strategy selection. These ready-to-go packages for teachers include accompanying guidance to develop their science subject knowledge, skills, values and attitudes, as well as a range of activities for students designed to improve their learning outcomes. However, not all ready-to-go packages contain all of the necessary elements that make them educative (Jones & Eick, 2007). Many such science curriculum kits require additional adaptations, often significant, that draw on the specialist PCK of the experienced science teacher.

For Davis and Krajcik, (2005), employing educative curricula leads to teachers:

\[
... developing and integrating one’s knowledge base about content, teaching and learning; becoming able to apply that knowledge in real time to make instructional decisions; participating in the discourse of teaching; and becoming enculturated into (and engaging in) a range of teacher practices. \text{(p 3)}
\]

What distinguishes educative curricula from typical teachers’ guides is that educative curricula help to develop teachers’ knowledge in specific instances of pedagogical decision-making, and PCK that is transferable to other teaching and learning situations. Teachers’ guides on the other hand simply support teachers’ instructional strategies and not teachers’ learning.

For Davis and Krajcik (2005) the benefits for the science teacher of using educative curricula to develop PCK are that they help the user to learn how to anticipate and to interpret what learners may think about or do in response to instructional activities and to support their learning of subject matter. In addition, they help science teachers to relate science units during the year, make visible the curriculum developers’ pedagogical assumptions, and to help them to design or select appropriate instructional strategies.
Educative curricula, therefore, make connections between teaching theory and practice by making teachers’ judgments transparent. This ‘educates’ the teacher into when and how to apply particular instructional strategies, after taking the other components of PCK into account, and thus develops teacher PCK in the process. To gain further understanding of how educative curricula educate the teacher into when and how to apply instructional strategies, after taking the other components of PCK into account, Section 2.6.1 provides further detail on the principles for designing educative curricula.

2.6.1 Basic design principles for educative curricula

The overriding design principle for educative curricula is that the final curriculum materials must simultaneously achieve two aims: to enhance science teacher PCK and to improve student science learning outcomes. In its usual practical form, this requires designing a student workbook containing the content, skills, values, and attitudes students are required to learn as part of the curriculum and a teacher workbook providing guidance to teachers on how to design instructional strategies to achieve the student-learning outcomes specified in the curriculum. Taking each of these interconnected and interdependent components and dealing with them separately, the design principles for the student curriculum are discussed in Section 2.6.1.1 and those for a teacher learning that curriculum are discussed in Section 2.6.1.2.

2.6.1.1 Designing the student curriculum component of educative curricula

As far as designing student curriculum materials is concerned, Bybee (2006) and Donovan and Bransford (2005) provide guidance on developing science content materials for students based on a constructivist approach and employing the 5Es model (Bybee, 2006). The first step in the design process is to link three basic principles for student learning in the sciences to curriculum design. This is shown in Table 2.7.

Table 2.7: Basic Principles of Learning for Curriculum and Instruction in the Sciences

<table>
<thead>
<tr>
<th>Basic Principle of Student Learning</th>
<th>Implications for Curriculum Design</th>
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</table>
Students have preconceptions about how the world works. Science curriculum and instruction should facilitate conceptual change.

Students' competence in science requires factual knowledge and conceptual understanding. Science curriculum and instruction should be based on fundamental concepts and complementary facts.

Students can learn to control their own learning through metacognitive strategies. Science curriculum and instruction should provide opportunities for students to learn and develop metacognitive strategies.

Table 2.7 shows the basic principles for designing student science curricula based on constructivist principles of teaching and learning. The left hand column of Table 2.7 basic presents the constructivist principles for student learning, with their corresponding implications for curriculum design shown in the right hand column. Building on these principles, Bybee (2006) introduces a second design step involving developing greater linkages between curriculum, instructional design and the principles for student learning in the sciences. Table 2.8 outlines this process and shows the second design step in the process for developing educative curricula for students by developing greater linkages between curriculum, teaching strategies and the principles for student learning in the sciences.

Table 2.8: Design Principles for Linking Curriculum to Science Pedagogy and Student Learning.

<table>
<thead>
<tr>
<th>Key findings from How Students Learn</th>
<th>Implications for science teaching</th>
<th>Requirements for curriculum materials</th>
</tr>
</thead>
<tbody>
<tr>
<td>Students come to educational experiences with preconceptions.</td>
<td>Teachers should recognise preconceptions, engage the learner, facilitate conceptual change, and employ strategies that respond to students’ prior knowledge</td>
<td>Incorporation of information about common preconceptions in the process of conceptual change, and the means by which the curriculum can bring about conceptual change. Inclusion of structured sequences of experiences that will elicit challenge and provide opportunities to change preconceptions.</td>
</tr>
<tr>
<td>Students should develop a factual knowledge based on a conceptual framework.</td>
<td>Teachers should have a conceptual understanding of science and the appropriate factual knowledge aligned with the concepts</td>
<td>Base the curriculum on major concepts of science. Connect facts to the organising concepts. Provide relevant</td>
</tr>
</tbody>
</table>
The third step for Bybee (2006) involves employing a ‘backward-design’ process based on using the 5Es teaching and learning sequence to ensure the curriculum materials identify what students need to learn by highlighting the ‘enduring understandings’ required by the student. In addition, the curriculum materials must state the required learning outcomes and provide clarity on what will serve as acceptable evidence of student attainment of the ‘enduring understanding’ to guide assessment of learning. Finally, the curriculum materials need to provide clarity on what experiences would most effectively develop students’ knowledge and understanding of the ‘enduring understanding’ or targeted content.

The fourth and final step involves taking the ‘enduring understanding’ and content outcomes and moving to the ‘Evaluate’ element in the 5Es model by designing an activity to assess students’ knowledge and understanding of the content then designing experiences to provide students with opportunities to learn the relevant content. The process concludes by eliciting evidence of student learning of those particular content outcomes selected by providing opportunities to students to apply their learning using the literacies of science aided by the use of ICTs (Bybee, 2006).

2.6.1.2 Designing the teacher learning component of educative curricula

As far as designing educative curricula to develop teachers’ PCK is concerned, Davis and Krajcik (2005) provide guidance based on employing nine heuristics to guide designers of educative curricula to achieve teacher learning. The guiding heuristics presented to designers of educative curricula are addressed in the following sections.
2.6.1.2.1  Engage students with topic specific phenomena

This refers to providing teachers with advice on how to use props and experiments to help students understand scientific phenomena. It also refers to providing advice to teachers on why the props and experiments used are scientifically and pedagogically appropriate. This heuristic also refers to providing guidance to teachers on which experiments are important, which are feasible for students to conduct themselves and advice on those experiments that may be more appropriate as demonstrations. The curriculum materials advise teachers of potential pitfalls with experiments and help teachers think about productive sequences for student-learning experiences.

2.6.1.2.2  Use scientific instructional representation

This refers to providing teachers with advice and guidance on appropriate instructional representations of scientific phenomena (e.g., analogies, models, and diagrams), supports them in adapting and using the representations as well as helping them to determine the most salient features of an instructional representation. The educative curricula should state explicitly why particular instructional representations are scientifically and pedagogically appropriate. They should also warn what non-scientific ideas might be promoted if the instructional representations are used incorrectly.

2.6.1.2.3  Anticipate, understand and deal with students ideas about science

This refers to providing teachers with a set of alternative conceptions that the research indicates students at that age might hold, for example, that the seasons are caused by the Earth’s distance from the Sun, together with suggestions for dealing with the idea in the classroom, such as suggestions about language to use or avoid, questions that might be asked or experiments that students might perform.

2.6.1.2.4  Engage students in questions

This refers to providing teachers with guidance on constructing questions to frame a unit and helping them to identify focus questions for guiding class discussion. The educative
curricula should help teachers engage their students in asking and answering their own scientific questions by providing suggestions on productive questions.

2.6.1.2.5 Engage students with collecting and analysing data

This involves providing teachers with guidance on how to help students collect, compile, organise, analyse, and understand data and observations as sources of key evidence in scientific inquiry.

2.6.1.2.6 Engage students in designing investigations

This refers to ensuring the educative curricula provide guidance to teachers on how to support students to carry out their own investigations. This includes providing ideas for appropriate student designs.

2.6.1.2.7 Engage students in making explanations based on evidence

This refers to providing guidance to teachers on how to support students in making sense of the data they have collected to generate explanations based on evidence and scientific principles. The rationale for using data to generate scientific explanations should be made clear to teachers in the educative curricula.

2.6.1.2.8 Promoting scientific communication

This refers to providing guidance to teachers on how to promote productive communication between students and between students and teachers in the learning environment. This includes advice on the advantages and disadvantages of different types of written and spoken communication.

2.6.1.2.9 Develop subject matter knowledge (SMK)

This refers to supporting teachers in developing their factual and conceptual knowledge of the science content and particularly the concepts likely to be misunderstood by students (Mortimer & Scott, 2003; Taber, 2003). The support provided for teachers should be at a level beyond the level of understanding needed by the students. In this way, teachers are
better guided to explain science concepts and understand the views of their students who are engaging with the material (Hewson, 2007; Loucks-Horsley, Hewson, Love & Styles, 1998).

Incorporating the design principles for student learning with those for science teacher learning to improve student learning and teachers’ PCK simultaneously give educative curricula their power. Combining approaches for developing PCK using the framework from the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986), with the guiding heuristics provided by Davis and Krajcik (2002), suggests that designers include the following components when designing educative curricula.

First, approaches and resources should be included to assist science teachers to examine their pre-existing ideas and beliefs on the topic. This could include a general introduction on the important role science orientations and teacher beliefs play in achieving effective science learning (Keys, 2006).

Second, advice should be given on distilling the essential learning for students from the curriculum rationale and goals. Providing advice on developing CoRes and accompanying PAP-eRs is a useful starting point to assist science teachers to link science content to instructional strategy selection (Loughran, Milroy, Berry, Gunstone & Mulhall, 2001).

Third, advice on areas in the curriculum students typically find difficult to learn will assist educative curricula to develop teachers’ PCK. This includes commonly held student alternative conceptions on the topic of study together with strategies to help students move their knowledge towards the accepted scientific knowledge (Taber, 2003; Tsai & Chou, 2002).

Fourth, educative curricula should contain sufficient science content knowledge to ensure teachers understand the topic and to help them develop their SMK. This aspect is important when developing their science PCK. This ensures that teachers have the content knowledge to deal with students’ questions and to identify parts of the science content students typically find difficult to learn (Ball, 2000; Ball, Thames & Phelps, 2008).
Fifth, advice on appropriate science assessments should include those parts of the curriculum to assess as well as providing suggested strategies will also assist PCK development. This should cover examples of diagnostic, formative, and summative assessment (Abell & Siegel, 2011).

Sixth, advice on evidence-based instructional-strategy selection or development is important. This could include advice on the various science instructional strategies teachers can select to help students to learn (e.g., Duit & Treagust, 2003).

Seventh, advice on how to apply the following elements of PCK holistically and fluidly in the learning environment to achieve student learning will help not only the development of PCK but also the progression of teachers to become highly effective, as these are characteristics of experienced teachers:

1. Knowledge of student context and areas they find difficult to learn as well as students’ alternative conceptions;
2. Instructional strategy selection and deployment;
3. Assessment tools, selection implementation;
4. Knowledge of the curriculum; and,
5. Personal orientations to science.

This could include providing PAP-eRs or vignettes specifically collected for the topic, advice on linking with expert science teachers, advice on seeking and partnering with a mentor, and advice on more sophisticated approaches to developing PCK based on employing self-video analysis of lessons or employing 360-degree lesson feedback from experienced teachers (e.g., Mulhall, Berry, & Loughran, 2003).

Finally, advice on strengthening necessary emotional attributes such as encouraging resilience, persevering, self-reflecting, providing and receiving constructive feedback and building relationships with students should be included (Akerman, MacGregor, Salter & Vorhaus, 2009).

Combining approaches for developing PCK using the framework from the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986) with the guiding heuristics provided by Davis and Krajcik (2005) provides an educative approach required to assist teachers to
develop their PCK while simultaneously providing the curriculum materials to allow student-learning outcomes to improve. It is important to note that using educative curricula in this way to provide an alternative approach to face-to-face professional learning to develop PCK in the case of rural and remote teachers, incorporates many of the better practice principles teachers would experience in receiving regular professional learning. This alignment ensures educative curricula are a useful alternative for developing teacher PCK when face-to-face professional learning is not possible.

To illustrate the alignment, Timperley, Wilson, Barrar, and Fung (2007) describe a number of features required of science teacher face-to-face professional learning for the approach to work effectively. Their meta-analysis of 72 studies assessing the effect of professional learning on student outcomes in a range of subjects including Science, Mathematics, writing and reading in English, found an overall effect size on student outcomes of 0.66, with the highest effect sizes being for Science (0.94). The following is a description of how the features that work best for face-to-face professional learning for developing science teacher PCK in Timperley et al.’s (2007) study align with those for developing PCK using educative curricula, provided by combining the works of Kind, (2009b), Magnusson et al. (1999) and Shulman (1986) for developing PCK with the guiding heuristics provided by Davis and Krajcik (2005).

First, Timperley et al. (2007) found that professional learning experiences need to occur over an extended period of time. This is consistent with the notion from Kind, (2009b), Magnusson et al., (1999) and Shulman (1986) of the continuous development of PCK requiring both external support and an ongoing culture of self-driven teacher improvement.

Second, Timperley et al. (2007) found the involvement of any external experts needed to be related more to overall student success than within-school initiatives. This is consistent with the aim of educative curricula being to develop PCK to improve overall student learning outcomes including their scientific literacy.
Third, they found that strong teacher engagement was required during the professional learning process to deepen knowledge and extend their skills to improve student outcomes. This is consistent with the role of educative curricula in deepening science teacher content knowledge, knowledge of assessment, knowledge of students’ alternative conceptions and knowledge of teacher orientations in order to design effective instructional strategies to improve student-learning outcomes.

Fourth, the authors found that effective face-to-face professional learning is required to challenge teacher preconceptions on student learning as well as how to teach particular curricula more effectively. This is consistent with design principles for educative curricula requiring teachers to examine and understand their own preconceptions and orientations and to build knowledge of student difficulties in learning the curriculum along with strategies to address those difficulties.

Fifth, Timperley et al. (2007) found that the creation of a community of learners by facilitating teacher talk on teaching and learning between teachers provided effective ongoing face-to-face professional learning. This is consistent with implicit notions in educative curricula of science teachers being part of a community of science teacher learners assisting each other to develop their PCK. It should be noted that while professional isolation can be a barrier to establishing effective communities of practice in rural and remote areas, technology is able to assist.

Sixth, when challenging teacher beliefs, they found that effective face-to-face professional learning required grounding the discussion in student artefacts. This is consistent with strategies in the design principles for educative curricula that provide illustrations of student work and make explicit assessment strategies for assessing student work samples. Focusing discussion on student work samples is also one way to help make teacher beliefs about students explicit allowing reflection on these beliefs.

Seventh, the authors found that face-to-face professional learning works best when school leadership supports the professional learning. This is implicitly assumed in this study with its focus on science teachers. The case studies in Phase 1 of the current study,
however, reveal the need for leaders to provide greater support to science teachers to develop their PCK.

Eighth, access to relevant expertise assisted face-to-face professional learning. Kind (2009b) and Magnusson et al. (1999) acknowledge that teachers will call on relevant teacher expertise to assist when available, but the issue for rural and remote teachers is a lack of availability of this support necessitating the provision of expertise in the form of educative curricula.

Finally, Timperley et al. (2007) found that what works best for face-to-face professional learning is providing time for teachers to process and apply new information. This is consistent with the design heuristics and to provide this advice in written format for effective educative curricula that assist teachers to make instructional decisions. It is also consistent with the notion of educative curricula developing science teachers to become self-reflective practitioners who use CoRes and PAP-eRs.

Educative curricula are intended to promote simultaneously student and teacher learning. Moreover, given that the design principles align with the principles for face-to-face science teacher learning, the question arises as to whether educative curricula can be used to address the challenges that teachers of science in rural and remote middle schools face in developing their PCK? That is to say, will educative curricula develop teachers’ science PCK in rural and remote middle school settings where, for example, science teachers lack access to face-to-face professional learning, access to experienced science teacher coaches, access to a pool of casual teachers to facilitate ongoing professional learning, and lack confidence to teach science due to little or no exposure to science content knowledge or science methods training? One example of educative curricula currently in use by some Australian rural and remote middle schools is the *Eye Observatory Remote Telescope Project: Practical Astronomy for Years 7, 8 and 9* (McKinnon, 2005) referred to in this study as the Middle Years Astronomy Project (the Project). This study explores the ability of this educative curriculum to improve science
teacher PCK thereby improving science teacher effectiveness in middle school settings in rural and remote areas.

2.7 Chapter Summary

The Australian Curriculum describes what young Australians should learn as they progress through school in order to meet the national aims of schooling. These aims include providing the foundations necessary for successful, lifelong learning and participation in the Australian community so that each young Australian can engage effectively with and prosper in a globalised (knowledge) economy (ACARA, 2011).

Science as one of seven-mandated KLAs F–10 in the curriculum plays a key role in achieving the aims of the Australian Curriculum. The study of science provides benefits to students by developing their scientific literacy skills and provides benefits to the economy by equipping students with the innovative, inventive, creative abilities to generate and apply new ideas required of knowledge workers in an interconnected and interdependent global economy. The Australian Curriculum clearly states the study of science F–10 is for all students regardless of location, gender, cultural background, or socio-economic status.

Interrogating the national and international assessment data and literature on how well the aims of the Australian Science Curriculum are being achieved reveals strong student performance on average in national and international assessment programs, suggesting science education overall is travelling well. However, the interrogation also points to areas where science education can be improved to reach the ideal picture of science education described by Goodrum et al. (2001). One area is the middle-school years where there is strong evidence pointing to the need to achieve the ideal picture of science education for students in the final years of primary schooling and the early years of secondary schooling. The second area is the performance of rural and remote students, where there is strong evidence to show that rural and remote students suffer major educational disadvantage adversely affecting their performance on a range of education indicators.

Science teachers are critical to achieving Goodrum et al.’s (2001) ideal picture of science education in the middle years of school education in rural and remote areas. Key to
achieving the ideal picture of science education is improving the effectiveness of teachers of science by improving their PCK. Improving science teachers’ PCK through traditional face-to-face professional learning activities is challenging in these rural and remote settings. This is due to factors such as unavailability of casual relief teachers to support teachers engaged in professional learning and through difficulties in attracting and retaining science teachers to provide experience, including mentoring, to less experienced science teachers. In addition, science teachers in rural and remote areas experience significantly fewer professional learning opportunities than their metropolitan counterparts. Finally, there is strong evidence that science teachers in rural and remote areas lack science content knowledge and some have had limited exposure to science PCK development in their teacher training. This adversely affects science teacher confidence to teach the subject (Appleton, 2005) and the frequency of science lessons provided to students with NAP-SL (2011) data show almost one in five students receive science lessons ‘hardly ever’.

Educative Curricula designed to improve teacher PCK provide an alternative to traditional face-to-face professional learning for science teachers. One educative curriculum currently in use in some in rural and remote areas is the Middle Years Astronomy Project (McKinnon, 2005). The purpose of this study is to explore the efficacy of the Middle Years Astronomy Project (McKinnon, 2005) to develop science teachers’ PCK in the middle years of schooling in rural and remote areas of Australia.

Chapter 3 describes the context within which this study is undertaken.
3  CHAPTER 3 Context

The purpose of this chapter is to present the context within which this study takes place. Section 3.1 describes the background to the study, provides an overview of the study together with a detailed description of the content and design of the Middle Years Astronomy Project focusing on the educative nature of the curriculum materials. In addition, Phase 1 and Phase 2 schools are discussed. Section 3.2 provides a summary of the context of the study.

3.1  Background to the study

Picture the following scenario: You have a role as a school improvement officer in a rural region that requires you to analyse data forensically, to discuss that data with principals and teachers having allowed them the opportunity to present their analysis of the data and you then jointly set a course of strategic action to improve the data discussed. Now as part of this role, you aggregate the data and, during meetings with colleagues from metropolitan areas compare the aggregated data. You are continually struck, year after year, by the difference between the data for rural students and metropolitan students. You work with passionate, committed teachers and leaders who want to improve learning outcomes for all students yet the gap between rural and metropolitan student data is not closing. In fact, during some years it widens. You also recognise a trend in the data showing education outcomes declining with remoteness from metropolitan areas. You ask yourself ‘Why is it so?’ ‘Can this be changed?’ and ‘How.’

This scenario represents my personal background to this study. Having worked in a number of school-improvement roles in rural and remote New South Wales (NSW), the Northern Territory (NT) and Victoria, the researcher has witnessed firsthand the adverse effects of rural education disadvantage on school communities. Regrettably, the battle against rural education disadvantage is not yet won, as the data presented in Section 2.2.6 of the previous chapter indicate.

As an economist by qualification, training and passion working in rural and remote parts of Australia, the researcher has appreciated for quite some time the impact of the declining
rural economy on employment opportunities for those wishing to remain in the bush. Equally, the economic literature (e.g., Australian Bureau of Statistics, 2003; Australian Government Treasury, 2015) makes it quite clear that it is not only the absolute number of job opportunities that are declining in rural and remote areas but also the nature of those opportunities. Rural job opportunities are changing away from agrarian and mining employment to jobs requiring the skill sets of knowledge workers for the knowledge economy. The education system plays a critical role in developing knowledge workers and, therefore, Australia’s stock of human capital for the knowledge economy.

If the education system results in some students missing out altogether on, or receiving less than optimum exposure to a full school curriculum designed to assist their development as knowledge workers, then there is a problem. The researcher became aware very early in his work in school improvement that this is the case with rural and remote students studying science. School curriculum audits conducted by the researcher in school-improvement roles quickly established that an unexpectedly high number of rural and remote primary schools were not offering any, or were offering a limited number of, science lessons. In addition, visits to classrooms by the researcher revealed the quality of the science lessons being presented to students was questionable. This was captured in a quote from a Department of Education and Early Childhood Development (DEECD) Science Consultant who had worked in rural Victoria with over 100 primary schools for a number of years when she said to the researcher while referring to science teaching in those schools:

*The vast majority of primary school teachers that I have worked with have very little science experience. A lot of teachers think that because they make chocolate crackles once a fortnight then that’s their science because they are melting stuff, and that’s science. And that’s a start, but you really need to draw out the real scientific method when you make chocolate crackles, and they don’t do that. So most primary teachers lack confidence and expertise and don’t know the reasons why science is important. They just don’t. Very few of them have done science themselves beyond Year 10 at school and they do very little at teacher training. They tend to hone in on the literacy and numeracy aspects of the science they teach and also things like art, which is really visible, but they neglect the science.*
This is a problem for two reasons. Firstly, science is an important Key Learning Area (KLA) in the Australian Curriculum that develops knowledge workers’ scientific literacy skills (Goodrum et al., 2001; Lawrence, & Palmer, 2003; OECD, 2001, 2004, 2006; Parliament of Victoria Education and Training Committee, 2006; Prime Minister’s Science, Engineering and Innovation Council, 2003). Secondly, the study of science provides benefits to the national knowledge economy (ACCI, 2007; Alston & Kent, 2006; Marginson et al., 2013; OECD, 2001, 2004, 2007; Productivity Commission, 2007, 2010).

In addition, having access to school improvement data, undertaking visits to a number of primary schools offering no science, observing limited science lessons and science lessons of questionable quality, as well as the opportunities afforded to visit many secondary science classrooms in rural and remote schools revealed that science was taught using mainly transmissive pedagogical approaches that appeared to be having the effect of turning students off science. These data and visits seemed to the researcher at the time to be at odds with the role of schools in equipping students with the exit-outcome skills required to thrive in the knowledge economy. Schools are required to provide skills such as conceptual skills, creative development skills, technology skills, information literacy skills and higher-order thinking skills (Johnson, 2005) to equip students to thrive in a world economy increasingly dominated by information. As the data and observations accrued, it appeared that extant practice was designed to serve one end—to increase further the educational disadvantage experienced by rural and remote students. One manifestation of this further disadvantage is reduced access to a range of educational and employment opportunities that together help determine educational attainment, work-life productivity, length of working life, standard of living and health outcomes (National Rural Health Alliance, 2014; Nguyen & Cairney, 2013; Robinson, Silburn, & Arney, 2011).

A change in role from school improvement to one involving the development of national school education policies for the Commonwealth Government did little to change my perceptions of the negative impact on rural and remote students. Rather, a common message coming from key Commonwealth education stakeholders, for example, professional teacher associations, Deans of Science and national parent bodies, was the
need for a greater focus in national school policy development on strategies to redress the education disadvantage being experienced in rural and remote locations. This greater focus included the delivery of a full curriculum to rural and remote school students, including science delivered by effective teachers. These experiences prompted the researcher to look for strategies to support this aim.

Initial efforts to reduce education disadvantage for rural and remote students saw the researcher focus on embedding constructivist pedagogies in distance-education learning materials using *Cognitive Flexibility Theory* (e.g., Jacobson & Spiro, 1995) and *Question Based Navigation* (Schank & Kass, 1994) with the aim of making distance-education learning materials ‘educative’ in order to improve teacher PCK. A move to another role within the Commonwealth government meant the researcher lost touch with the approach and its outcomes. However, the initial design work to embed constructivist approaches into distance-education materials led to the researcher encountering the Middle Years Astronomy Project (McKinnon, 2005) and stimulated an interest in exploring any potential for this educative curriculum to ensure science was taught and also to improve science teaching and learning in rural and remote areas. Subsequent doctoral candidature presented an opportunity to explore and investigate any ways in which the Middle Years Astronomy Project could improve the quality of science lessons by improving science teachers’ PCK in the primary and middle years of schooling in a remote region of Western Australia and in a relatively isolated rural area of Victoria.

With this background in mind, Section 3.1.1 presents an overview of the current study together with a description of the Middle Years Astronomy Project.

### 3.1.1 Overview of the study

This study builds on the scientific and education literature, including the national and international student performance data presented in Chapter 2 indicating that students in rural and remote areas of Australia experience education disadvantage when compared to their metropolitan counterparts. This literature includes Alston and Kent (2006), Australian Council of Deans of Science (2005), Council of Australian Governments (COAG)
(2013), Department of Education and Early Childhood Development (DEECD) (2013),
James (1999), Mission Australia (2006), the OECD (2013), Sidoti (2000), and The National
Centre for Science, Information and Communication Technology, and Mathematics
Education for Rural and Regional Australia (SiMERR) (2006). Rural and remote educational
disadvantage is demonstrated in a range of education measures including national
achievement data (National Assessment Program for Science Literacy 2003–2012); school
survey data (DEECD, 2013); international achievement data (Program for International
Student Assessment, 2012; Trends in International Mathematics and Science Study, 2011),
and the findings of significant studies conducted by government agencies (ACOLA, 2013;
DEECD, 2013; DEST, 2007; Sidoti, 2000; VAGO, 2014). Rural and remote education
disadvantage includes science education disadvantage (Australian Senate, 2009; National
Assessment Program-Science Literacy, 2003–2012; OECD, 2013; SiMERR, 2006; VAGO,
2014).

This study thus seeks to explore any potential for the Middle Years Astronomy Project, an
integrated science, technology, and mathematics hands-on, inquiry-based approach to
teaching science (McKinnon, 2005) targeted at upper primary and junior high school
students in the middle school years, to improve science teacher effectiveness by
improving teachers’ PCK.

The study happened in two phases:

- Phase 1 occurred in a remote region of Western Australia and involved exploring
  the impact of the Middle Years Astronomy Project in one rural and three isolated
  schools comprised of two remote F–12 schools, one rural middle school for Years
  7–9, and one remote distance education school for Years F–7. It should be noted
  though that while the term ‘rural’ has been applied to a middle school, that school
  is located approximately 433 kilometres from Perth, described as the most isolated
  city in the world, and is a service centre to surrounding remote towns. For the
  purposes of this study the school can be thought of as more ‘remote’ than rural
  and has been classified in this way. During the study, Year 7 was the final year of
  primary school in Western Australia. More recently Year 7 has been included in
  High School; and,
• Phase 2 occurred in rural Victoria and involved exploring the impact of the Middle Years Astronomy Project in four rural F–6 primary schools. Year 6 is the final year of primary school in Victoria.

The term ‘F’ or ‘Foundation’ refers to the first year of schooling. It is the terminology of the Australian Curriculum and is equivalent to ‘K’ or ‘Kindergarten’ or ‘P’ or ‘Preparation’.

Section 3.1.2 provides an overview of the Middle Years Astronomy Project, its background, and a detailed description including its educative design principles.

3.1.2 Overview of the Middle Years Astronomy Project

McKinnon conceived the Middle Years Astronomy Project when he was a science-teaching specialist at Charles Sturt University (CSU). With a background in physics and astronomy and research interests in science education, teacher professional learning and the application of ICTs in education, McKinnon developed the project in response to key findings of the research literature identifying:

• Astronomy is poorly taught in primary schools (e.g., Dunlop, 2000; McKinnon, 2005; Skamp, 1998);
• Both teachers and students possess many alternative conceptions about astronomical and other scientific phenomena that persist following exposure to the curriculum content, and the instructional and assessment strategies extant within practice (e.g., Dunlop, 2000; Rider, 2002);
• The study of astronomy is a valuable motivator of students to engage them in scientific processes and the study of science more generally (McKinnon, Geissinger, & Danaia, 2002; McKinnon & Mainwaring, 2000); and,
• A number of science teachers, particularly in rural and remote areas, lack scientific content knowledge, PCK and the confidence to teach science (Appleton, 2005; Gerbaldi, 2005; Hemenway, 2005).

In response to this research, McKinnon (2002, 2004, 2005) developed an approach to support the teaching of astronomy for students in the middle years comprised of a number of components discussed in the next section. What follows is a description of the Middle Years Astronomy Project relevant to each phase of this study.
3.1.2.1 Phase 1 Rural and Remote Schools in Western Australia

For Phase 1, the Project involved a number of components, some of which interacted with each other. These components and their interaction are described in the following subsections.

3.1.2.1.1 Telescope

This component refers to teachers and students accessing the CSU Remote Telescope, a computer controlled 12-inch Schmidt-Cassegrain Telescope. Internet access allows both students and teachers to control the telescope and its cameras to photograph astronomical phenomena as the basis for their investigations and further study. It was designed as an important motivator to engage students in learning about the sky while they also learned how to use the telescope and its cameras (McKinnon, Geissinger, & Danaia, 2002).

3.1.2.1.2 Teacher’s Guide

The Teachers’ Guide for this phase of the study consisted of a book Practical Astronomy for Years 7, 8, and 9 containing eight chapters and 32 student projects mapped to curricula for each jurisdiction (McKinnon, 2004), which were designed to improve both teachers’ astronomy PCK and student learning outcomes in astronomy, a component of each state or territory’s science curriculum.

3.1.2.1.3 Teacher’s Guide Content

The Teachers’ Guide for Phase 1 of the study, incorporating the design principles for educative curricula discussed below, comprised integrated science, mathematics and technology approaches to learning and teaching astronomy. The Teachers’ Guide employed a social-constructivist approach to science teaching and learning based on five components of the ideal picture of science identified by Goodrum et al. (2001). This ideal picture of science involves science being relevant to the needs, concerns and personal experiences of students. The second component involves the teaching and learning of science being centred on inquiry with students investigating, constructing and testing
ideas, and explanations about the natural world. The third component of the ideal picture involves assessment serving the purpose of learning and being consistent with and complementary to good teaching. In the fourth component, the teaching-learning environment is characterised by enjoyment, fulfilment, ownership, and engagement in learning. The final component involves mutual respect between the teacher and the students, with both having access to excellent facilities, equipment and resources to support teaching and learning (McKinnon, 2005).

The Teachers’ Guide contained eight chapters designed to improve science teacher PCK while simultaneously improving science student astronomy learning outcomes. These chapters were:

- Introduction to the Project and the approaches used;
- Planning to take control of the CSU telescope (5 projects);
- Image processing and telescopes (2 projects) with many investigations;
- The Moon (7 projects);
- The Solar System (8 projects);
- Stars and constellations (9 projects);
- Galaxies and the rest of the universe (1 project); and,
- Where to from here?

Each of the chapters provides teachers with guidance on selection of instructional strategies for the astronomy projects. Instructional strategy selection takes into account the science curriculum content knowledge provided in the chapters and projects, guidance on assessment strategy selection, guidance on identifying students’ alternative conceptions with strategies to bring these closer to accepted scientific knowledge, and guidance for making teachers’ alternative conceptions explicit thus allowing conceptions representing accepted astronomy knowledge to be developed.

3.1.2.1.4 Educative Curriculum Design Employed in the Teachers’ Guide

There is very strong alignment between the design of the Teachers’ Guide and the design heuristics developed by Davis and Krajcik (2005) for designing educative curricula. These
nine design heuristics are discussed in detail in Section 2.6.1. They are re-presented here in summary:

**Design Principle 1: Provide advice to teachers on examining their own pre-existing ideas and beliefs on the topic.**

The Teachers’ Guide encourages teachers to work through the materials as a student to make explicit their beliefs and any alternative conceptions they may have.

**Design Principle 2: Provide advice to teachers on distilling the essential learning for students from the curriculum rationale and goals.**

The Teachers’ Guide helps them to focus their teaching on the essence of each investigation by providing content and guidance on the key concepts covered in each chapter as well as by making learning intentions explicit.

**Design Principle 3: Provide advice to teachers on areas in the curriculum that students typically find difficult to learn including commonly held student alternative conceptions on the topic of study together with strategies to help students move their knowledge to accepted scientific knowledge.**

The Teachers’ Guide helps teachers diagnose students’ alternative conceptions, including by using an Astronomy Diagnostic Test (ADT), and provides guidance on teaching strategies for dealing with them.

**Design Principle 4: Provide sufficient science content knowledge to teachers to ensure they understand the topic and to help develop teacher subject matter knowledge (SMK).**

Each project or Mission includes sufficient science content knowledge to teach the topic and to assist teachers to build on their own knowledge of students’ alternative conceptions (e.g., that the seasons are caused by distance from the Sun during the Earth’s annual orbit). Knowledge of the context and of their students together with knowledge of assessment to select or design appropriate instructional strategies is also provided in each Mission.

**Design Principle 5: Provide advice to teachers on science assessment including the best parts of the curriculum to assess, as well as suggested assessment processes.**

The Teachers’ Guide provides advice for each Project or Mission on assessing student learning for the common alternative conceptions identified using the ADT. In addition, assessment matrices are provided to help teachers to track student-learning outcomes.
**Design Principle 6: Provide advice to teachers on evidence-based instructional strategy selection.**

The Teachers’ Guide provides considerable advice on how to develop and apply evidence-based instructional strategies. A comprehensive list of these strategies is provided in Appendix 3.1.

**Design Principle 7: Provide advice to teachers on holistically applying in the classroom knowledge of instructional strategies, knowledge of student context, assessment selection, knowledge of the curriculum, and personal orientations to science.**

Each Mission develops holistically the teachers’ PCK by making explicit the interconnectedness between teacher knowledge of their students, knowledge of the curriculum, assessment strategy selection, knowledge of their own beliefs about teaching and learning science, and their instructional strategy selection.

**Design Principle 8: Provide subtle advice to teachers that help nurture and strengthen appropriate emotional attributes.**

Constant support and encouragement is provided throughout the Teachers’ Guide with messages of encouragement such as *Don’t panic! Help is at hand*; and the materials abound with advice on where to get assistance.

**Design Principle 9: Apply PCK to achieve growth in student science learning outcomes.**

In addition to improving teachers’ science PCK, the Project materials improve student-learning outcomes in astronomy by developing students’ knowledge, skills, values and attitudes. Matrices are provided to help students achieve the learning intentions.

Equally, the Teachers’ Guide aligns strongly with the elements for developing PCK identified in the combined works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986). This ensures the approach employed in the Project is ‘educative’, assisting teachers to develop their PCK as they frame instructional strategies based on knowledge of their students’ alternative conceptions, knowledge of the assessment strategies that work best for their students, knowledge of the scientific content and knowledge of their own orientations to teaching science.

3.1.2.1.5 Investigative Projects—Guidance for Teachers

This component refers to 32 investigative projects arranged into the eight chapters to assist students to develop astronomy curriculum knowledge, skills, values, and attitudes. A
Journey through Space and Time provides the common theme for linking the 32 student investigative projects. Each Project includes teacher guidance designed to improve their astronomy PCK and student astronomy learning outcomes. A description of teacher guidance provided for each Project is provided at Appendix 3.2

3.1.2.1.6 Design Principles for Investigative Projects

The design principles for the student investigative projects also demonstrate strong alignment between the educative curricula design principles and heuristics devised by Davis and Krajcik (2005). The design principles also show strong alignment with the design principles suggested by Bybee (2006) for improving student science outcomes by linking curriculum to science pedagogy and student learning. These steps require the educative curriculum materials to incorporate the components dealt with below. The following sections address each of these points in turn.

3.1.2.1.7 Preconceptions and Alternative Conceptions

The educative design principles employed in the Project materials provide guidance to teachers on common student (and teacher) alternative conceptions. These are the differing views that students (and teachers) may hold on key astronomy concepts, such as the Earth’s movement around the Sun causes night and day or the Earth orbits the Sun daily or seasons are caused by the Earth’s distance from the Sun. In addition to providing guidance for teachers to identify commonly held student alternative conceptions, the Teachers’ Guide provides advice on developing instructional strategies for bringing about conceptual change so that each student’s science knowledge moves closer to currently accepted science knowledge.

3.1.2.1.8 Major Concepts

The educative materials also provide guidance to teachers on the major astronomy concepts in each of the 32 student-investigative projects that are relevant to the Science Curriculum. Teacher guidance on transferring the concepts to new situations is also provided.
3.1.2.1.9 Explicit Goals

The introduction to each student investigative project makes the learning intentions for the project explicit for the teachers. Accompanying each project is advice on when to use small-group work and on developing student metacognitive or learning-to-learn skills.

3.1.2.1.10 Enduring Understanding

Each student investigative project clearly states what students are required to learn by making explicit the learning intentions for the particular project. For example, Mission 4.1: ‘The Moon Journal’ requires students to record their observations of the Moon over at least 15 days to be able to use their observations to learn what causes the phases of the Moon. In addition the Teachers’ Guide makes explicit for teachers what students will learn from the investigation, such as why the shape of the Moon changes, the definition of earthshine and what causes it as well as strategies for disconfirming students’ (and their own) alternative conceptions.

3.1.2.1.11 Clarity on what will serve as acceptable evidence

Each student investigative project provides clear evidence to the teachers and students on what will serve as acceptable evidence of learning so that students can frame their responses using a variety of scientific literacies supported by ICTs to demonstrate effective learning.

3.1.2.1.12 Clarity on Teaching and Learning Experiences

The investigative projects provide the teacher with guidance on the instructional approaches to employ to ensure that students learn the key concepts and to embody them within the enduring understanding. This guidance includes identifying and dealing with alternative conceptions, guidance on identifying and employing suitable assessment strategies and suitable science content to improve Subject Matter Knowledge (SMK). Davis (2004) defines SMK as, “the topics, facts, definitions, procedures or algorithms, concepts, organising structures, representations, influences, reasons, truths and connections within the area of study and the connections outside of the area of study to other areas” (p. 5).
The student investigative projects and Teachers’ Guide improve SMK by providing key facts, definitions, concepts, and representations for each astronomy mission together with authentic connections to mathematics, technology, art and English.

3.1.2.1.13 Assessment Activities

Each project includes advice on assessing student learning commencing with assessing their prior knowledge, including the alternative conceptions they possess. The projects also include advice on identifying and employing appropriate formative and summative assessment. An assessment matrix detailing the learning outcomes for each mission is provided to allow teachers and students to check regularly on achievement of the learning goals.

3.1.2.1.14 Student Workbook

Students received a workbook organised along the same chapter headings as the Teachers’ Guide, providing the following:

- A detailed outline for conducting each of the 32 projects, including learning intentions for studying the project;
- Facts and content knowledge for the project and the investigation to be undertaken;
- Sequenced learning activities, including assessment activities; and,
- The resources needed to be able to complete each project.

3.1.2.1.15 Multimedia Education Resources

Multi-media education resources are provided on a DVD to support the textual and photographic materials in the Teachers’ Guide and 32 projects. Included in the DVD is a document folder containing guides for accessing the telescope, as well as proformas for recording students’ image processing investigations and a software folder containing planetarium software to locate objects of interest in space in readiness for taking control of the remote telescope. Image-processing software is also included to assist with the processing of photographs taken using the special cameras on the telescope.
In addition, the DVD contains a slideshow folder introducing students to the topic and containing guidance for teachers and students on how to control the telescope and cameras, as well as how to download and process images. An image folder containing a bank of unprocessed images, which students can use for practice to develop their image-processing skills. A movie folder containing a movie showing the telescope in action, an Internet explorer folder, and an Acrobat Reader folder were also included in the DVD.

Finally, the DVD contained a link to access an Internet website with details for accessing the CSU Remote Telescope, together with access for teachers to a chat site to promote social professional teacher learning as well as to provide access to additional resources and contact details for additional support, if required.

3.1.2.1.16 Professional learning

Phase 1 of the Project comprised two forms of professional learning for teachers. These involved the embedded professional learning within the project materials and a more directed form of professional learning delivered face-to-face and via digital technologies.

3.1.2.1.17 Embedded professional learning in the Project Materials

This refers to the educative nature of the materials designed to improve teachers’ PCK by providing guidance on applying the instructional strategies for astronomy projects, knowing their students’ alternative conceptions, employing the most appropriate assessment strategies, implementing the astronomy curriculum content, and gently addressing their personal beliefs and orientations regarding science teaching and learning.

3.1.2.1.18 Directed professional learning.

This refers to the more traditional on-going forms of face-to-face and on-line teacher professional learning that included:

- An intensive one-day professional learning program for teachers from each of the case study sites conducted at a central location. Content included an introduction to project resources, discussion about the constructivist pedagogical approach
employed in the materials, and coaching of the practical, hands-on approaches to be adopted during the teaching of the materials;

- Support from a science educator/researcher from Charles Sturt University; and,
- Ongoing email and telephone support from Professor McKinnon.

A feature of the Teachers’ Guide (2004 2nd edition) design was the inclusion of more projects than a teacher could usually be expected to deliver in the time allotted to science in the curriculum. This deliberate design feature facilitated student and teacher choice concerning which projects to study with suggestions for the sequence. While this provided opportunities for student voice and their interests in the selection of curriculum content, recommendations are made as to which projects should be covered if students get a particular item wrong in the ADT in a direct attempt to deal with their alternative conceptions. Suggestions were also provided to teachers on how to use projects not selected for immediate study including use as extension work, project work or homework.

3.1.2.2 Phase 2 Rural Schools in Victoria

Phase 2 of the study involved making modifications to the Middle Years Astronomy Project resulting from the lessons learned during the Phase 1 implementation of the study. However, the educative-curriculum design of the Project remained the same for Phase 2 of the study. The educative curriculum continued to focus on developing science teacher PCK and improving student astronomy learning outcomes in topics such as the causes of day and night, the causes of the seasons, the Solar System and the Sun and the stars. The underlying theory of student learning and teaching response remained constructivist and based on employing an inquiry, hands-on, investigative design for students and teachers who remotely controlled on-line telescopes in the USA to collect scientific images that provided data for study in class. The theme remained A Journey through Space and Time with the design placing more emphasis on the integrated nature of the astronomy materials with mathematics, technology, literacy and the arts. Two extra missions were included to provide a total of 34 missions.

In addition, educational resources were provided to teachers on flash drives rather than a DVD, a hyperlinked student assessment matrix was provided in Excel spread sheet
software to support teachers’ recording of student learning, and explicit instructions were provided on how to conduct experiments that were illustrated with many colour photographs to assist teachers and students. A full list of modifications in the later version design (McKinnon, 2012) resulting from the lessons learned from implementing the Project during Phase 1 is included at Appendix 3.3.

3.1.2.3 Professional Learning for Phase 2 of the Study

In addition to the professional learning support to develop their PCK in the teaching of astronomy in the educative curriculum, teachers continued to receive direct professional learning support face-to-face via Skype, online with Video Conferencing and email. However, the initial professional learning support consisted of three components.

First, an intensive daylong professional learning experience was structured to explain the Project and its key components. This occurred in the State’s Regional Office. Explanations and discussion covered the constructivist approach to teaching and learning, the content included in the project, and the methodology employed in the student investigative missions. By placing the teachers in the role of learners of the key astronomy concepts used in the missions during the session, they were able to make explicit their own preconceptions, alternative conceptions and science orientations, and they addressed these within the activities they carried out during the day. The experience also included modelling and coaching by the presenter to assist teacher learning on how to set up models, how to elicit and challenge their own and the students’ alternative scientific concepts, and how to get students to test their concepts to arrive at more currently accepted and accurate scientific views while using technology and mathematics.

Second, teachers received instruction on accessing the remote telescope in Wyoming, taking control of it to image objects in the dark sky above the USA and interacting with the operator, removing most, if not all, of their anxiety related to the technology involved. They also interacted with the telescope support person in the USA and came to understand that if anything went wrong, he was there to help (that said—nothing went wrong).
Finally, the mechanics of how to access the further professional support from CSU was provided. The additional support from CSU was provided via video-conferencing, email exchanges and/or Skype sessions. These all included direct access to Professor McKinnon.

3.2 Summary

The driving force for this study lies in investigating strategies to reduce the impact of rural disadvantage on science teachers and their students in rural and remote middle school education settings. One major factor that contributes to education disadvantage for teachers and students in the middle years is limited access to face-to-face professional learning activities that focus on developing teachers’ science PCK in order to improve students’ learning outcomes. Educative curricula designed to simultaneously improve both of these issues provide an alternative means of delivering professional learning to traditional face-to-face approaches. The Middle Years Astronomy Project (McKinnon, 2005, 2012) is one example of an educative curriculum designed to improve primary teachers’ science PCK and student astronomy learning outcomes. This study thus explores the potential of the Middle Years Astronomy Project to ameliorate education disadvantage for rural and remote teachers in the middle years of schooling by improving their PCK. The study occurred over two phases in two states, and targeted middle-school teachers and students in a total of eight rural and remote schools.

For Phase 1 of the study, each participating school received the Middle Years Astronomy Project educative curriculum materials, access to the CSU Remote Telescopes in Australia, as well as an initial one-day face-to-face professional learning activity, support from astronomy specialists, and access to and ongoing on-line professional support. For Phase 2 of the study, each school received an enhanced version of the educative curriculum materials, access to telescopes in Australia and in Wyoming, USA as well as an initial one-day face-to-face professional learning session and ongoing online professional support.

Chapter 4 presents the research questions, justifies and describes the methods used in this study, justifies site and participant selection, identifies threats to validity and outlines the actions taken to minimise these threats.
4 CHAPTER 4 Methods

The purpose of this chapter is to describe and present the arguments for the methods employed in this research, which explored the capacity of the Middle Years Astronomy Project educative curriculum (McKinnon, 2002, 2005, 2006, 2012) to improve teachers’ science Pedagogical Content Knowledge (PCK) in the middle years of schooling in rural and remote settings. This chapter has three major parts. The first part presents the research questions, as well as the rationale for selecting and employing a Type IV Case Study methodology (Yin, 2014) to explore the impact of the Middle Years Astronomy Project educative curriculum on the development of middle-year teachers’ astronomy PCK. The second part of the chapter justifies the choice of sites and participants, describes access to the sites and presents the ethical considerations. The final part of the chapter considers the role of the researcher, data collection procedures, and the threats to the reliability and validity of the study.

4.1 Research Questions

The main research questions this study explored were:

1. Does the Middle Years Astronomy Project have any potential for improving teachers’ science PCK in the middle years of schooling in rural and remote areas, with the concomitant potential to help ameliorate rural education disadvantage?
2. If it does/does not have potential, what are the reasons for this?
3. What, if any, are the implications from this study for supporting science teachers in the middle years of schooling in rural and remote areas to improve their science PCK?

4.2 The Case Study Approach to Research

Yin (2014) points to the rising recognition over the past 30 years of case-study research as a valuable research method and argues that the more research questions seek to explain the how and why of some social phenomena at work. Where the phenomenon being investigated is a contemporary set of events over which the researcher has little or no control, the more that case-study research will be a relevant methodological approach.

Scope

The investigation requires a holistic, in-depth, empirical study in real-life settings of a contemporary phenomenon where the researcher has no control over the behavioural events of the participants in the ‘case’.

Features

Case-study enquiry copes with the technically difficult situation where there will be many more variables of interest to the researcher than data points. As a result of this, Yin (2014 pp. 16–17) argues that the study should rely on multiple sources of evidence with no single source of data having a complete advantage over others. Rather, sources of data might be complementary and can be used in tandem. Using multiple sources of data facilitates triangulation of evidence increasing the reliability of the data and processes for gathering them. Yin (2014) advises that data collection and analysis can be guided from the prior development of theoretical propositions.

Burns (2000), Merriam (1998) and Yin (1994) argue that the case-study approach is particularly relevant when the behaviours that the researcher is seeking to investigate are not open to manipulation and when a rich descriptive real-life account is required to understand the case being investigated. Thus, a case-study approach was particularly suited to this study for the following reasons:

1. This study explored a contemporary issue acknowledged in the literature as difficult to resolve, that is, the teaching of science in the middle years of schooling in rural and remote settings (Chubb, 2012, 2014; Marginson et al., 2013; Productivity Commission, 2007);
2. The study also explored the contemporary and problematic issue of addressing disadvantage by developing teachers’ science PCK when they operate in rural and remote areas (DEECD, 2012; Sidoti, 2000; VAGO, 2014);
3. In setting out to explore solutions to this contemporary issue, the questions of *how* and *why* the educative curriculum may or may not assist in improving teachers’ science PCK were central to the research.

4. In order to explore *how* and *why* the Middle Years Astronomy Project may or may not improve teachers’ *science-teaching effectiveness*, it was necessary to interact with the teachers implementing the Project in the context of their ‘real-life’ settings in schools in rural and remote Australia. Similarly, it was necessary to interact with students in the context of the *real-life* setting of their schools. (Burns, 2000; Merriam, 1998; Yin, 2014);

5. Multiple sources of data, both quantitative and qualitative, provided by teachers and students from multiple sites were necessary to facilitate triangulation of results (Yin, 2014); and,

6. In undertaking this study, the researcher had no control over the operation of the field sites, or the participants/subjects of the study. The sites were schools and the subjects were engaged in their various roles within those schools (Burns, 2000; Merriam, 1998; Yin, 1994).

Expanding on point 5 (above) regarding collecting data from multiple sources, Greene, Garacelli and Graham (1989), Mathison (1988), Rossman and Wilson (1985) and Scholz and Tietje (2002), all argue that a mixture of data derived from qualitative and quantitative sources enhances a case study by:

- Facilitating the triangulation of results;
- Permitting the discovery of overlapping and different facets of any phenomenon to emerge;
- Allowing each set of data to inform the others;
- Unearthing fresh contradictions and perspectives; and,
- Adding scope and breadth to the study.

Consistent with these intentions, this study analysed data derived from both qualitative and quantitative sources at each of the participating sites. Thus, these multiple sites and sources of data allowed a classification of the most appropriate case-study design.

Yin (2014) classifies case-study design on the basis three factors:

- Single or multiple cases;
- Holistic or embedded approach (global or sub-units of study and analysis); and,
- Data gathered and analysed (single or multiple mixed sources of data).
A Type IV multiple-case, embedded mixed-methods design (Yin, 2014, pp. 51–56) was best suited to this study because it explored the efficacy of educative curricula to improve teachers’ science PCK in multiple schools in rural and remote locations, involving embedded units within sites (students, teachers, KLA consultant, administrative officer) and collecting and analysing multiple sources of data.

4.2.1 Summary

This section has provided a rationale for selecting a Type IV multiple-case, embedded mixed-methods design (Burns, 2000; Merriam, 1998; Scholz & Tietje, 2002; Yin, 1994, 2003, 2014) based on:

- The nature and difficulty of the contemporary issue being investigated;
- The need to explore ‘why’ and ‘how’ a social phenomenon works;
- The degree of researcher control over the contemporary events;
- The need to study multiple cases with sub-units; and,
- The need to gather multiple sources of data from ‘real life’ settings.

In providing these cogent reasons for selecting a case study approach to this study, the next section discusses the selection of sites and participants.

4.3 The Choice of Sites and Participants

School year-level nomenclature for each educational jurisdiction is slightly different in the different educational jurisdictions in Australia. In Victorian schools the primary years are designated F–6, with P=Preparatory. At the time of the study in Western Australia, the primary school years were K–7, with K=Kindergarten. Recently, in Western Australia the Year 7 students have been absorbed into high schools to align the structure of schooling with all of the other jurisdictions.

The Australian Curriculum is designed for use by teachers of F–10 with F = Foundation to represent the Preparatory term in Victoria and Kindergarten in Western Australia. In addition, schools can be designated as P or K to Year 6, 10 or 12 depending on the catchment from which they draw their students and the population of the region. Typically, in rural and remote areas with low population density, schools are either K–10
or K–12. This thesis adopts the Australian Curriculum nomenclature of F = the first year of formal schooling: thus, schools are F–6, F–10 or F–12.

The purpose of this section, therefore, is to describe and justify both the selection of the school sites and the selection of participants within them. The section comprises two parts based on the two phases of the research and describes the contexts that gave rise to each phase together with the reasons for site and participant selection.

4.3.1 Phase 1 of the research

The context for Phase I of this research was an Australian Telescope National Facility (ATNF) led project, *Wildflowers in the Sky* that gained Federal funding under the Australian Schools Innovation in Science, Technology and Mathematics (ASISTM) scheme. The ATNF was a division of the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The ASISTM project aimed to bring about real and lasting improvements to the teaching of science, technology and mathematics in schools (Tytler, Syminton, & Smith, 2009).

At that time, Australia was bidding competitively to host the Square Kilometer Array (SKA) Telescope. The SKA will be the largest radio telescope in the world with a collecting area of one square kilometre: hence its name. The Mid-West region of Western Australia emerged as the leading Australian site because of its lack of radio interference. In addition to the SKA, the Mid-West region is the region for the development of the MIRANdA and the MIRA Wide-field Array radio telescopes that are both test devices for the larger SKA project. Both the ASISTM and SKA projects had educational objectives. While the ASISTM project’s key objective was to improve school Science, Mathematics and Technology, one of the SKA project objectives was to make available data for educational purposes. Importantly, the region in Western Australia where the SKA was to be built lies on Aboriginal Traditional Lands and education support for schools in the region was seen as an important component of building high quality community links. Given the radio-quiet nature of the region, the reader should understand that the population density is extremely low, approximately 200 people in almost 50,000 square kilometres of dry
country, with very few towns or schools. It is a large distance from the state capital of Perth (750 km) over roads that can be problematic in adverse weather conditions.

The *Wildflowers in the Sky* ASISTM project was a collaboration between the ATNF, the Western Australian Department of Education and Training, the SciTech Discovery Centre, the Department of Industry and Resources (DOIR), five schools in the areas closest to the proposed SKA core site, and Charles Sturt University (CSU) in NSW. With its focus on astronomy, and part of the science curriculum in all jurisdictions at the time and subsequently part of the Australian Curriculum, the ASISTM project involved 26 teachers and about 700 primary and secondary students working together with astronomers and educators to improve teacher pedagogy and expand students’ understanding of astronomy. Professor McKinnon headed the CSU research team in which the researcher was a member.

As part of the ASISTM project, teachers were required to assist students to implement hands-on activities and engage in inquiry-based learning to observe such things as the day and night sky using a range of technologies from the unaided eye, to remotely controlled telescopes via the internet, including the CSU Remote Telescope located in Bathurst, NSW. The resources provided to support teachers comprised the version of the materials described in Chapter 3 and were modified slightly for the Middle Years Astronomy Project being implemented in this remote region.

Teachers and students also had the opportunity to work with young scientists from the ATNF who, in part, acted as role models. This was consistent with Goodrum et al.’s (2001) advocacy for science teachers to use the expertise of practicing scientists in their science lessons. In addition to tapping into the expertise of these scientists, this strategy sought to debunk stereotypical myths on the work of scientists (e.g., that all scientists wear white lab coats and work with microscopes, test tubes, mice and chemicals).

A key component of the ASISTM project was the development and delivery of effective professional learning for the teachers in the isolated and collaborating schools. Professor McKinnon, representing the CSU partner, was engaged to support ATNF to deliver this
component as well as to oversee the research. An initial teacher workshop, *Astronomy in your Classroom and Beyond*, was held in a regional centre proximal to the collaborating schools, attracting more than 20 teachers from those schools and from schools as far away as Perth. It was proximal only in the sense that there was nothing else between the five schools and the common location. All teachers in the other four schools had to travel varying distances up to 450 km or the 660km for a few participants from Perth who had heard of the project.

One of the collaborating school sites also hosted a second professional learning day. In addition, the ATNF Education Officer (also an astronomy educator) and two astronomers spent a week visiting the ASISTM partnering schools. Students met with the scientists and took part in daytime and nighttime astronomy activities. As part of the ASISTM project, each school received an eight-inch reflecting telescope for nighttime viewing, and a sun spotter telescope for observing the Sun safely and for recording locations of sunspots during the day.

The involvement of CSU in the ASISTM project provided the opportunity for the researcher to work with the ASISTM partnering schools as a CSU Co-Investigator. In this way, the researcher was able to explore the potential for an approach based on using the Middle Years Astronomy Project to improve the middle-school teachers’ science PCK in these remote locations.

The ASISTM project was thus the key-determining factor in determining site selection. Each of the partner sites were invited by the researcher to participate in the present study to explore the issues related to implementation of the Middle Years Astronomy Project (the Project) in their schools. However, a second factor was at play that could have augmented the choice of ASISTM Project schools if required. This was the influence of the literature in profiling common elements of rural and remote sites (ACER, 2011; ASPA, 2006; NT DET, 2014; Lyons, 2006) by helping to frame a search for such sites. Indeed, all of the following features were present in the ASISTM sites. In many ways, they epitomise a representative sample of Australian rural/remote schools:
• Remoteness from the capital city, the regional service centre and from other surrounding schools;
• A middle-school structure catering for both primary and secondary students that facilitated easier exploration of science in the middle years of schooling;
• High staff turnover and challenges in attracting and retaining teachers, including science teachers;
• A high proportion of teachers and leaders in the early stages of their career;
• A high proportion of staff with little or no experience or training in teaching science;
• A significant proportion of students with an Aboriginal background;
• A high degree of student absenteeism; and,
• Few, if any, relief teachers able to support education program continuity as well as release of teachers to engage in professional learning activities.

Driving participant selection was the need to derive data from subjects engaged in the process of implementing the Project in the real context of their schools and classrooms. This meant inviting participating teachers and leaders who would implement the Project as well as a sample of students who were to experience it. The student sample was important to explore the impact of the Project on the development of students’ learning outcomes. Each of the sites involved in Phase I of the research, together with participants, are described below in order to provide a clear rationale for selection and sufficient details of each case-study context to allow the reader to appreciate the researcher’s sampling choices.

4.3.1.1 Site 1: F–12 School

This school catered for students from Kindergarten to Year 12 (Year 7 was the final year of primary school in WA until 2014). The school had a total enrolment of 180 students at the time of the study with the majority being primary-aged Aboriginal students. The school’s enrolment trend was downward. The school was located 800 kilometres from Perth and 370 kilometres from the nearest regional population centre (population 37,000 people).

The school had a staff of 20, including the principal, all of who were in the early stages of their career (i.e., all had been teaching or in a leadership position for three or fewer years). The participants who agreed to take part in the study at this site were either directly engaged in implementing the Project or supporting it, viz., the principal, a middle
manager and the teacher coordinating the science curriculum delivery within the school. In addition, the seven students from the science coordinator’s class were invited to participate in the study.

4.3.1.2 Site 2: Primary School expanding to include Years 8–12

This school was located 658 kilometres from Perth and approximately 230 kilometres from the nearest regional centre of 37,000 people. The school had an enrolment of 23 students in Years F–7 and 10 students in Years 8–10. The vast majority were Aboriginal students. The school had a staff establishment of a principal, 3.30 classroom teachers, a registrar, two Aboriginal and Islander Education Officers (AIEOs), an Education Assistant, a library officer and a gardener. The principal was in his third year at the school and two of the teachers had been teaching for fewer than three years.

At this site, two of the classroom teachers agreed to participate and the principal directly supported them during implementation of the Project. In addition, a sample of students (N = 3), from one of the participating teacher’s classes, were invited to participate in the study.

4.3.1.3 Site 3: Distance Education Provider: School of the Air F–7

This School of the Air is located 775 kilometres from Perth, and approximately 535 kilometres from the same regional centre as the first two schools. At the time of the study, the school had an enrolment of 49 students from F–7 with the great majority of the students living on isolated cattle stations. The staffing establishment, appointed on the basis of merit, consisted of the Principal, six full-time teachers, a Library Support Officer and a Registrar. In addition, the school had a Special Teacher Learning Support to assist staff in developing programs specifically suited to the individual needs of students in their isolated locations. The school also relied on Home Tutors (a parent or governess) to supervise the students as they worked in their home locations, to help organise the distance education materials, and to play an active role as a tutor of the student. Those who elected to take part in the study were the principal, the Year K–3 classroom teacher, the Year 4–7 classroom teacher and a student from each teacher’s class. One teacher who
also worked in a teacher-support role was the music teacher who collaborated with the K–3 class teacher to form a Year 3–6 Science Club.

4.3.1.4 Site 4: Middle-Years College Years 8–9

This school was a purpose-designed middle school for students in Years 8 and 9 with an enrolment of 652 students drawn from the regional centre, smaller schools in surrounding areas and boarders from isolated schools. The maximum capacity for boarders was 120 students. The student enrolment trend inferred from the staff establishment of the school showed a slight decline. At the time of the study, 24% of the enrolments were Aboriginal students. This school was located approximately 420 kilometres from Perth, in the regional centre referred to above.

At the time of the study, the College had a leadership team of a principal and three assistant principals. At the middle leadership level, the school had seven heads-of-learning one of whom was the Head of Learning Area: Science, and a Student Services Coordinator. The school had a total of 53 Classroom Teachers, 20 Support Staff (Lab Assistants, AIEOs, Computer Technicians etc.), 10 Administrative Staff and three Specialist Staff (Psychologist, Nurse and Chaplain).

4.3.1.5 Community School F–7

This Community School was located 753 kilometres from Perth and approximately 330 kilometres from the regional centre referred to above. Road conditions and access were subject to weather condition, with flash flooding making it four-wheel drive access only during the cyclone season (November–April). Regrettably, during the first visit to the area, the researcher was unable to visit the site due to road closures resulting from the passage of a tropical cyclone close to the area. On the follow-up visit, the researcher was similarly unable to go through because of road closures due to bad weather.

The school is an integral part of an Incorporated Aboriginal Community and provides education for the community and employment for some of the community members. The school had two classrooms for the 20 students from F–12. In common with many of the
remotes sites described above, this site lacked teachers who identified as having any background, experience or specific training in teaching astronomical concepts or in teaching science more generally.

The inability of the researcher to visit this remote site meant that it had to be excluded from the analysis. However, it demonstrates the remote and isolated conditions in this part of Western Australia under which the teachers have to conduct their craft and the difficulties they encounter in accessing any professional learning programs.

4.3.1.6 Summary

Of the five sites invited to participate in Phase 1 of the Project, four took part with one having to be excluded due to an inability to reach the school because of poor weather conditions. Table 4.1 summarises the remaining four sites by structure, type, participants, and location. Table 4.1 shows the following participants provided data for Phase 1 of the study: four Non-Teaching Principals, one Middle Manager, nine Teachers and 261 Students.

Table 4.1: Phase 1 Participating Sites by Structure, Participants, and Location.

<table>
<thead>
<tr>
<th>Site Structure all Public Co-educational</th>
<th>Participants</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. F–12 School</td>
<td>Non-Teaching Principal 1 Middle Leader 1 Teacher 1 Teacher 2 Students (n=7)</td>
<td>Remote</td>
</tr>
<tr>
<td>2. F–12 School</td>
<td>Non-Teaching Principal 2 Teacher 3 Teacher 4 Students (n=3)</td>
<td>Remote</td>
</tr>
<tr>
<td>3. Distance Education Provider F–7</td>
<td>Non-Teaching Principal 3 Teacher 5 Teacher 6 Students (n=2)</td>
<td>Remote</td>
</tr>
<tr>
<td>4. Middle Years School Years 8–9</td>
<td>Non-Teaching Principal 4 Teacher 7 Teacher 8 Teacher 9 Students (n=261)</td>
<td>Rural Provincial, 1.7 hours flying time from Perth</td>
</tr>
</tbody>
</table>
After the end of Phase I of the investigation, the researcher moved from being employed by the Federal government to a senior position with the Victorian Department of Education and Early Childhood Development as a Regional Director.

4.3.2 Phase 2 of the Research

During Phase 2 of the research, the researcher held a key leadership role as a Regional Director. The regional profile (182 schools and 230 childcare settings) included schools in regional centres with large student populations in excess of 1000, rural towns with student populations that varied from between 200 and 400, and small settlements with enrolments of 120 or fewer students (70 in total). Of these 70 schools, 48 had 52 or fewer students. These are described as ‘small rural schools’.

Lifting the performance of students in the schools was a strategic priority for the region, with Department of Education and Early Childhood Development (DEECD) NAPLAN literacy and numeracy achievement data demonstrating a wide variation in achievement scores. Indeed, the distribution of student results showed a skew toward the lower achievement bands for Years 3, 5 and 7, the grades from which the data were collected. Specialist Key Learning Area (KLA) and cross-curriculum consultants formed part of the resource base to help lift school-achievement data in the region. One of these was a specialist Science KLA Consultant who provided support to the schools including science curriculum, assessment and pedagogical advice, teaching and learning resources and professional-learning support designed to improve science curriculum outcomes based on the AusVELs (Victorian) science curriculum (DEECD, 2012, 2013). The professional-learning support included provision of traditional face-to-face professional-learning experiences, online support and mentoring and direct coaching during school visits.

Following an approach from the science consultant seeking ideas for improving science teaching and student learning outcomes in the region’s priority area of the isolated small rural schools, strategic discussion around the middle years of schooling linked improving science teaching and student outcomes with improving literacy and numeracy outcomes. This called for a cross-curriculum approach focusing on science, literacy and numeracy.
This brought the Middle Years Astronomy Project into the discussion with the researcher’s knowledge of the ability of this approach to achieve the strategic outcomes that the consultant was seeking.

Following lengthy discussions, agreement was reached for the Science Consultant to identify a cluster of small schools to implement the Project on a voluntary basis. Such a cluster was identified in the relatively isolated alpine region of North East Victoria. The sites that were invited by the Science Consultant to participate in this study were five small rural primary schools and located approximately 250–300 kilometres from the state capital, Melbourne. All were approximately 50 kilometres from the nearest regional centre with a population of approximately 28,000 people.

With the Science Consultant managing the day-to-day implementation of the Project, site selection preceded a change to the extant ethics approval to conduct the research. Following the Science Consultant securing agreements from the principals to implement the Project in their schools, the researcher subsequently sought ethical approval to collect data and approval from Principals to use and collect photographs and video. All approvals were granted by CSU Ethics in Human Research as an amendment to the original approval for the Project in Western Australia and by the Principals.

While there may be a perceived power imbalance between the researcher’s position of authority within the region and the authority of the principals invited to participate in the study, in reality this is not the case. Principals in Victorian Public schools have enjoyed a high degree of autonomy relative to the principals of schools in other states and territories in Australia for over 25 years. With this autonomy comes devolution of authority covering a range of policies and practices such as selection of staff, whole-school budgeting and financial management based on an allocated amount for each student, choice of curriculum materials to support the achievement of AusVELS outcomes and, approving expenditure on staff attending professional-learning courses. Principals have absolute delegation on matters affecting their schools including determining involvement in research and they exercise this delegation carefully, especially in small schools where
the demands on both teaching principals and teachers is greater than in larger schools where there is more capacity to share the workload.

In exercising these devolved powers to participate in this study, one principal elected not to participate. Not long afterwards, on the retirement of this principal, the school’s new principal did decide to implement the Project. This school, however, is not part of the current study. Another exercised her power to determine both the pace of implementing the Project and decided not to access the remote telescope in the USA. Three principals chose full participation in the study. Thus, while a total of five schools were invited to participate, four participated to a greater or lesser extent with one school electing not to participate at all in the study.

In accord with policy to support all KLA Consultants who could implement new regional initiatives, the Assistant Regional Director, Teaching and Learning allocated a budget of $30,000 from regional funds to the Science Consultant to support the Project. This was mainly to cover the small cost of accessing the SkyTitan telescope in Wyoming, USA and the cost of teacher relief for professional learning in relation to implementing the Middle Years Astronomy Project. These costs amounted to US$5,000 and Au$2,100 respectively, with the balance of funds being returned to the regional initiatives budget to fund other approved regional KLA initiatives. Thus, the total cost of this initiative was less than $7000 due to a favourable exchange rate with the American dollar at that time. Professor McKinnon provided his services at no cost.

Although each school and cluster is unique, the sites who volunteered to participate in this study had much in common with other small schools and clusters in the region, as well as in other parts of Victoria, NSW and the NT with which the researcher is familiar. Such characteristics include the following features.

- Relative rural isolation;
- The schools serve small settlements, surrounding farms and hamlets, and are the focus of the community both educationally and socially. They usually enjoy strong community involvement;
• Student populations are fewer than 52 enrolments and structured on a Years F–6 basis. Within the F–6 structure, the school usually has two teaching spaces with Years F–2 in one and Years 3–6 in the other and a principal who teaches. Principals in these schools also perform the same administrative duties as those with much larger student enrolments and greater administrative and leadership support. They also have responsibility for teaching the students in one of the two multi-level classrooms;
• In belonging to a cluster of schools, principals and staff work cooperatively to share teaching programs, professional learning, staff, students and community expertise;
• The schools tend to have a relatively stable and experienced staff (i.e., teachers and principals have considerably more than five years teaching experience, often in the one school);
• The student profile is usually one with a low frequency of Non-English Speaking Background or Aboriginal students; and,
• Unlike remote WA and the NT, there is a supply of casual relief teachers available who can cover both unforeseen and planned teacher absences.

The need to access those involved in directly implementing or supporting implementation of the Project drove participant selection. Teaching principals and staff accepted the invitation to participate in the study. In addition, a sample of students from participating schools were invited, and also agreed, to participate in the study. Students provided a view on implementation from their perspectives. The following sections describe the sites that participated on a voluntary basis in Phase 2 of the Project.

4.3.2.1 Site 5: Primary School F–6

This site was a small rural school of 36 students located approximately 300 kilometres from Melbourne and 50 kilometres from the nearest rural centre with its population of approximately 28,000 people. The school is a focal point and resource for the small rural community it serves.

The school staff included a Year F–2 teacher, a Year 3–6 Teaching Principal, a Literacy/Numeracy intervention teacher (0.2 EFT), and a music teacher (0.4 EFT). Various other teachers provide private instrumental lessons to extend the curriculum offering.
Integration Aide (0.4) supports the students with special needs. An office manager provides administrative support to the Principal. In addition, the Principals of the five sites who were involved in Phase 2 of the Project had previously agreed to fund jointly a 0.2 EFT staff position (Cluster Coordinator) who was employed to provide support and to coordinate cluster activities. Participants who elected to take part in the study from this site were the Teaching Principal and the Year F–2 teacher. In addition, the Science KLA consultant and Cluster Coordinator also participated in the study.

4.3.2.2 Site 6: Primary School F–6

This site had an enrolment of 30 children across Years F–6 at the time of the Project, with the great majority of children travelling to school from surrounding properties and hamlets. The school was located approximately 280 kilometres from Melbourne and 30 kilometres from two rural centres with populations of approximately 9,500 and 28,000 people. At the time of the Project, the school had two full-time teachers, one of whom was the part-time Teaching Principal who, when undertaking administrative duties was replaced by one of the other two part-time teachers, two integration aides and an office manager. The participants from this site were the Teaching Principal who taught the Year 3–6 class and the Science Consultant.

4.3.2.3 Site 7: Primary School F–6

This primary school, located approximately 310 kilometres from Melbourne and 50 kilometres from the nearest rural centre with a population of approximately 28,000 people, had an enrolment of 14 students in Years F–6 at the time of the research. The school’s staffing component comprised one part-time and two full-time teachers. One of the full-time teachers was the part-time Teaching Principal. The school also had a business/ administrative support staff member. In addition, the school benefitted from visiting Art and Library Teachers, as well as a visiting Technology assistant. The 0.2 EFT Cluster Coordinator was located at this school. Participants at this site were the Teaching Principal the one student in Year 5–6, the Science Consultant and the Cluster Coordinator supporting the Project.
4.3.2.4 Study Site 8: Primary School F–6

This school was located approximately 280 kilometres from Melbourne and 45 Kilometres from the nearest regional population centre of approximately 28,000 people. At the time of the study, the school had an enrolment of 27 students across Years F–6 with two full-time teaching staff (one teaching Years F–2 and the other Years 3–6) and a part-time Teaching Principal who also took on the duties of student integration. The participants from this site were the teaching principal, the teacher implementing the project, seven Year 3–6 students. In addition, both the Science Consultant and the Cluster Coordinator also participated.

4.3.2.5 Site 9: Primary School F–6

This site, originally chosen by Science KLA Consultant, was located approximately 280 kilometres from Melbourne and 26 kilometres from the nearest regional centre of approximately 28,000 people. The school had an enrolment of 44 students with a staffing component of a part-time Teaching Principal 2.4 teaching staff and a 0.5 EFT Business Manager. The enrolment trend for the school was significantly down from previous years and with a declining trend over the longer term.

The Principal, however, elected not to participate in this study and thus no data were collected. It is interesting to note, however, that a short time later, the principal had to retire and was replaced though merit selection by the Science Consultant who did choose to involve the school in using the curriculum materials supplied in the Project but did not supply any data because it was outside of the data collection period.

4.3.2.6 Summary

Of the five schools invited to participate in Phase 2 of the study, four agreed to do so in whole or in part. Table 4.2 summarises the participating sites by structure, type, participants and location. Table 4.2 shows the participants who provided data for Phase 2 of the study: four Teaching Principals, one KLA Consultant, One Cluster Coordinator, three Teachers and seven Students.
4.3.3 Summary of all Participating Sites and Participants

This section has presented an overview of the eight sites that agreed to participate in the two phases of this study. The study involved eliciting data from 12 teachers, four principals, four teaching principals, one Science KLA consultant, one Cluster Coordinator and over 200 students. The eight schools and their locations, with a breakdown of their participants who supplied data, are summarised in Tables 4.1 and 4.2 above.

Having selected the methodology described in Section 4.2 to investigate the research questions with the sites and participants described in this section, the next consideration was gaining access to the sites and ensuring adherence to the principles for the conduct of ethical research. The next section discusses both access to the sites and the ethical considerations involved.
4.4 Access to the Sites and Ethical Considerations

The purpose of this section is to describe the processes used to gain access to the eight case study sites and to the subjects or participants involved in this study. Each of the two Phases involved different processes that are described below.

4.4.1 Phase 1

As indicated in Section 4.3.1 above, the involvement of researchers at Charles Sturt University (CSU) and their participation in the ASISTM funded *Wildflowers in the Sky* project provided an opportunity for the researcher to work with the partner schools that chose to implement the Project in Phase 1 of the study. A major element of support delivered to the collaborating schools was in the form of The Middle Years Astronomy Project materials, authored by Professor McKinnon, which provided a direct link between the ASISTM project and this study.

The researcher was included as part of the CSU partnership team in the ASISTM project as a Co-Investigator. CSIRO’s Australia Telescope National Facility (ATNF) had obtained approval to conduct research from the Department of Education in Western Australia for all partner schools in the ASISTM project. The researcher and the members of the CSU investigating team were included in this approval.

In order to participate, the researcher had sought approval from the Ethics in Human Research Committee at CSU to conduct the research project: *Ameliorating Educational Rural Disadvantage for Science Students and Teachers Using an Approach to Science Teaching based on the Eye Observatory Remote Telescope Project* (later termed the *Middle Years Astronomy Project*). The EHRC Protocol number is 2006/226, a copy of which is in Appendix 4.1. In addition, a condition of working on the *Wildflowers in the Sky* ASISTM project imposed by ATNF was possession of a Working with Children Check that involved clearance from the Australian Federal Police. Clearance was obtained prior to visiting the sites (see Appendix 4.2).
On receipt of the appropriate clearances, the researcher sent letters to each of the principals. The letters sought approval to enter the sites to conduct research in accord with the standards set by the CSU Ethics in Human Research Committee for the protection of the rights of human subjects participating in research. The letters also introduced the researcher, provided an outline of the research, made clear that participation was voluntary, and that the school and participants could withdraw at any time. The letter stressed that the anonymity of participants would be maintained at all times in all aspects of the research, particularly when outlining research findings (see Appendix 4.3). All principals responded positively and reiterated their support for the Project and for the research to be conducted.

Follow-up contact occurred with each principal by telephone and email to explain personally the purpose of the research in greater detail, to reiterate the CSU ethical conditions under which the research was being conducted and to provide details of the Ethics Approval and the Working with Children Check documents. In addition, each principal’s support was sought to provide a date for a site visit, to identify suitable subjects to be interviewed (teachers as well as students) and to help facilitate permission from parent/care-providers for any students aged 14 years and under who voluntarily agreed to be interviewed (see Appendix 4.4). All participating principals provided dates for site visits and facilitated approval of parent/care-givers for students volunteering to provide data for the study.

Teacher interviews took place on the proviso of them being able to withdraw from their class at any convenient time to maintain the confidentiality of their responses and with the added assurance of their anonymity being maintained when referred to in this thesis. Principals at all sites gave their approval for the researcher to approach any other staff member in order to elicit additional information for the research as the Project unfolded if there was an emergent need to pursue lines of inquiry that had not been anticipated. Student interviews occurred on the same basis as teacher interviews. That is to say, they occurred in a public place but one in which confidentiality of response was assured.
4.4.2 Phase 2

The motivation for implementing the Project in Phase 2 of the research came from the desire to look at alternative ways to support rural small schools to deliver a science curriculum and to have that science curriculum contribute to the improvement of literacy and numeracy outcomes. Selecting the Project was therefore an agreed strategic decision between the Science Consultant and the researcher. The Science Consultant managed the day-to-day implementation of the Project.

While the researcher had delegation to conduct and commission research and to introduce evaluations and inquiries designed to improve student-learning outcomes in the region’s schools and early childcare settings, he elected not to choose this path. Instead, he elected to seek approval from the Performance and Evaluation Division, DEECD Victoria to conduct the research. Approval was granted.

In addition, approval from participating principals was necessary under the Victorian DEECD as principals have delegation on most matters affecting their schools, including participating in research. Seeking approval from principals, as with Phase 1 sites, involved making principals aware that participation was voluntary and the school and subjects could withdraw at any time. Principals were made aware of the conditions governing anonymity of participants, particularly when outlining research findings. Three of the principals agreed to participate fully in the study with one declining the invitation and another principal deciding to participate partially in the study.

Teachers invited to participate in Phase 2 of the research did so on the same basis as teachers taking part in Phase 1, that is, being able to withdraw at any time and with conditions of confidentiality and anonymity applying. All teachers approached agreed to participate in the study. Principals also gave permission for the researcher to view student work samples, including any student-made videos, as well as permission to use photographs and videos in this thesis. The Science Consultant and the Cluster Coordinator also agreed to participate in the study on the same basis as the teachers.
4.5 The Role of the Researcher

This section deals with the role of the researcher during this study and provides information on the beliefs of the researcher in Section 4.5.1. The researcher’s experiences in conducting research are considered in Section 4.5.2 and the role of the researcher during the study is presented in Section 4.5.2.1.

4.5.1 Beliefs relating to this study

As indicated in Section 3.1, as part of the contextual background to this study, the researcher has first-hand experience of working in senior-educational and public service roles in rural and remote regions of NSW, NT and Victoria. This helped to cultivate beliefs that rural and remote students and teachers face educational disadvantage because of their distance from regional and metropolitan centres. Sidoti (2000) claimed that disadvantage rose almost in direct proportion to their distance from such centres. One element of this educational disadvantage is access to a full curriculum that builds productive citizens with democratic values and the knowledge, skills, values and attitudes required to thrive in knowledge-based economies. Supporting these beliefs, as discussed in Sections 2.2.7, 2.2.8 and 2.2.9, is a comprehensive literature base describing and accounting for rural educational disadvantage along with a wealth of national, international and jurisdictional education assessment data highlighting significant performance gaps between students in rural and remote locations compared with their peers in metropolitan locations. (Australian Council of Australian Governments (COAG), 2013; Commonwealth Senate, 2009; National Assessment Program-Scientific Literacy (NAP-SL), 2003–2012; OECD PISA, 2004, 2012; Sidoti, 2000; TIMSS & PIRLS-2011, 2012; VAGO, 2014).

Both the research literature and national assessment data indicate that science teachers do not deliver adequately the Australian Curriculum in Science to all rural and remote students irrespective of location. The researcher holds beliefs that this further compounds the extant rural disadvantage and that the search for solutions to this problem involves using approaches that:
• Acknowledge, and provide strategies to address, the issue of rural education
disadvantage during teacher preparation;
• Recognise the challenges facing teachers in rural and remote areas of Australia in
shifting student achievement curves positively by, for example, providing solutions
through non-traditional face-to-face professional learning approaches;
• Implement a career-long approach to developing teacher Pedagogical Content
Knowledge (PCK); and,
• Provide certainty in documentation involving policy and procedures, including
strategic plans, curriculum documents and educative professional learning
materials when staff members are unable to provide that certainty through
corporate knowledge due to high teacher turnover.

While the efficacy of the Middle Years Remote Telescope Project to improve science
teacher PCK in the middle years of schooling in rural and remote settings remained
uncertain at the outset of this study, it is fair to say the researcher held beliefs that the
ability of properly designed and implemented educative curricula to develop PCK was an
area worthy of investigation.

4.5.2 Experiences in conducting research including collecting and analysing data

From 1993 to 2000, the researcher’s role included conducting investigations, inquiries and
evaluations of all aspects of schools’ operations in various NSW DET organisational
settings at cluster, district, region and state levels for the purposes of improving student-
learning outcomes. This required the NSW DET to provide training in interview techniques
and well as in conducting investigations, reviews and evaluations.

From 2000 to 2010, the researcher’s role included conducting investigations, reviews, and
evaluations at the Federal level. In addition, the role involved conducting financial
compliance monitoring as well as the monitoring of key performance indicators in publicly
and privately funded organisations involved in early childhood, school, employment-
training and tertiary education that were in receipt of any Australian Federal Government
funds. In several cases, monitoring led to investigations and in some cases cancelling of
contracts. In extreme cases, investigations led to criminal prosecutions. Building capability
to perform these functions effectively was a key component of the researcher’s ongoing professional learning and training.

From 2010 to 2014, the researcher resumed the role of monitoring the performance of schools and early childcare settings in a Victorian DEECD region. This regularly led to research investigations being undertaken. The role also included evaluating targeted early childhood and school interventions. Ongoing professional learning experiences featured prominently in the skill sets acquired during this time.

4.5.3 Role during the research

The role of the researcher in Phase 1 of the study was both to conduct the research by co-investigating the implementation of the Middle Years Astronomy Project at the partnering school sites and to feed-back any concerns from the intervention sites to his principal supervisor to assist in the implementation process. The latter role involved providing solutions to implementation issues facing principals and teachers during site visits and from ongoing communication with schools.

During Phase 2 of the study, the Science Consultant took on the role of providing implementation advice to schools and of managing the Project as a regional initiative. In addition, some principals requested and received implementation advice directly from Professor McKinnon. The researcher’s role involved conducting the research and liaising regularly with the Science Consultant to discuss the progress of the Project.

Having selected both a case-study methodology for this study and the sites and subjects, as well as having considered the role of the researcher and dealt with the ethical issues for conducting this research, the next consideration was the collection of data in an attempt to answer the research questions. Section 4.6 describes the data collection procedures.

4.6 Data Collection and Analysis Procedures

The purpose of this section is to describe and justify the data collection procedures employed in this study and to explore the three main questions as outlined in Section 4.1. In summary these are:
1. Does the Middle Year’s Astronomy Project have any potential for improving teachers’ science PCK in the middle years of schooling in rural and remote areas, with the concomitant potential to help ameliorate rural education disadvantage?

2. If it does/does not have potential, what are the reasons for this?

3. What, if any, are the implications from this study for supporting teachers in the middle years of schooling in rural and remote areas to improve their science PCK?

The Middle Years Astronomy Project ran for approximately one term (approximately 10 weeks) during each Phase of the study with site visits occurring during implementation to gather data. In addition, follow-up visits and communication occurred following implementation to allow further probing by the researcher and to allow time for reflection by participants involved in the study. To help investigate potential answers to the research questions, Section 4.6.1 outlines and summarises the data collection instruments used in the study while Section 4.6.2 provides descriptions of the data collection instruments and outlines how the instruments were used to gather data.

4.6.1 Sources of Evidence

Yin (2014) argues that the most commonly used sources of evidence in case study research include:

- **Documentation** relevant to the case study with the major functions of data collected being to provide information and to corroborate and to augment evidence from other sources;

- **Archival records** relevant to the case study with the major function of data collected being to corroborate and augment evidence from other sources;

- **Interviews**, described as “The most important source of case study evidence” (Yin, 2014, p. 110) that may take the form of prolonged case study interviews (over two hours duration); shorter case study interviews (up to one hour’s duration) or survey interviews with the major functions of data collected being to provide insights into phenomena being studied and to corroborate findings;

- **Direct observations** in the real world setting of the case with the major function being to observe relevant social and environmental factors that can help to provide additional information concerning the topic being studied;
• **Participant observations** where the researcher is not merely a passive observer but rather a participant in the actions being studied with the major function of data collected being to perceive reality from the point of view of someone inside the study; and,

• **Physical artefacts** relevant to the case study with the major function of data collected being to collect physical evidence related to the study to supplement other data.

In addition to these most commonly used sources of evidence, Yin (2014) advises that a complete list of sources of evidence can be quite exhaustive and include films, video clips and photos. Given the multiple potential sources of evidence to support case studies, Yin (2014) cautions that no single source of evidence has an advantage over any of the other sources and counsels the researcher to obtain evidence from multiple sources from which to derive findings for their study. Greene, Garacelli and Graham (1989), Mathison (1988), and Rossman and Wilson (1985) argue further that in addition to obtaining these, a mixture of both qualitative and quantitative data enhances a case study.

In the Middle Years Astronomy Project, the materials suggested that teachers should probe their students’ alternative conceptions about celestial phenomena before they begin teaching the content. This probing takes the form of the Astronomy Diagnostic Test (Danaia & McKinnon, 2008; Deming & Hufnagel, 2000; Hufnagel, 2002; Slater, Hufnagel & Adams, 1999), which is designed to be administered and marked by the teacher. This assessment of students’ alternative conceptions is designed to provide guidance to the teacher as to what content they should consider covering with their students to address the relevant outcomes of State or National Curricula. It was also suggested in the Project that the same questionnaire could be administered again at the end to see how students’ conceptions had changed.

Given the nature of such data, the researcher had intended to seek access to the information the diagnostic test generated as it had the potential to provide important quantitative data on students’ developing understanding of astronomical ideas. Access to these data did not always happen. In some cases, full sets of pre– and post-intervention
data were assiduously collected and forwarded to the researcher by the implementing teacher while in others it was not collected at the end, or it was lost or misplaced in the chaotic environments that characterise the day-to-day operation of a school by time-poor teachers. This paucity of ADT data was despite many telephone calls and emails to teachers at the participating sites.

The nature of this study also required investigating the reactions of science teachers, students and other individuals or groups in the rural and remote sites as they implemented aspects of the Middle Years Astronomy Project. As it was neither practical nor possible for the researcher to become a participant in this process, therefore, no formal data (from being a participant observer) was gathered. This is not to say that such observations were not possible during site visits. Inevitably, they were and were noted. Nonetheless, planned visits to the sites were undertaken and, during these, both formal and informal interviews were conducted with the various individuals who included: principals, other school leaders, assistants, students and more rarely with parents who happened to be present.

Thus, following the advice of Caracelli and Greene (1997), Greene, Caracelli and Graham (1989), Mathison (1988), Merriam (1998), Rossman and Wilson (1985), and Yin (2014), this study generated data on the implementation of the Middle Years Astronomy Project over two phases from a variety of sources. A rich set of data, while not exhaustive, was collected from sources such as documentation, archival records, interviews, direct observations and artefacts, as well as other qualitative and quantitative sources as suggested by Merriman (1985), and by Scholz and Tietje (2002). A summary of the data sources collected for Phases 1 and 2 of the study is presented in Table 4.3.
Table 4.3: Summary of Sites, Participants and Data Sources for Phases 1 and 2

<table>
<thead>
<tr>
<th>Site</th>
<th>Participants</th>
<th>Sources of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1 F–12 School</td>
<td>Teacher 1, Teacher 2, Principal 1, Leader 2, Students (N=7)</td>
<td>Teacher Interviews, Principal Interview, Middle-School Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
<tr>
<td>Site 2 F–12 School</td>
<td>Teacher 3, Teacher 4, Principal 2, Students (N=3)</td>
<td>Teacher Interviews, Principal Interview, Middle-School Leader Interview, Student Interviews, Archival Records, Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
<tr>
<td>Site 3 Distance Education Provider F–7</td>
<td>Teacher 5, Teacher 6, Principal 3, Students (N=2)</td>
<td>Teacher Interviews, Principal Interview, Student Interviews, Archival Records, Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
<tr>
<td>Site 4 Middle School Yrs. 8–9</td>
<td>Teacher 7, Teacher 8, Teacher 9, Teacher 10, Students (N=42)</td>
<td>Teacher Interviews, Principal Interview, Middle-School Leader Interview, Student Interviews, Archival Records, Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
<tr>
<td>Site 5 Primary School F–6</td>
<td>Teaching Principal 1, Teacher 11, KLA Consultant 1, Cluster Coordinator 1</td>
<td>Teacher Interviews, Principal Interview, Science KLA Consultant Interview, Cluster Coordinator Interview, Student Interviews, Archival Records, Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
<tr>
<td>Site 6 Primary School F–6</td>
<td>Teaching Principal 2, KLA Consultant 1, Cluster Coordinator 1</td>
<td>Principal Interview, Science KLA Consultant Interview, Cluster Coordinator Interview, Documents, Researcher Direct Observations</td>
</tr>
<tr>
<td>Site 7 Primary School F–6</td>
<td>Teaching Principal 3, Cluster Coordinator 1, KLA Consultant 1, Student (N=1)</td>
<td>Teacher Interviews, Principal Interview, Science KLA Consultant Interview, Cluster Coordinator Interview, Student Interview, Archival Records, Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
<tr>
<td>Site 8 Primary School F–6</td>
<td>Teaching Principal 4, Teacher 12, KLA Consultant 1, Cluster Consultant 1, Students (N=7)</td>
<td>Teacher Interviews, Principal Interview, Science KLA Consultant Interview, Cluster Coordinator Interview, Archival Records, Documents, Researcher Direct Observations, Astronomy Diagnostic Test</td>
</tr>
</tbody>
</table>
4.6.2 Description of the Sources of data

Six major sources of data were employed in this research. These sources were: documentary; archival records; interviews of participants; direct observations; physical artefacts; and, student tests. These are dealt with in turn in this section and how they were used to generate data for analysis in the Case Study.

4.6.2.1 Documentary sources

Using documentary methods refers to the analysis of documents containing information about the phenomenon being studied (Payne & Payne, 2004). Barzun and Graff (2003) argue that a document is an artefact, which has as its central feature an inscribed text. Individuals and groups generate documents in the course of their every-day practices and gear these exclusively for their own immediate practical needs (Yin, 2014). Written with a purpose in mind, such documents contain particular assumptions and possess a certain style. Yin (2014) cautions the researcher to be fully aware of the origins, purpose and the original audience of such documents in order to be able to take into account any potential bias of the author(s) of the documents.

Payne and Payne (2004) and Barzun and Graff (2003) refer to two sources of documents:

- *Primary documents*, which refer to eye-witness accounts produced by people who experienced the particular event or the behaviour being studied; and,
- *Secondary documents*, which refer to the accounts of people who were not present at the scene, but who compile their documents after reading or receiving eyewitness accounts.

4.6.2.1.1 Using Documents to generate data

Documentary evidence for all sites in this study consisted of primary sources. For the sites in Phase 1, documentation consisted of newsletters, teacher lesson notes, and school profile information presented to the researcher, as well as data collected from school websites. For Phase 2, sources comprised school newsletters, teacher lesson plans and school websites.
The documentary evidence generated data to describe each of the settings in terms of their ‘remoteness’ or ‘rural context’. In addition, documentation from all sites was used to corroborate interview and direct observation data on the implementation of the Middle Years Astronomy Project. To illustrate this latter point:

- Teacher lesson notes at Site 8 were used to provide implementation data on the extent to which units of work from the Middle Years Astronomy Project informed teacher lesson planning;
- An astronomy club newsletter from Site 3 was used to provide data for insights into the degree to which students were engaging with the Project materials in their Astronomy Club; and,
- Teacher lesson notes from Site 4 provided implementation data on the degree to which teachers were employing units of work from the Middle Years Astronomy Project.

4.6.2.2 Archival Records

Archival records refer to past records of stored materials, usually of a historical nature, used in conjunction with other sources of evidence to illuminate a case study.

4.6.2.2.1 Using Archival records to generate data

Two documents of a historical nature assisted in generating data:

- A copy of the ATNF *Wildflowers in the Sky* ASISTM report to the Curriculum Corporation (Hollow, 2007); and,
- A report by Tytler, Symington, Smith and Rodrigues (2008) detailing 16 ASISTM case studies that illustrate better science innovative practice, and in which *Wildflowers in the Sky* was one project described.

Both documents assisted with interpreting and triangulating the broad directions of data that emerged for Phase 1 of the study.

4.6.2.3 Interviews

The strength of the interview as a data-collection process lies in its ability to augment other data gathering techniques by not only confirming emerging patterns but also
following up on unexpected results and probing into the motivations of respondents for responding as they do (Burns, 2000; Cohen & Manion, 1989; Kerlinger, 1986; Rubin & Rubin, 2011; Yin, 2014). Kerlinger (1986) also points out that interviews used in this way are especially suitable for research with children in that it can provide information in a way that is flexible and adaptive to the individual student’s circumstances.

Cohen and Manion (1989) caution the researcher to think of the interview in terms of a theory of motivation recognising a range of non-rational factors governing human behaviour such as emotions, unconscious needs and interpersonal influences. For this reason, Cohen and Manion (1989), Rubin and Rubin (2011) and Yin (2014) indicate that the interview inevitably has a bias that may be due to any combination of the following factors: poorly articulated questions; response bias; inaccuracies due to poor recall by the researcher; and, reflexivity, which involves interviewees giving what they think the interviewer wants to hear. Rubin and Rubin (2011) and Yin (2014) direct the researcher to recognise these sources of bias and attempt to control for them. Cohen and Manion (1989) and Kerlinger (1986) argue that a major way to recognise and take account of bias is both by exploring inconsistent and contradictory answers and by triangulating interview data with other sources of data (convergent validity) to provide a good measure of plausibility for interpreting the interview materials collected.

As indicated above, Yin (2014) argues that interviews are the most important source of case-study data. For this reason, this study employs interviews extensively in both Phases 1 and 2 of the study involving teachers, principals, middle-school leaders, students, and other significant agents involved in implementing the Project.

4.6.2.3.1 Using Interviews to collect data

Interviews can be unstructured, semi-structured or structured, and of short duration (up to one hour) or of long duration (up to two hours) (Burns, 2000; Rubin & Rubin, 2011). Short (about 30 minutes) semi-structured interviews with key agents were undertaken at each site with those involved in implementing the Middle School Years Astronomy Project, and carefully planned to include a list of focus questions (see Appendix 4.5a,b,c).
Respondents included teachers, principals, middle-school leaders, a KLA consultant and a Cluster Coordinator. During Phase 2 of the research, some parents were also involved in data collection, as they interacted with the researcher while visiting the school. Where the opportunity presented itself, informal discussions through unstructured interviews occurred with parents on their child’s involvement with the Project. These unrecorded interviews formed part of the set of observations gathered during visits to the sites. Interviews were undertaken with all of the teachers who were implementing the Project at all the sites.

Student interview questions were derived from the same set of general or stem questions as those asked of teachers and support personnel and followed the same semi-structured format. This format provided latitude to keep the flow of the interview going with respondents who were often quite shy. In order not to intrude too much into student-lesson time, and for reasons of manageability, it was decided to interview a sample of students at Sites 1, 2, 3, 4, 7 and 8. That is to say, at two of the Phase 2 sites, no formal interviews were conducted with students primarily due to the small number of those involved. Nonetheless, at these sites, there were many informal interactions between the researcher and the students as he was being conducted around the school. The students were forthcoming and wanted to communicate what they had been doing. These interactions were noted after the visit and helped generate an overall impression of excitement amongst the students who were experiencing the project.

In addition to interviewing the teachers, principals, and students at two of the schools during Phase 2 of the study, the Science KLA Consultant and the Cluster Coordinator employed by the schools on a part-time basis also provided interview data. Both were key agents in supporting the implementation of the Middle Years Astronomy Project for that phase of the study.

Short semi-structured interviews were chosen to limit the impact of the interviews on respondents. Respondents for Phase 1 of the study were, in the main, in the first few years of their teaching careers and were time poor as they focused on classroom
management techniques and the demands of their role. Respondents in Phase 2 were teaching principals, teachers or support personnel with part-time allocations and therefore had limited time to participate in the study due to other competing site demands.

A further reason for selecting semi-structured interviews is that they provided flexibility, thus allowing the re-ordering of questions or the amending of wording in interview questions to maintain the flow of the interview with the benefit of making the conversation as natural as possible, albeit interrogative and probing. In addition to a general or stem interview question, other probes were included. For example, the opening interview question to teachers relating to implementing the Project simply asked ‘How has it been going?’ Further probing then occurred as to how the teachers had generally found the materials. A teacher focus question exploring their general views on improving the curriculum materials involved probing the detail of what these improvements might look like.

Follow-up interview visits with teachers for Phase 1 of the study were not always possible due to high staff turnover. That is to say, between the first site visit and the second, these teachers had transferred to centres closer to the capital city or to other larger regional centres. Follow-up interview data were therefore not available for Teacher 2 at Site 3 and Teachers 3 and 4 at Site 2 who had moved to new schools prior to the second site visits by the researcher. In contrast, high staff retention rates occurred in Phase 2 sites thus allowing for follow-up interviews. The only exception was the principal at Site 7 who had retired, but kindly agreed to a follow-up interview at his residence.

All formal interviews were recorded and transcribed on a fee-for-service basis. The transcripts thus provided data for the case study and investigation of any patterns and variations across sites.

4.6.2.4 Direct observations

This study dealt with participants in their ‘real-world’ settings, i.e., at their school sites, which also presented opportunities to undertake direct observations. Yin (2014) notes
that some social and environmental conditions may be available for observation to provide additional information to the study, particularly during other data gathering phases of the research such as interviews.

De Walt and De Walt (2011) and Yin (1994, 2014) caution against selectivity in recording participant observations due to broad coverage of the case being difficult without a team of observers, and reflexivity where interviewees provide responses they believe the interviewer wishes to hear. Minimising reflexivity involved making and recording direct observations in real time during site visits. Where immediate recording of observations were not possible, recording occurred at the end of each site visit (i.e., by sitting quietly in the researcher’s car and noting everything that had occurred in a journal).

To minimise intrusion into the real worlds of the participants and to avoid the cost to the researcher of using a team of observers while preserving the ‘real-world, real-time’ data gathering processes of the study, a team of researchers was not employed to make classroom observations. Indeed the use of such a method would have created major disturbances in these small rural and remote schools beyond any benefits that could be generated by employing such a team. Nowadays, such data can be collected much more discreetly using techniques involving small cameras located within the classroom. Thus, in this study, all observations were made and recorded by the researcher alone.

4.6.2.4.1 Using Direct Observations to gather data

Site visits for the purpose of gathering interview data provided the researcher with multiple opportunities to make direct observations concerning the work of staff and their interactions with students as well as environmental factors operating at the sites, for example, the students’ thematic decorations of their classrooms and the apparent engagement of pupils during their lessons. Such observations were recorded in a journal kept for that purpose. In addition, photographs and videos were acquired from the teachers that helped paint a picture of how the Project was being implemented.
4.6.2.5  Physical Artefacts

Physical or cultural artefacts refer to physical evidence used to augment other data in a case study (Yin, 2014). Examining physical evidence facilitates a broader understanding of the case study.

4.6.2.5.1  Using Physical or Cultural Artefacts to gather data

In Phase 2 of the study the cluster coordinator created a password-protected Dropbox location for participating sites (sites 5, 6, 7, 8) to share support material, implementation ideas, and teacher– and student-generated videos. There were three types of teacher- and student-generated videos:

- Teacher-produced pretest/posttest videos for the purpose of demonstrating students’ understanding of astronomy and space, made respectively at the commencement and end of the study;
- Teacher-produced images and videos illustrating students at work on key astronomical concepts, for example, working on the scale of distances to the planets and to the nearest star from the Sun, or working on explanations for the seasons; and,
- Student-produced videos at the end of a topic, demonstrating students’ knowledge of the astronomical concept or concepts from studying the topic.

Copies of videos provided by Principals at Sites 5, 7 and 8 were used to augment and triangulate other data.

4.6.2.6  Student Testing

The Astronomy Diagnostic Test—Southern Hemisphere Version, modified to elicit students’ thinking about certain astronomical phenomena, was administered to students at sites 1, 2, 3, 4, 5, 7 and 8. A copy of the test is provided at Appendix 4.6a. The test contains 15 items that probe concepts normally contained in the primary– and middle-school science curriculum. Concepts cover such things as the causes of day and night, the phases of the Moon, the seasons and the scale and size of the planets and the Solar System. Associated concepts covered by the test include the movement of the Sun and Moon in the sky and the colours of stars. The first four questions of the Astronomy
Diagnostic Test (ADT) ask students to draw a diagram to explain the causes of day and
night; why it is warmer in summer compared with winter; the orbits of the Earth and
Moon about the Sun; and the phases of the Moon. The questions then ask the students to
explain what their drawing means. These four questions are drawn from Dunlop (2000).
The remaining 11 questions are multiple-choice items that largely cover these same four
concepts but with the added request that students explain why they have made a
particular choice. Alternative conceptions are identified for teachers in Appendix 4.6b with
suggestions as to which projects should be covered if these are identified.

4.6.2.6.1 Threats to the reliability and validity of the ADT

A national project was set up in the USA to examine the reliability and validity of the ADT
(then 21 ‘tick-the-box’ multiple-choice items) in measuring students’ knowledge of certain
astronomical phenomena. The study involved sample sizes of 5346 students for the
pretest and 3842 students for the posttest (Deming, 2002). The internal consistency
reported respectively for the pretest and posttest (Cronbach’s alpha) was 0.65 and 0.76.
Deeming the lower level of internal consistency on the pretest acceptable due to the high
level of difficulty experienced on this occasion by the respondents that led to guessing, it
was concluded that the ADT is a reliable measure of students’ knowledge of certain
astronomical phenomena (Deming, 2002).

McKinnon and Danaia (2005) later reduced the number of ‘tick the box’ items to 11 and
added four drawing response items from Dunlop’s (2000) Astronomy Survey to make a
total of 15 questions. These items mapped to the Science Curriculum for Years 5–8.
Responses also included room for students to explain their answers, and provided a
further window into students’ thinking. Further work by Danaia (2007) on the content,
construct, face, predictive and concurrent validity of the ADT confirmed the test’s validity
and reliability for measuring students’ knowledge of certain astronomical phenomena.
Thus, the 15-item test is focused on the outcomes of the primary school and lower high
school science curricula and is a good measure of both prior knowledge and students’
alternative conceptions that make it an ideal assessment device for this thesis.
4.6.2.6.2 Using the ADT to gather data

Principals at Sites 1, 2, 3, 4, 5, 7 and 8 administered the ADT on both a pretest and posttest occasion. For the purposes of this study, the ADT was used as a broad indicator of change in students’ understanding of the astronomical phenomena tested and the data from the test applied to augment other case-study data from interviews, direct observations and documentary evidence. In using the ADT this way, it was deemed inappropriate to apply extensive statistical validity and reliability tests to the ADT results given the very small number of students at some of the sites. Rather, where the ADT signalled evidence of change in students’ understanding of concepts, this became an indicator along with other data. Viewing changes in ADT scores in this way saw the test used as an indicator of concept growth during implementation of the Project rather than being solely attributable to the implementation of the Middle Years Astronomy Project given that no experimental processes were possible such as random assignment to treatment or control groups.

There was one additional issue that arose in using ADT performance as a source of data. At only one of the sites was the ADT faithfully administered both before and after the Project’s implementation and returned to the researcher for analysis. This was in spite of numerous attempts through emails and telephone calls to prompt teachers to administer and return both the ADT pretest and posttest. At some of the sites, no post-intervention occasion data were acquired. At two others, the numbers of students from whom data were acquired was so low. In one case, there was only one student in the class at the relevant grade level. It is for these reasons that no repeated measures statistical analysis is possible. Rather, the ADT performance, where available, is used as an indicator of the impact of the Project materials, and the way these were used by the teacher, on the students’ learning. Nonetheless, for the one large school in Western Australia that did provide extensive pre- and post-intervention data, means and standard deviations are calculated together with effect sizes using Cohen’s d.
4.6.3 Data analysis and interpretation

Following data collection from the various sources listed above, analyses occurred at the site level then by the phases of the research to look for emerging patterns using the descriptors ‘remote’ for Phase 1 sites and ‘rural’ for Phase 2 sites. Convergent– and divergent-based patterns then emerged. The process of triangulation tested each pattern. In this way, explanation building (Yin, 2014) occurred to account for occurrences at the individual and aggregated site levels for Phase 1 and Phase 2 of the study. The process of explanation building by triangulating the data involved developing rival explanations (Yin, 2014). Incorporating emerging propositions to create new explanations occurred where data supported this.

Examining data for evidence of PCK growth through using the educative curriculum involved applying the framework developed in Section 2.4.1 (Davis & Krajcik, 2005; Kind, 2009b; Magnusson et al., 1999). No attempt is being made here to attribute causality. Rather, the evidence to emerge is left to speak for itself. This framework is used to indicate improvements in teacher astronomy PCK occurring where data identified improvements in any of the following components:

- Teacher ability to scan holistically the teaching and learning environment to assess and reassess the effectiveness of teaching and learning approaches and to make in-the-moment modifications in response to changes occurring in any of the five components of PCK described by Magnusson et al. (1999); or
- Knowledge of science instructional strategies and their implementation; or
- Knowledge of areas of science that students find difficult to understand together with strategies to remedy this; or
- Knowledge of one’s personal orientation to teaching science; or
- Knowledge of the science curriculum; or
- Knowledge of science assessment; or
- Improved teacher confidence to teach astronomy as a consequence using the educative curriculum; or
- Improved personal attributes; or,
- Improved student astronomy learning outcomes.
In addition, as discussed in Section 2.6.1.1 implementing educative curricula can lead to improvement in astronomy PCK along a continuum. At one end of this continuum is improvement in one or two components of PCK. At the other end of the continuum is improvement in the ability to scan holistically the teaching and learning environment to assess and reassess the effectiveness of teaching and learning approaches to be able to make *in the moment modifications* in response to changes occurring in any of the five components of PCK listed by Magnusson et al. (1999). This continuum, along with the framework to indicate PCK improvement, is used for describing teacher astronomy PCK growth.

4.6.4 Summary of data-gathering procedures

Data to answer the research questions were gathered from *real world* participants at eight sites using six sources: documentary evidence, archival records, interviews, direct observations, physical artefacts and the Astronomy Diagnostic Test. Data gathered were analysed for patterns of convergence and divergence at the individual site and aggregated site levels as well as at the ‘remote’ and ‘rural’ levels corresponding with the Phases of the research. Analysing data for science PCK growth involved applying the framework developed from the works of Davis and Krajcik (2005), Kind (2009b), Magnusson et al., (1999) and Shulman (1986) and presented in Section 2.5.1. This led to ‘explanation-building’ that incorporated the testing of emerging explanations against rival theories in an attempt to provide answers to the research questions.

4.7 Threats to reliability and validity of the study

Yin (2014) argues there are four tests for judging the quality of case-study methodology: Construct Validity, Internal Validity, External Validity and Reliability. These constructs are first defined before dealing with the approaches employed either to improve them or to minimise the threats.
4.7.1 Construct validity

Construct validity refers to the accuracy with which the case study reflects the concepts being studied, or the extent to which the study investigates what it claims to investigate. Yin (2014), Burns (2000) and Merriam (1998) argue that the construct validity of a case study can be tactically improved by using multiple sources of evidence, by triangulating that evidence and by establishing a chain of evidence.

4.7.1.1 Minimising threats to Construct Validity

Construct validity was improved in this case study by using multiple sources of data on the implementation of the Middle Years Astronomy Project that derived from a range of sources and sites reflective of the rural and remote settings. The range of sources of data was documentation, archival records, interviews with teachers, students and other key actors, direct observations, physical artefacts and the ADT. Data were derived from both qualitative and quantitative sources with the student performance data from the ADT pre– and posttest performance augmenting the qualitative data sources where it was available.

Providing a description of the data gathering techniques from identification of the initial research questions to the conclusions drawn provides a sequence of events linking the evidence to the findings and conclusions for other researchers to follow and replicate (Burns, 2000; Yin, 2014).

Explanation building developed from analysis of the triangulated data was also used to improve construct validity. In addition, improving explanation building occurred by comparing explanations reached in this study with those presented in the ASISTM reports (Tytler, Symington, Smith & Rodrigues, 2008).

4.7.2 Internal validity

Internal validity refers to the strength of the cause–effect links established by the case study. Improving internal validity involves using data analysing techniques such as pattern
matching and explanation building, as well as addressing any rival explanations (Burns, 2000; Kerlinger, 1986; Yin, 2014).

4.7.2.1 Minimising threats to Internal Validity

Improving internal validity in this study ensued by analysing data from all sites in an attempt to identify any patterns that lay within the information collected. This prevented what Silverman (2005) refers to as anecdotalism, i.e., the practice of basing findings on a few well-chosen case-study examples. In addition, improving internal validity ensued from triangulating the data to find convergence among multiple sources of data and to account for divergent and deviant case results (Silverman, 2005). The use of multiple sources facilitated explanation building founded on consideration of rival explanations from the ‘craft’ and ‘real world’ of teaching (Creswell, 2007; Creswell, & Clark, 2007; Yin, 2014).

4.7.3 External validity

External validity refers to the extent to which the findings from a case study are capable of being generalised to other situations not part of the original case study, or, the ability of the research to transfer to situations with similar parameters, populations and characteristics (Silverman, 2006; Yin, 2014). Improving external validity involves selecting cases within a case study on the basis that repeating the study is likely to produce similar findings.

4.7.4 Minimising threats to External Validity

External validity, the ability of research to transfer to situations with similar parameters, populations and characteristics, is constrained in this case study due to the small number of sites, teachers, students and other actors implementing the Middle Years Astronomy Project. The eight sites in two states are not representative of all remote and rural school sites. However, the sites, teachers and students and other agents in this study do bear many similarities to those in other rural and remote settings in NSW, NT and Victoria with which the researcher is familiar.
The focus on teachers of science and students in the middle years of schooling in this study requires caution if any attempt is made to generalise the findings from this study to other year levels or other locations. With this cautionary note in mind, evidence indicating successful implementation of the Project may be suggestive of some generalizability of findings to other schools involving these years in such rural or remote settings. This case study should be regarded, therefore, as part of a larger body of research on improving the efficacy of science teaching in rural and remote areas rather than an attempt to generalise the study’s findings to every rural or remote setting.

4.7.5   Reliability

Reliability refers to the consistency and repeatability of research procedures so that if a later researcher follows the same procedures as the present researcher to analyse the same case-study data again, then the later researcher will arrive at the same conclusions. Improving reliability involves ensuring well-planned and well-documented procedures for conducting the case study and for analysing the data generated.

4.7.5.1   Minimising threats to Reliability

As indicated above, improving reliability in this study occurred by leaving a clear description of how data were derived and used for other researchers to follow and replicate (Burns, 2000; Yin 2014). In addition, strategies implemented during data analysis to improve both the validity and reliability of this study included:

- Considering plausible explanations;
- Explanation building; and,
- The use of cross case studies, where the results for each individual case-study site were examined prior to examining patterns across all case study sites.

4.8   Summary of methodology

The Middle Years Astronomy Project targeting teachers who were teaching science in the middle years (Years 7–9 in WA and Years 6–8 in Victoria) was introduced at eight sites in remote and rural settings over two phases to answer research questions concerning the ability, or otherwise, of the Project to improve teachers’ science PCK. Improving the
middle-year teachers' science PCK assists in achieving the ideal picture of science painted by Goodrum et al. (2001) and thus helps to ameliorate education rural disadvantage for science students in the middle years of schooling.

The two phases of research were conducted using a Type IV multiple case, embedded mixed-methods case study design (Yin, 2014) with data being gathered from six sources from real-world participants in their schools, viz., documentary evidence, archival records, interviews, direct observations, physical artefacts and an Astronomy Diagnostic Test.

Attempts are described to reduce the threats to construct validity, internal validity, external validity and reliability. These included using data from multiple sources to develop findings, triangulating data in explanation building and accounting for divergent results. Chapter 5 provides, explores and interprets the data collected in this study to investigate the research questions outlined in Section 4.1 of this chapter.
CHAPTER 5 Results—Phase 1

This chapter presents the results obtained from analyses of the various sources of data related to Phase 1 of the Type IV multiple-case, embedded mixed-methods design presented in Chapter 4 and whose context is described in Chapter 3. The chapter is organised around a descriptive-analytic framework describing each of the case-study sites followed by an analysis of the data from that site. The organisational framework adopted is to present the results from case-study schools where implementation worked most successfully, concluding with sites where it was judged to have worked least successfully. The results obtained from analyses of the various sources of data related to Phase 2 of the study are presented in Chapter 6 with Chapter 7 providing a summary and analysis of the results for both phases of the study.

5.1 Results from the Phase 1 Case Studies

This section presents the results from the four case studies commencing with the sites where, in the researcher’s opinion, implementation worked most successfully and concluding with sites where it worked less successfully. It is organised in this way in order to investigate the issues related to the development of science Pedagogical Content Knowledge (PCK) in relation to the teaching of the Middle Years Astronomy Project employing an educative curriculum structure. In doing so, it makes clearer any potential answers to Research Question 2: “If it does/does not have potential, what are the reasons for this?” where “it” refers to the Middle Years Astronomy Project.

5.1.1 Notes on naming participants

The participants in this Phase of the study comprised principals, teachers and students. Interview data have been attributed to each of these using the following conventions to indicate their role and the site at which they worked. In each of the case study analyses below, the site within the code attributed to each respondent is provided so that in Chapter 7 when results are amalgamated, the convention presented here renders an easier interpretation of what was happening at the sites that allows a global picture to be developed.
Thus, a principal is assigned a letter and number for the Role (P) and a subscript for the site at which they were located. The same mechanism is used for teachers (T) and for students (S). Thus:

- \( P_{1S} \) would indicate that this person is the Principal at Site 1
- \( T_{1S} \) would indicate that this person is a Teacher at Site 1
- \( S_{1S} \) would indicate that this person is a Student at Site 1

Each different principal, teacher or student is indicated by a separate cardinal number, e.g., \( T_{3S} \) or \( S_{4S} \) etc.

5.1.2 Site 4 Regional School in Western Australia

This school is located 420 kilometres from Perth, the state capital, in a regional centre with a population of approximately 37,000 people. The main economic activities of the regional centre are fishing, farming, mining, transport and tourism. The school is a purpose-built middle school for students in Years 8 and 9 with an enrolment at the time of 652 students drawn from the regional centre, smaller schools in surrounding areas and boarders from isolated schools. The maximum capacity for boarders was 120 students. Twenty four per cent of students enrolled were of Aboriginal descent.

The school had a leadership team comprised of a principal, three assistant principals, seven heads of learning area (including a Head of Science) and a Student Services Coordinator, 53 classroom teachers, 20 support staff comprised of laboratory assistants, Aboriginal and Islander Education Officers, computer technicians etc. 10 administrative staff and three specialist staff of a psychologist, a nurse and a chaplain. All students had a laptop and access to WiFi. Retention for teaching staff from the previous year was 77%. A total of 14 new teachers were commencing duty at the time of the study. Years of teaching experience ranged from a maximum of 14 years to a minimum of 4 years.

Regrettably, the West Australia Education Department’s IT firewall security measures restricted Internet access to some external sites, thus blocking students and teachers from controlling the Charles Sturt University Remote Telescope. At the time Phase 1 took place, there were no USA telescopes available.
In terms of meeting the WA Government Schools *Attainment Target* of 45% of students for Science—*Investigating*, 29% of students had reached the target at the time of the study. In terms of the backgrounds of the science staff, all had training in biology with little or no exposure or experience in teaching astronomy or the other sciences. In response to a researcher question on teaching experience and qualifications, one teacher (T7s4), who was teaching the Project to Year 8 and Year 9 students, indicated that she was a trained biology teacher with six years’ experience as a science teacher and had taught astronomy as part of a ten-week unit on two occasions.

As part of the discussion on qualifications and experience to teach astronomy, T7s4 indicated to the researcher that she was undertaking a professional doctorate in education “because I see inconsistencies in my understanding of what teaching is and what I actually deliver.” T7s4 then reflected aloud to the researcher and said:

> You really have to know the kids and what they are capable of, and know how each of those kids is different before you even start to teach. It is such a demanding thing.

T7s4 is describing the need to meet each student’s individual learning needs and understands that this means treating each student as an individual learner, including understanding any alternative conceptions they may have when designing instructional approaches. She also understands that teaching may not lead to effective learning and that the ultimate test of effective teaching is that it assists the student to learn.

In the discussion that followed and in her responses to researcher questions, it became apparent that T7s4 was trying to manage a number of issues with her students:

- Dealing with behaviour-management problems in general, especially with a group of boys in two Year 8 classes who found it difficult to maintain focus on any task. This adversely affected T7s4’s confidence to design instructional strategies for practical lessons as she envisaged this group of boys continually disrupting the class.
- Devising strategies for maintaining learning continuity for a group of students who were predominantly male with high absentee rates.
- Managing implementation of the Project initially without laptops. While the school had intended to make laptops available to assist with implementation at the
beginning of the Project, they did not arrive until approximately half way through the school term. This meant that a number of activities programmed for the first few weeks of the Project, for example using Stellarium software, required rescheduling for the latter part of the Project.

- Managing the ability of many Year 8 students to interpret text in the Project’s materials. T7S4 perceived a need to modify the language in the Project materials. This was to allow students with lower levels of literacy skills to understand the content of the materials. T7S4 indicated that the spread of literacy abilities ranged from level 2 to level 5 with level 5 being the highest level.

- Lack of time for designing instructional approaches, especially for differentiation or to modify Project material text was a problem. The time issue was exacerbated by her attendance at the professional learning day for the ASISTM Project. This required one day of travel to the workshop, one day to attend and one day to return. None of these three days were counted as part of her agreement. The school management decided that other priority areas in the strategic plan be allocated the three days. As science was not one of these, the professional learning days for the ASISTM project did not count as part of the three days’ worth of activities that she needed to prove she had attended. This meant she was required to attend three other activities in priority areas run by the school at the end of the school year.

As T7S4 also indicated when describing her student’s literacy levels:

I feel that there was a version of this book that was for Years 7, 8 and 9 but [some of] my kids would need a book about Year 5 [level reading age]. That sounds terrible but it’s just the literacy level of the kids.

Differentiating instructional approaches was required to meet the diverse range in students’ abilities in her classes. As T7S4 indicated when responding to a researcher question on what modifications, if any, she would like to see in the Project materials to improve their effectiveness:

I just try and pitch at Level 3 but if you pitch at Level 3, you get the ones that are capable of moving to Level 4 trying to get them moving there, but the Level 2 ones fall through the cracks and that’s terrible.

One researcher observation is that T7S4 had reached a stage in her career when she needed assistance with finessing her classroom management and instructional design technique to differentiate instruction, for example, by using group work based on student ability groupings and dealing with Year 8 and Year 9 boys who found it difficult to focus on
the (any) task. Visits to T7s4’s Year 8 and Year 9 classes confirmed that she employed a traditional approach to teaching that would have benefitted from this finessing. In addition, T7s4 spent the time at the front of the class directing learning activities for students seated in three rows facing her.

However, T7s4 was using the Project materials to address the issues identified above. For example, applying knowledge of the context of her students, she introduced the theme ‘What is coming towards Earth?’ as an umbrella theme to unite various pieces of work from the Project units and to create a sense of anticipation and motivation in her students to learn about objects from space that could collide with Earth. This approach included teaching strategies that employed snippets of disaster movies with meteors or comets colliding with Earth to devastating effect. The umbrella theme then allowed T7s4 to move freely into Project topics such as distances in space, a description of the planets, and distances of the planets from the Sun where she could use the guidance provided within the educative curriculum.

As indicated above, T7s4 had simplified the text in the materials by producing a number of activity sheets on the umbrella theme for students. Examples of activity sheets designed by T7s4 are at Appendix 5.1. As T7s4 describes her approach …

*I have made up my own worksheets with just the basic facts and links to different websites but I’ve used a lot of questions about the planets and stuff [from the Project materials].*

To scaffold learning for her students, T7s4 had designed and implemented a web page that incorporated Project and additional support materials and web links to the areas of content knowledge students needed to research when seeking answers to the activity-sheet questions.

To get to the stage where she could design these instructional strategies, it can be inferred that T7s4 has:

* Read the Teachers’ Guide and student workbook to enhance her content knowledge on astronomical phenomena. She also used questions from both resources in her class activity sheets;*
• Discussed with students the possible alternative conceptions they had. She mentioned starting with the alternative conception many students had in her class that the moon is visible only at night. She then used the Moon charts provided in the Project materials to challenge students’ alternative conceptions;
• Analysed the ADT pretest data to help identify students’ alternative conceptions allowing her to understand students’ prior learning when designing teaching and learning experiences;
• Employed a constructivist approach to teaching and learning that, for example, employed the framework ‘What do I know?’; ‘What do I want to find out?’ and ‘What did I learn?’. Students applied this framework for each lesson in the Project as a whole; and,
• Employed the 5E Learning Cycle for undertaking investigations.

This demonstrates that T7S4 used the Project materials to develop: instructional strategies based on the knowledge of her students including their alternative conceptions, knowledge of the curriculum materials, further knowledge of her constructivist orientations to science teaching, and, knowledge of assessment. This suggests T7S4 used the Project materials to improve her science PCK.

Interestingly, when asked if the Project materials had improved her confidence to teach astronomy, T7S4 provided the following response:

_I would have rated myself a 1 [out of 5] at the start, which is not very confident because I had only tried to teach it a couple of times previously, and now that I’m more into it maybe a 2 because I’m trying to make improvements and improve my own conceptual understandings. I have lots of problems dealing with numbers myself so to actually teach kids about numbers for me is difficult so I need support in terms of the mathematical side of the astronomy stuff. But, the more I find out about how I should be doing things the less confident I am. I am at the stage now where I am less confident; I was confident, I thought I’m going to do my doctorate in this kind of stuff and now that I’ve actually looked into the theory that I should be prescribing I’ve gone ‘Oh!’ And so I’ve come back down. I did have a peak where I said ‘Oh I know this stuff’ and then I realised how much stuff I didn’t know._

The researcher assured T7S4 that she was doing well and that, from his experience in working with many teachers at her career stage, she was making sound progress in her growth as a professional. However, the researcher observed that T7S4 was seeking
continual reinforcement and support. One researcher conclusion is that such support may be necessary for all teachers and, for T7s, could have come from her Head of Learning Area, her colleagues or from a Science Consultant, if the employer provided this form of support service to teachers.

Student interview data indicated that the great majority of 30 Year 9 students found the lessons enjoyable. They indicated they enjoyed the meteor impact experiments involving measuring the depth and breadth of craters they made in boxes of flour with ‘impactors’. They also indicated they enjoyed using the Stellarium planetarium software as well as the experiments related to the phases of the Moon and in observing the Sun and sunspots. Figure 5.1 shows students at the school observing the Sun with their teacher using the Sun-spotter device.

![Figure 5.1: Students and teacher (at right) at Site 4 observing the Sun](image)

Two students indicated that they found the Project a little boring having previously done some of the work on the planets in primary school. They compared the study of astronomy at high school unfavourably with sport and art both of which they described as “non-boring subjects.” During a visit to the Year 9 class, the researcher observed that the great majority of students were actively engaged with Project activities, which involved them plotting the distance of planets from the Sun.
Table 5.1: ADT Pretest and Posttest data for T7S4’s classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Pretest</th>
<th></th>
<th></th>
<th></th>
<th>Posttest</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
<td></td>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>8V1</td>
<td>no results</td>
<td>no results</td>
<td></td>
<td></td>
<td></td>
<td>no results</td>
<td>no results</td>
<td></td>
</tr>
<tr>
<td>8V2</td>
<td>1.571</td>
<td>1.207</td>
<td>21</td>
<td></td>
<td></td>
<td>0.800</td>
<td>1.320</td>
<td>15</td>
</tr>
<tr>
<td>9V1</td>
<td>1.636</td>
<td>2.013</td>
<td>22</td>
<td></td>
<td></td>
<td>1.350</td>
<td>1.496</td>
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</tr>
<tr>
<td>9V2</td>
<td>1.500</td>
<td>1.606</td>
<td>25</td>
<td></td>
<td></td>
<td>3.1875</td>
<td>1.721</td>
<td>21</td>
</tr>
</tbody>
</table>

The ADT pretest and posttest scores for T7S4’s classes are shown in Table 5.1. Coupled with the lack of ADT data for the 8V1 and outcomes for Year 8V2 and 9V1 classes, these results are reflective of the challenges she identified above concerning keeping a group of boys with challenging behaviours on task, maintaining learning continuity when faced with high absentee rates for some students and managing the inability of students to interpret the text of Project materials. In contrast, the ADT data for 9V2 suggests that between the pretest administered in Week 1 of the Project and the posttest administered in Week 10, some students experienced a changed understanding of those astronomical phenomena tested in the ADT to align more with accepted scientific concepts. The differences tend to suggest that T7S4 had been successful in implementing the approach and that the negative effect sizes for the two classes with challenging behaviours are more reflective of student engagement both with the Project and with schooling more generally.

T8S4 and T9S4 had, respectively, four and five years teaching experience. T9S4 had a science major in Biology but no methods training or experience in teaching astronomy. In terms of experience and qualifications in teaching astronomy, T8S4 indicated:

\[ I \text{ have a Diploma in Education with science as my major but I did a health promotion degree. I really don’t know much about astronomy though. } \]

Both T8S4 and T9S4 found the Project materials helpful for designing instructional activities and improving their astronomy content knowledge. For T8S4, the literacy levels of the materials were an issue for her Year 8 and Year 9 classes resulting in, as she pointed out, the need to modify the language demands of the materials provided to students, \textit{viz.}, worksheets on the Moon, day and night and the Solar System. Commenting on behaviour issues and the negative impact these had on motivation in her classes, T8S4 provided the following response to an interview question on how the students had found the materials.
I think we had done it [referring to the Project] for nearly ten weeks and the kids started to get a bit bored, but the first units they were interested in and we had a break for the holiday in the middle of it all ... for the first eight weeks they were pretty good. One of my [Year 8] classes really liked it so we had a viewing night last term and they loved it.

T9_s4 said of the Project:

I have enjoyed it. I expected the students to be a bit more motivated about it than they were. I thought it would be something they would be quite excited about. I guess it depended on the class. I had one class that was hard to motivate and a couple of classes that were good. I think that the [difficult to motivate] class was affected by the behaviour of the class and that affected their motivation. I enjoyed it and found it very interesting and seeing their perception of space and how things in space work.

T9_s4, like T8_s4, while finding the Teachers’ Guide and support materials “very good” found the materials “very hard to use for our kids because of their literacy standards, so it was a bit overwhelming.” As a result, T9_s4 modified the materials by breaking them down into simple sentences. As she commented in response to a researcher question on “whether modifying the text was required for all students or just certain groups of students,” T9_s4 said:

I think the better kids coped with the concepts but not the text. There’s a lot of writing and it’s not broken down. Independently, I don’t think they would even have coped. They still need that teacher involvement even one on one.

Both T8_s4 and T9_s4 reported that their confidence to teach astronomy had improved because of implementing the Project. For T8_s4, applying a self-rating scale from 1–5 with 5 being very confident, the increase in confidence represented a movement from a “1” at the beginning of implementation to a ‘2’ or a ‘3’ towards the end of implementation. For T9_s4, the improvement over the same period represented movement from a 1 to a 4.

T9_s4 indicated she was assessing students’ alternative conceptions when she was designing the instructional activities, and particularly when working with the materials on the Moon (Chapter 4, Projects 8–14). In one Year 8 class, students had the alternative conception that the Moon caused the night by blocking the Sun. To challenge this, T9_s4 used the Moon Journal (Project 8) and students were able to see that the Moon was also visible during the daytime sky causing them to rethink their alternative conception. T9_s4
demonstrated an understanding of the challenges in assessing and changing students’ alternative conceptions when she said to the researcher:

*The problems were they initially said they had a misconception and then we learned about the reality but then when I asked them about six weeks later about it, they had gone back to their misconception. It hadn’t stuck with them so that was a surprise to me!*

Interviews with a sample of students selected by the researcher from T8S4’s Year 8 and Year 9 classes provided mixed responses to all questions with some students indicating they found the work interesting, learned about the causes of day and night, enjoyed using the Moon Charts, and when using the *Stellarium* software on their laptops. In contrast, other students reported finding the work a *bit boring* due to them wanting more *experiments*. However, class visits by the researcher to T8S4’s classes revealed that students were engaged with the materials with many preparing a final report on what they had learned during their work on space for publication on a Blog or for presentation as a Power Point.

Interviews with a sample of students from T9S4’s class, randomly selected by the researcher, indicated that students had enjoyed the work and had “*gone much better*” in the second test, the ADT posttest compared with the pretest. These students too had enjoyed learning about the Moon and the distances of planets from the Sun as well as being able to use the *Stellarium* software to locate certain astronomical phenomena.

ADT test data for T8S4 and T9S4’s classes are shown in Tables 5.2 and 5.3.

<table>
<thead>
<tr>
<th>Class</th>
<th>Pretest</th>
<th>Posttest</th>
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<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>8W1</td>
<td>1.217</td>
<td>0.998</td>
<td>23</td>
</tr>
<tr>
<td>8W2</td>
<td>1.000</td>
<td>0.970</td>
<td>18</td>
</tr>
<tr>
<td>8W3</td>
<td>2.458</td>
<td>1.215</td>
<td>25</td>
</tr>
<tr>
<td>9W1</td>
<td>1.000</td>
<td>1.214</td>
<td>29</td>
</tr>
<tr>
<td>9W2</td>
<td>1.588</td>
<td>1.698</td>
<td>22</td>
</tr>
</tbody>
</table>

The data for T8S4’s classes are suggestive of students having had some of their alternative conceptions changed to more accepted scientific concepts over the course of the Project’s
implementation. This is particularly the case for 8W3 and 9W1 with effect sizes (Cohen’s d) of 1.602 and 1.022 respectively that can be described as large to very large.

Table 5.3: ADT Pre– and Posttest data for T9S4’s Classes

<table>
<thead>
<tr>
<th>Class</th>
<th>Pretest</th>
<th>Posttest</th>
<th>Cohen’s d</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>N</td>
</tr>
<tr>
<td>8X1</td>
<td>1.250</td>
<td>1.391</td>
<td>24</td>
</tr>
<tr>
<td>8X2</td>
<td>0.739</td>
<td>0.864</td>
<td>23</td>
</tr>
<tr>
<td>8X3</td>
<td>0.571</td>
<td>1.028</td>
<td>21</td>
</tr>
<tr>
<td>9X1</td>
<td>1.273</td>
<td>1.352</td>
<td>27</td>
</tr>
<tr>
<td>9X2</td>
<td>1.375</td>
<td>1.544</td>
<td>21</td>
</tr>
</tbody>
</table>

The data for T9S4’s classes are also suggestive of students having had some of their alternative conceptions changed to align more with accepted scientific concepts over the course of the Project’s implementation. This was most notable for students in 8X2, 8X3 and 9X2 with effect sizes (Cohen’s d) of 0.985, 1.012 and 1.194 respectively. These can be described as large effects.

5.1.2.1 Comments about Site 4

Data from the teacher and student interviews, direct observations, archival materials and documents provide evidence of the Project materials improving T7S4’s science PCK. They also show the science PCK of T8S4 and T9S4 improving as a result of implementing the Project materials.

In summary, when applied to data from Site 4, the framework developed in Section 2.5.1 to suggest science PCK improvement indicates that:

- T7S4 used the Project materials to develop a more fluid application of science PCK to holistically designing astronomy instructional strategies. There was emerging evidence that T8S4 and T9S4 were beginning to develop a more fluid approach to employing science PCK by improving their knowledge of instructional strategies, content knowledge of astronomy, and confidence to teach astronomy;
- T7S4, T8S4 and T9S4 improved their knowledge of science (astronomy) instructional strategies and their implementation;
- T7S4 and T9S4 improved their knowledge in areas of science that students find difficult to understand together with strategies to remedy this;
- There is some evidence of T7S4 improving her knowledge of her orientations toward a constructivist approach to teaching and learning when designing
instructional strategies to implement Project activities. T7s4 also realised that effective teaching leads to student-learning growth;

- T7s4, T8s4 and T9s4 improved their content knowledge of science (astronomy) as well as the astronomy curriculum contained in the educative curriculum as a result of implementing the Project;
- T7s4, T8s4 and T9s4 improved their knowledge of science assessment strategies, particularly those identifying students’ alternative conceptions in astronomy;
- T7s4, T8s4 and T9s4 improved their confidence to teach astronomy as a result of implementing the Project;
- T7s4, T8s4 and T9s4 continued to implement the Project despite not being able to access the telescope in Bathurst, NSW. Through researcher observations, there is evidence of all three teachers striving continuously to improve their science PCK in the face of challenging student behaviours and lack of external support from, for example, a community of likeminded colleagues in other schools or a Science consultant; and,
- There is evidence of students enjoying and engaging with the Project materials. This does not include access to the remote telescope and associated activities as the telescope could not be controlled through the Internet due to WA Education Department IT and firewall difficulties.

5.1.3 Site 3 Remote School F–12 in Western Australia

Site 3 is located 800 kilometres from Perth, and approximately 370 kilometres from the nearest regional centre (population of approximately 37,000 people). It is in the same town as the school at Site 1. The function of the site is to provide curriculum by distance education to students on isolated rural properties unable to access face-to-face education provision because of their distance from the nearest school. That is to say, the students live at least 100 kilometres from a school and have to travel on unsealed roads that are impassable in wet weather.

At the time of the study, the school had an enrolment of 49 students from Kindergarten to Year 7. The staffing establishment, appointed on the basis of merit, consisted of the principal, six full-time teachers, a library support officer, and a registrar. In addition, the school employed a special teacher learning to support and assist staff in developing programs specifically suited to the individual needs of students in isolated locations. The
school relies on home tutors, e.g., a parent or governess, to supervise the students as they work, to organise materials and to play an active role as a tutor in the learning process.

Families had the option of *air lessons* delivered through the *SatWeb*, a satellite communications system, or by *non-air lessons* that are based on distance-education-learning materials sent out one term in advance and returned completed through the surface mail system. If families choose the *non-air lesson option*, their children received the same written work, but not the daily contact through high frequency radio with the school. Thus, *air lessons* involve contact through high frequency radio transceivers to receive synchronous lessons from the teacher based at the school. A transceiver is a special type of radio that allows the user to both send and receive messages. This means that students can talk to each other as well as the teacher during classes.

*Non-air* students return a completed *lesson set or unit of work* through the surface-mail system each fortnight. These lesson sets are later returned through the same surface-mail system once marked by their teachers. The turnaround time for a marked set of work can be three weeks or more depending on how often the mail is collected, the route it takes to arrive at its destination or the vagaries of the weather, which can make travel by mail vehicles difficult.

The school profile at the time of the study indicated the school offered a number of clubs or curriculum options over the air. These included Choir/Music, Art and a Book Club. Teachers visit their students and families up to three times per year. In addition to these home visits, face-to-face contact with students occurs in a number of ways. These include:

- An annual Learning Seminar held for all Home Tutors and students. This seminar provides the opportunity for Home Tutors to develop further their teaching knowledge and skills;
- An annual camp for all students;
- Students and family visits to the school site; and,
- Mini Camps and Activity Days held at the school site, at least once per term.

On the industrial front, and together with the with the Principals of Sites 1 and 2, the principal at this site shared the desire for increased remote-locality allowances for staff as
well as the availability of subsidised housing accommodation. Site 3 was the preferred workplace for any casual-supply teachers in the town and so experienced relatively fewer problems than Site 1 in the same town, described below, in attracting casual-relief staff. For both schools at Sites 1 and 3 though, having two casual-supply teachers available for a combined staff of 26 teachers presented organisational challenges in providing relief-teacher coverage for the various organised activities and for teacher illness.

The same social and environmental factors affected both Site 1 and Site 3. In summary, these included difficulty in attracting and retaining staff, lack of staff accommodation, lack of casual-supply teachers, competition for staff with nearby mines and high student-absentee rates. Each is discussed more fully on pp. 201–202. Regrettably, prior to the second visit, an additional major event affecting staff was a recent fire at Site 3 that resulted in the destruction of infrastructure and teachers’ support materials and resources. This unfortunate event forced the relocation of the school to Site 4, several hundred kilometres from Site 3. This resulted in staff being redistributed between Site 4 and Site 1, and posed organisational challenges for the school’s leadership. Fortunately, the non-face-to-face nature of distance learning minimised disruption to students’ learning programs.

Interview data indicated that T5\textsubscript{S3} was the new music teacher at Site 3, in her second year of teaching while T6\textsubscript{S3} was the Kindergarten teacher and neither of who were the direct targets of the Project. In terms of experience with teaching science and astronomy in particular, T5\textsubscript{S3} indicated:

\textit{Not a lot [of experience teaching science]. Last year [T5\textsubscript{S3}’s first year of teaching], I was teaching in two different schools and I was only teaching two different classes and I was teaching half a day of science in one class ... so not much’}.

As far as training in science methods is concerned, T5\textsubscript{S3} indicated that her only training had occurred at university as part of her teacher training, which she indicated “\textit{wasn’t a lot}.”
T6\textsubscript{S3} provided the following response to the question on years of experience and training in teaching science:

At university, we only did about two units of science. Each unit went for one semester. I don’t feel overly confident in teaching science.

In a novel approach to teaching the content of the Middle Years Astronomy Project, T5\textsubscript{S3} and T6\textsubscript{S3} jointly formed a club called the Astronomy Society, which met virtually after school on a Friday afternoon and included students from Years 3 to 7. This decision to form the club was as a result of T5\textsubscript{S3} and T6\textsubscript{S3} being the staff at Site 3 who had attended the professional learning session for teachers undertaking the Project. Their participation had been due to school organisational reasons. T5\textsubscript{S3} and T6\textsubscript{S3} were able to attend whereas the teachers of the Year 4 and Year 5–7 students had been unable to do so. In addition to the Astronomy Society, students were taught the content from the Project during camps that occurred on the few single days each term when they travelled to Site 3 for face-to-face lessons.

Prior to commencing teaching the Project units, T5\textsubscript{S3} and T6\textsubscript{S3} engaged in a two-week program of stimulating student interest in the units. This involved setting up the Astronomy Society and explaining its purpose, conducting a camp focused on a study of the Moon using content and resources from Mission 4.1 in the Teachers’ Guide and using these visits to the distance education centre to elicit support for the club.

Using a website especially designed for the Astronomy Society, the project materials were used to stimulate learning by providing images of astronomical phenomena, posing challenge questions to students and posting Projects for them to complete. Figure 5.2 is an illustration of one astronomical object for students to try to observe or to research and is designed to stimulate conversation and further research on astronomical objects more generally. T5\textsubscript{S3} and T6\textsubscript{S3} posted this image on their webpage for the Astronomy Society hosted at Site 3. It is important to note that this object would not be able to be observed with the equipment students would normally have on their remote cattle stations. This is indicative of the lack of science content knowledge the teachers possessed.
The Crab Nebula is a supernova remnant. It is the expanding debris from the death of a massive star. How cool is that Astronomers!

**Figure 5.2: Item posted by T5_{53} and T6_{53} on the Astronomy Society website at Site 3**

Teacher interview data revealed that T5_{53} and T6_{53} were both using the Middle School Astronomy Project materials to increase their own science content knowledge. T5_{53}, who had little experience or training in science teaching in general and none in teaching astronomy in particular, indicated when discussing the Project materials to support teaching of the project on Day and Night:

*The excitement and involvement of the kids has been good and I’ve been quite surprised by the level of understanding as well because I am not confident to teach science but I have definitely been using the resources that we have come across in the materials like the astronomy books. The phases of the Moon lesson we did last week was step-by-step out of the primary book so that was really good and a useful one to use I think.*

T5_{53} also used the Project’s resources to build her astronomy content knowledge on phases of the Moon and setting up telescopes for a viewing night. As she indicated when responding to a researcher question on how she was using the Project materials:
We use the booklets [Teachers’ Guide and student workbook] and we have some charts [Moon charts] that were given to us and we put them on the white board because it was hard to do without any physical or visual examples so we used them as well as some photos and we put them on the whiteboard in sequence. We’ve given them [the students] the Moon calendar for homework for the next month so they’ll fill that in and we’ll see how they go. That is the first bit we’ve actually taught other than other small bits and pieces on our astronomy night learning to use the telescopes and things. [The telescopes had been supplied as part of the ASISTM project.]
Figure 5.3: The Moon chart activity students were required to complete

Figure 5.3 shows an illustration of work from the Project prepared and posted by T5_{S3} and T6_{S3} on the Astronomy Society webpage. The posting provides some content knowledge on the Moon, and a reminder to students to complete their Moon charts that will be used to challenge their alternative conception that the phases of the Moon are caused by the Earth’s shadow as assessed in the ADT.
Another illustration of T5s3’s adaptation of the Project materials occurred in response to a question on how she was finding the Teachers’ Guide and support materials when she commented:

*I like the way that the resources have been set up and they have been broken up well with all the headings and things. I think that there are a lot of resources around but you need a lot of time to sort through it all. So the fact they’re broken down on the CD so that I know where it is, saves a lot of time. I have had so many intentions of going through it all but I just don’t seem to have the time.*

T6s3 was also using the Project Materials to build her content knowledge of astronomy. As an illustration, T6s3 provided the following response to a question of how she was using the Project materials:

*This week we are getting the kids to start on the Moon part [Moon Journal, Project 4.1] so they will spend a whole month on that and we got that out of the book [observing the Moon and referring to the Teachers’ Guide]. T5s3 and I are learning as well as we go along. At camp, we got them to look at the star chart [referring to the Stellarium software].*

When asked to rate her confidence to teach science on the five point scale with five being absolutely confident, T5s3 rated herself a two prior to receiving the Project support materials along with the accompanying professional learning support and four afterwards. As she pointed out to the researcher:

*I feel more confident because if I didn’t have any of that [professional learning and Project support materials] I would probably be a 2.5, but I feel I know where to look now.*

However, T5s3 issued the following caution on the effectiveness of one-off professional learning and the need for follow-up when she commented:

*You learn a lot at PD and you turn up on Monday morning and you think I’m going to put that into practice. You might get to use a little and you put some of it in but then over time you lose it.*

Here, T5s3 is referring to the need for ongoing professional-learning support, off-site as well as on-site, to help her put her professional learning into practice and to reflect on those practices. As T5s3 indicated when asked what would help her become more confident in teaching astronomy, there is a need for support from like-minded colleagues,
an experienced teacher or member of the executive at school or from the WA Education Department.

...experience, discussion with other people. If you’ve got someone in your school you can always use them.

Responding to the same question of her confidence to teach astronomy prior to and following implementing the Project, T6S3 gave herself a rating of three out of five and four point five, respectively. T6S3 agreed with T5S3 on the nature of further support to improve her confidence to teach science but also placed a high priority on experience in teaching the subject when she indicated:

I think it would just come down to experience in teaching science, just practicing the teaching side of it. Getting to understand the concepts, I think.

An indication of their increasing confidence to teach astronomy is the viewing night they conducted for students and parents attending a school camp. T5S3 and T6S3 were extremely dubious and nervous to begin with when planning the event, but following coaching and modelling from a science educator from Charles Sturt University they conducted the evening and received great feedback from students and parents.

When asked to describe students’ attitudes to the materials thus far, T6S3 indicated:

So far they are loving it. They get into role-play with the aliens and things. We’ve made them up ID badges and they took them to camp with them. The principal’s daughter, she wears her badge all the time. They’ve got funny faces and their astronomy names on them. They are really enjoying it.

Here, T6S3 is referring to the Astronomy Society names students had given themselves and which had become their call signs for on-air meetings and are displayed on badges they wear. T5S3 echoed these comments concerning student enjoyment of the Project when she said:

The excitement and involvement of the kids has been really good and I’ve been surprised by the level of understanding as well.

A feature of these two teachers’ implementation that appeared to help increase student engagement was the web page with its chat facility set up for their club and where
students could post articles of interest. Commenting on the chat facility on the Astronomy Society Webpage, T5 noted:

_They learned little bits and pieces and we sort of talked to each other in a science language and it was quite fun. They’d come in and say they’d been looking at things and doing a bit of research about say Pluto or something and they put a bit into it._

T6 also offered the following favourable comment on the flow-on effect of the Project to student-learning outcomes.

_We have set up a blog and the kids get on it and write on it ... We’ve incorporated the [Year] 3s and 4s as well. They seem to be really interested in it and the feedback from the parents reflects that. I think looking at the sky really inspired them and we’ve had a couple of them really come on since then._

Interviews with two members of the student club were conducted by the researcher on air using the school’s communication systems. S1, a Year 6 student, provided evidence of the flow-on from the Project to student-learning outcomes when she responded that the club was “fun” and when explaining why it was fun indicated:

_I’ve always been interested in space and just finding out about the different things and then at night you can go outside and have a look at stuff and you know what you are looking at._

Her keenness to keep abreast of the club’s work through the website, particularly work she had missed, is highlighted in her comment:

_A couple of weeks ago I went down to Perth for a couple of weeks and when I got back I could go to the website and look at stuff [to catch up] and you know what you are looking at._

S2, a Year 5 student, echoed these comments when enthusiastically relating to the researcher the enjoyment he was having learning about the Moon, planets and Solar System through the club activities and how much he looked forward to it on Friday afternoons.

In spite of many emails and phone calls to the school requesting ADT pretest and posttest data, none was forthcoming. A reasonable explanation for this is the increased workloads
that T5S3 and T6S3 experienced as a result on implementing the Project in addition to their usual classes coupled with the chaos created by relocation due to the fire.

5.1.3.1 Comments about Site 3

Data from teacher interviews, an interview with the principal, student interviews, direct observations, documents, and the ADT results, indicate that the Project materials assisted two teachers, both of whom are teaching out of their area of expertise, to teach astronomy. Implementing the Project as an after-school club was an innovative and enjoyable activity for both teachers and students. The design and implementation of their Astronomy Society website tends to show that they had taken the materials and made them their own in light of the educational context of the School of the Air from where they were teaching the material to isolated students.

While the information technology restrictions hampered full implementation of the Project at this Site, innovative use of the electronic whiteboard on their web page to paste teacher-developed astronomy-related materials compensated for this to a degree. Unfortunately however, it did not allow students to engage in taking their own images by controlling the remote telescope and its cameras or processing them, nor doing other missions associated with controlling the telescope.

There is evidence from the data showing both T5S3 and T6S3 are using the Project’s educative curriculum to develop their own science PCK. This evidence includes using the Project materials to improve their astronomy content knowledge and to change instructional strategies to make them suitable for the distance education medium. In addition, the data show the confidence of T5S3 and T6S3 improving because of the Project materials. The data also indicate that T5S3 and T6S3 possess the emotional attributes required to continue their growth and development of science PCK, and hopefully with the guidance they have identified from within their school as well as through further professional learning.

In summary, when applied to data from Site 3, the framework developed in Section 2.5.1 to help organise evidence for science PCK improvement indicates that:
- There is no evidence to indicate science PCK is developing because of holistically and fluidly moving between components to help assess and reassess instructional activity to generate desired learning outcomes. Moreover, in the context of distance education, this would be difficult to identify. A direct observation is that this is linked to career stage as well as the need for further support to develop science PCK;
- T5S3 and T6S3 improved their knowledge of science (astronomy) instructional strategies and of their implementation;
- There is insufficient evidence from the data to indicate T5S3 and T6S3 are improving their knowledge of areas of science students find difficult to understand together with strategies to remedy this;
- While there is no direct evidence from the data showing T5S3 and T6S3 are increasing their own understanding of their personal orientations to science, they are quite clear on what needs to occur in this area to improve their science PCK;
- T5S3 and T6S3 improved their knowledge of science (astronomy) content as well as the astronomy curriculum contained in the educative curriculum as a result of implementing the Project;
- There is insufficient evidence to show T5S3 and T6S3 are improving their knowledge of science assessment;
- T5S3 and T6S3 experienced an increase in confidence to teach astronomy because of implementing the Project;
- T5S3 and T6S3 with little previous science teaching experience or methods training are showing perseverance as they teach outside of their subject expertise and are demonstrating aspects of being reflective practitioners striving to improve their science PCK. Both identify the need and type of further support required to do this; and,
- Students enjoyed and engaged fully with the Project materials. This does not include access to the remote telescope and associated activities.

5.1.4 Site 1 Remote School in Western Australia

This school is located approximately 800 kilometres from Perth and approximately 370 kilometres from the nearest regional centre (population of approximately 37,000 people). Getting there involves a flight of nearly two hours duration from Perth to the regional centre followed by a four-hour drive through very flat, sparsely-populated country dotted with occasional mine sites. On entering the town, one sees the relatively new motel as the first building followed by a small shopping centre containing a few shops providing the basic necessities as well as a few that were empty, and is reflective of the declining
commercial activity in many small rural and remote towns such as the one in which this site is located.

The school drew from a diverse population of around 1,000 locally and 2,100 district-wide representing Aboriginal communities, pastoral, mining and other related service industries. The school catered for Kindergarten to Year 12 students and had a total enrolment of 180 students the majority of who were in the primary school. The enrolment trend of the school was downward.

The school had a staff of 20 including the principal all of whom were in the early stages of their career, i.e., they had been teaching or in a leadership role for three or fewer years. There was a large Aboriginal population in the town. This resulted in over 90% of students at the school coming from Aboriginal families.

The school profile indicated that the school had a well-resourced early childhood area, specialist curriculum areas for music, art and horticulture, as well as design and technology facilities. The school was well endowed with Information Technology equipment and facilities. In addition, the school placed significant emphasis on literacy and numeracy learning and teaching, student well-being, school attendance, and on early intervention. A feature of this site was the lack of teachers who identified as having any background, experience or specific training in science or of teaching astronomical concepts. Other key features of the site included the following.

- Difficulty in attracting and retaining teachers.
- The principal and his wife (who was a middle leader at the school) reported that only four of the twenty staff at the school at the time of the study had returned for duty at the commencement of that school year. This had had a huge impact on the continuity of curriculum and instructional delivery, and had placed pressure on the leadership team to recruit staff. This was an annual occurrence.
- In terms of recruiting staff, the principal reported that in order to fill vacancies, recruitment practices involved recruiting from interstate and overseas, most notably from Tasmania and as far away as South Africa. Recruitment from these locations added to the difficulty of attracting staff with specific experience in, and knowledge of, teaching remote students many of whom were Aboriginal.
Providing adequate accommodation for staff was an ever-present problem. The availability and suitability of housing for staff was a major issue for the principal and affected adversely attracting staff. A further issue that impacted adversely on attracting staff was the absence of the maximum remote locality allowances. That is to say, provision of subsidised-housing rents (if housing was available), additional salary, additional holidays and funding for medical trips to major centres were all major issues with which the principal had to deal. The principal reported that the presence of an airfield in the town, mainly for fly-in, fly-out mineworkers, had allowed the WA Education Department to argue successfully against applying the highest remote-allowance classification to the school. The fact the school did not attract the highest locality allowance not only impacted adversely on attracting suitably qualified staff but also caused major dissatisfaction among existing staff, particularly as a town approximately 250 kilometres closer to Perth and which did not have an airfield attracted the highest allowances.

- There was a lack of casual teachers in the town.
- At the time of the study, there were only two casual teachers available in the district. The principal indicated that there was a preference for these casual staff to work in the Distance Education Centre also located in the town. This made it very difficult to cover staff absences due to sickness or to provide for attendance at professional learning programs.
- There was major workforce competition with the nearby mines.
- The salary differentials between the teachers and the mineworkers adversely affected staff retention. The principal reported two recent examples of staff retraining as truck drivers for mining companies and improving their salaries by about $30K per year.
- There was high student absenteeism, sometimes as great as 30%, which challenged the continuity of teaching and learning programs.

T1_{S1} and T2_{S1} were implementing the Middle Years Astronomy Project in Years 6 and 7 at this site. T1_{S1}, with one year’s teaching experience and no training or experience with teaching astronomy, had been given the role of Project Coordinator responsible for supporting implementation of the Middle Years Astronomy Project. T2_{S1} was a graduate teacher in her first year of appointment. When interviewing T1_{S1} and T2_{S1} together and asking about their experiences of teaching science and astronomy, T1_{S1} indicated she had “two units of science at university—energy and change” while T2_{S1} indicated that she had zero experience with science. Neither teacher had any experience in teaching astronomy.
When probing T1$_{S1}$ on the workload demands of her role as Project Coordinator and the amount of time devoted to science in the school curriculum, she responded that the school currently devoted two periods per week to science for that academic year. During the previous year, however, she advised that students in both classes taught by T1$_{S1}$ and T2$_{S1}$ had received no allocation for science in their curriculum.

The social and environmental factors affecting this site were significant. A researcher observation was that the school had the *feel* of a school under pressure from the impact of the factors listed above. However, it appeared that the school’s staff, and particularly T1$_{S1}$ and T2$_{S1}$, were enthusiastic, dedicated and committed to improving student-learning outcomes.

In addition to the environmental and social factors affecting the school, difficulties with the WA school education IT infrastructure, described above, led to the situation where a firewall prevented students’ controlling the CSU Remote Telescope through the Internet. It also prevented teachers receiving additional online professional learning support. This problem remained for the duration of the study, meaning that students could not use the telescopes to explore and take pictures of astronomical phenomena or engage in missions associated with these activities.

Despite this difficulty, T1$_{S1}$ and T2$_{S1}$ both indicated: “*We’ve had a lot of interest in the Project but it’s just starting up.*” (T2$_{S1}$). In their interviews, both teachers referred to using the support materials to improve their astronomy content knowledge allowing them, for example, to teach Day and Night and to use the Moon Journal. When responding to a researcher question on how she found the Project materials, T1$_{S1}$ said:

> *I like the step-by-step approach because I haven’t taught it before, so knowing exactly what I should do and what works best is good.*

This indicates T1$_{S1}$ is using the Project materials to obtain advice on instructional strategies and implementing them in her class. T1$_{S1}$ went on to add:

> *We’ve got these outcomes we have to get to but no direction on how we get to them really, especially for science. For literacy you can develop programs but when you only do two units of science at university on energy*
and change ... what would I do for that? So these types of resources really help.

When asked if the Project materials had provided that background knowledge and increased their level of confidence to teach the astronomy content or if it was too early to tell, given the early stage of implementation, T1s1 responded and T2s1 agreed that:

No it’s not too early to tell. The resource materials have increased my confidence because um, the ... I’ve been using them ... and I got notes from when I was in [location where the professional learning days took place] and they helped me heaps because they were all Day and Night things ... I wouldn’t have been anywhere without them really.

When asked to rate their level of confidence with teaching science on a five point scale with five being extremely confident to teach science and one being not confident to teach science, T1s1 and T2s1 rated themselves two to three and one respectively. Given the early stage of implementation the researcher decided on a follow up visit to ask T1s1 and T2s1 to rate their confidence now after having implemented the Project. T1s1 self-rated herself as now a four. T2s1 avoided the question and indicated that a transfer to a school in the state capital was imminent. When asked what would increase their level of confidence to teach science T1s1 responded:

Knowledge ... background knowledge ... and knowing what I’m teaching is the right way of going about it.

The jointly planned and conducted viewing night provided a further indication that the Project improved the confidence of T1s1 and T2s1 to teach astronomy. The teachers were proudly recounting their first viewing night, and indicated their keenness to organise a second night for the following term. When describing the first viewing night, T1s1 and T2s1 said:

Well our last viewing night we had something like 60 kids and 20 adults. We had a huge turnout ... No ... probably about 40 kids and 20 adults. There were about 60 people there (T1s1).

We were absolutely amazed because we’d only done two lessons, I think it was, and were thinking, in the main, like 10 kids very interested would come but everyone came. It was excellent (T2s1).

We started about five and finished up about nine thirty (T2s1).
Both teachers had read the Project materials together to plan the viewing night and had engaged their students with using Stellarium software that provides a representation of the night sky and helps students locate astronomical objects using the telescope provided to the school by the ASISTM project. This had increased their confidence and competence to organise the viewing night. On the afternoon prior to the viewing night, students used their new equipment to view the Sun safely. Figure 5.4 shows students from Site 1 with a representative from ATNF showing them how to observe the Sun safely using their Sun Spotter.

Figure 5.4: Students from Site 1 observing the sun

As further evidence of T1_{S1} and T2_{S1} using the Project materials to guide their teaching of astronomy, they drew three issues to the researcher’s attention that they hoped would be taken into account in any future development of the materials. The first issue is the literacy demands of the missions (then termed projects). T1_{S1} indicated that her class was having difficulty in meeting the literacy demands of the materials so she was adapting some of the materials for use with her students. As T1_{S1} indicated:

> We have some students who are capable writers and readers but I’d say 85% of my class has extremely weak literacy skills. So we have to take out anything to do with reading and writing and adjust it to them, but we do have to do it to a very different level to what the book is asking.

T1_{S1} and T2_{S1} were looking to have the resource materials modified in the Teachers’ Guide so they could be simply copied and provided to students, rather than having to adapt
them personally. This is an understandable request from two teachers early in their careers looking for lesson materials that are available for use” *just in time*” and “*ready-made to teach.*” However, the fact that the materials were able to be adapted by these two teachers to meet their students’ literacy-levels is suggestive that they had improved their science PCK and were able to differentiate materials to make them suitable for class delivery. Both teachers indicated the necessity of taking the needs of students with poor literacy levels into account in the Project materials without diminishing their aspirations to improve those literacy levels to that required by the Project materials.

The second issue identified in interview data by both teachers is the technology requirements of the Project. The firewall issue, discussed above, caused T1$_{S1}$ and T2$_{S1}$ to ‘vent’ with the researcher about the ‘myopia’ of the Department of Education to have restrictive rules that stopped them from designing educational experiences for their students. It caused a great deal of frustration and required both T1$_{S1}$ and T2$_{S1}$ to modify the approach suggested in the Project materials. It also denied students access to an exciting component of the materials. This issue was taken up in the later design of Phase 2 of the Project when a second telescope located in the USA was accessed using different software. This approach overcame the firewall problem.

The final issue is lack of implementation support from other sources. T1$_{S1}$ and T2$_{S1}$ were both asked by the researcher if they had support from a ‘master teacher’ or ‘science faculty leader’ or from an education departmental Science Consultant to assist them with implementing the Project. They both indicated that, to the best of their knowledge, there was no Science Consultant available to assist them, nor anyone at the school with science experience able to coach and mentor them. However, T1$_{S1}$ did recall receiving professional learning on another occasion from someone who was an experienced science teacher but they had to come from the regional centre 370 kilometres away to provide some professional development on a primary school science resource being used in Western Australia (which the researcher took to be *Primary Connections*).
Students in the classes of T1_{S1} and T2_{S1} were enjoying and engaging with the Project materials. During interviews with students, most of who were extremely shy, they identified topics from the astronomy projects including the size and temperature of the stars. Students also relayed some of the work they had been doing on the Moon recalling simple facts such as “Neil Armstrong was the first man to step on the Moon.” Reference was made by students to using telescopes to view stars on the viewing night and to “spot the Sun” while being careful to follow appropriate protective measures. Students also made reference to using the computer to identify the stars, i.e., using the Stellarium software.

Site 1 staff at the school did not forward the ADT pre–and posttest questionnaires. A reasonable explanation for this is that in focusing on their lesson planning T1_{S1} and T2_{S1} and also, in spite of numerous emails and phone calls requesting the data, these two teachers did not see the provision of data as a priority.

5.1.4.1 Comments about Site 1

The data collected at this site from interviews conducted with teachers, students, the principal and the middle leader as well as documents, participant observations and the ADT indicate that the Project materials were assisting the relatively new and inexperienced teachers to teach astronomy. IT restrictions hampered full implementation of the Project as envisaged by its designer. The data indicate that while T1_{S1} and T2_{S1} were using the materials to design instructional strategies and the materials were building content knowledge and confidence to teach astronomy, more needed to be done to support these two teachers to develop their science PCK. This is discussed more fully in Section 8.4.3.

In summary, when applied to the data from Site 1, the framework developed in Section 2.5.1 signify any teacher science PCK improvement indicates the following.

- There is no evidence of T1_{S1} and T2_{S1} holistically and fluidly moving between the components of science PCK identified by Magnusson et al. (1999) to improve science instructional strategies and student-learning outcomes;
• T1S₁ and T2S₁ improved their knowledge of science instructional strategies and their implementation;
• There is evidence of T1S₁ and T2S₁ redesigning components of the educative curriculum to accommodate students’ literacy levels but not of using knowledge of students’ alternative conceptions or of designing instructional strategies to address these. The experience of the teachers, the lack of ongoing on-site support provided to the teachers coupled with the IT problems are factors helping to account for this;
• There is no evidence to show that T1S₁’s or T2S₁’s understanding of their personal orientations to science are improving. Perhaps this will come with time and support.
• T1S₁ and T2S₁ improved their knowledge of science (astronomy) as well as the astronomy curriculum contained in the educative curriculum as a result of implementing the Project;
• T1S₁ improved her knowledge of science assessment strategies, particularly those identifying students’ astronomy alternative conceptions;
• T1S₁ improved and T2S₁ was improving in their confidence to teach astronomy as a result of implementing the Project;
• There is evidence that in a site with difficult social and environmental factors affecting the school, of T1S₁ and T2S₁ enthusiastically engaging with any assistance provided to develop their science PCK. At issue, is whether more assistance could be provided to T1S₁ and T2S₁ to assist them to improve their science PCK;
• There is evidence of students enjoying and engaging fully with the Project materials. This does not include access to the remote telescope and associated activities; and,
• Finally, there is evidence from the viewing evening of the Project engaging the wider school community in science education.

5.1.5 Site 2 Remote School in Western Australia

This school is located 658 kilometres from Perth and approximately 230 kilometres from the nearest regional centre (population of 37,000 people). Getting there involves a flight of nearly two hours duration from Perth and a drive through flat, sparsely populated country. On entering the town, one is struck by beautiful nineteenth-century sandstone buildings dating to an era of prosperity when the town was the centre of a thriving gold-mining region. Many of these buildings are now empty, reflecting the drift in population away from small rural towns such as this one.
At the time of the study, the school had an enrolment of 23 in Years K–7 and 10 in Years 8–10 who were predominantly Aboriginal students. The school has an establishment of a Principal and 3.30 FTE classroom teachers, a Registrar, two Aboriginal Education Officers, an Education Assistant, a library officer and a gardener. The principal was in his third year at the school. Two of the teachers had been teaching for less than three years.

The school catered mainly for primary students but was seeking to expand into attracting enrolments into the secondary section of the school. The reason provided by the principal for going in this direction was that Aboriginal secondary students from his area would not attend boarding schools at the regional centre or enrol in distance education where they found the literacy demands of the learning materials too challenging. The students in Year F–3 were taught in one classroom, the Years 4–7 in another and the senior students (Years 8–10) in a third. The school had a strong intervention program offering *Stay and Play* sessions as well as a program for three-year-olds twice a week.

The school profile indicated it had an inclusive philosophy and provided a wide range of activities such as camping, sport clinics, music incursions, swimming camps and drama incursions in order to support students’ social and emotional development as well as their academic learning as attempts to counter high student-absentee rates. An emphasis within the school was creating a safe and welcoming atmosphere. The school was well equipped with computers in each classroom with the Internet and intranet used extensively by both students and staff. All classrooms were equipped with interactive Smart Boards. There were also school-wide programs in place to support Literacy and Numeracy and the school delivered Aboriginal language lessons to all students. Other features of the site mirrored the features for Site 1 in terms of difficulties in attracting and retaining staff, lack of availability of casual teachers and challenges in attempting to attract increased remote locality allowances, which included subsidised rental accommodation. At the time of the study, the principal of this site was working with the principal of Site 1 as joint representatives of the Principals’ Professional Association and Australian Education Union to lobby the Department of Education and the Government for enhanced allowances for teachers at their respective schools.
A feature of this site was the lack of teachers who identified as having had any experience, background or specific training in astronomy, teaching astronomical concepts, or in teaching science more generally prior to coming to the school. Two teachers were involved in implementing the Project at this site. Interview data from these teachers indicated that T3S2 was a mature-age graduate who had three years teaching experience while T4S2 was in his first year of teaching. T3S2 was implementing the Project in a composite Years F–3 class while T4S2 was implementing the Project in a composite Years 4–7 class as well as in the composite Years 8–10 class.

T3S2 indicated that she had studied physics and chemistry at high school and had been inspired by a tutor at university who had written science textbooks. She, therefore, had experienced some science methods training in her degree. In contrast, T4S2 indicated:

*I don’t have a science background. I have a languages background.*

In addition, T4S2 offered the following comment on himself, which indicates an honest and reflective teacher with the necessary attributes to continue to improve his skills.

*I’m still at the crawling stage. Sometimes when I learn, it’s not till after the fact, or something else comes up down the track and I go “Oh, so that’s what that’s about!”*

As similar social and environmental factors were impacting on this site as Site 1, one observation made by the researcher was that this school also had the feel of a school under pressure. In addition, a further observation was that all teachers at this site were early in their careers and, like most in this category, were learning classroom-management techniques. As an illustration of this, while recording an interview with a senior student there was continuous yelling and shouting in the background coming from the class next door. This was indicative of a class requiring implementation of more effective classroom management strategies. Also like the teachers at Site 1, the teachers at this site were enthusiastic, dedicated and committed to achieving improved learning outcomes for their students. As T3S2 put it and which is also somewhat indicative of a reflective teacher with favourable attributes ...
This is only my third year out but I’m a mature-age graduate so I’m in it because it’s what I want to do. It’s not just a job.

When asked if she was using the Teachers’ Guide and accompanying resources, T3s2 indicated:

I haven’t seen them, so no. I just run my own program.

Her program comprised an integrated curriculum approach she had designed using materials from the university tutor referred to above who had inspired her to teach basic astronomical concepts using a very hands-on approach across a number of KLAs. T3s2 described her approach:

I have a child-centred program so the children chose last term to do aliens this term. So I have brought into that all the different aspects of exploration of space. So they are not only learning about the planets. We have integrated it into technology so they have been learning about systems and satellites and communication systems. They were looking at that as if they were aliens … how they were going to communicate, that sort of thing. So the theme goes through the curriculum. They’ve also been integrated into the health program and they had to come up with a space rocket so they had to survive.

[The students had constructed a rocket capable of seating two students located in centre of the classroom.]

So we’re learning about protection and protective behaviours so if they were going into space what would be a safe way to do it. What would they need and all sorts of things. So that was great. In the arts they have built their own solar system and things like that, jewellery, and all sorts of alien face masks and things. So it’s right through the whole curriculum.

One observation that could be made is that while the approach is interesting, it is difficult to ascertain from the interview or documents how students were learning the key science discipline-based concepts or how closely the approach was based on the state science curriculum. When asked what, if any, support was available at the school to help her implement the science curriculum, T3s2 indicated there was no one she could really link with in the region in science apart from her colleague at her own school who was “also new to the teaching profession”, (i.e., T4s2). When asked what support would be helpful, T3s2 identified “state science-teacher conferences where you could learn a lot if you lack
confidence, websites and webinars” but noting that in the online environment “computers crash”, and through teachers sharing “what works”. As T3s2 indicated:

You could also produce a DVD or CD, that way it’s portable too and all the information is there, the good stuff and you can access it at home as well.

T3s2 was referring to ready-made resources she could use with her classes. She appeared not to be aware that was what the Middle Years Astronomy Project CD-ROM was providing. When prompted again by the researcher on whether she had given the Project CD-ROM a good look, T3s2 emphasised that she had not done so and was using her own program described above in the interview extract.

Interview data from T4s2 revealed that while the science content knowledge was new to him, he had embraced the materials and was implementing them, albeit slowly, with his composite Years 4–7 and Years 8–10 classes. T4s2 had linked his Years 4–7 class with a class in Canada so that his students could share their experiences including their learning of the astronomical concepts. When asked how this had happened, he indicated that the “person at CSU had provided the link.” When asked by the researcher to comment on the Project CD-ROM containing teacher resources, including the Teachers’ Guide, T4s2 responded:

I’m guilty of not going into too much depth. I didn’t have the time or wasn’t prepared to spend too much time on it. I’m slowly getting there but it’s taking a while.

In making these comments, T4s2 is reflecting the usual difficulties of an early-career graduate teacher in managing his time while also having to learn how to develop PCK for all KLAs. T4s2 described the importance of acquiring science content knowledge from the resources on the CD while understanding how to apply that knowledge in the classroom when he indicated:

They [the students] do like it [the Project]. Even just the Solar System they say “Wow it’s so cool.” But some of the stuff is even over my head. Like I don’t really know what a black hole is. Because they [the students] are full of questions, I can only give basic answers. And sometimes when the kids are having a bad day behaviour-wise and you can just get through it in the
morning ... but when the afternoon comes you really have to have something that gets their attention.

One could conclude that these comments might be expected from a teacher new to the profession and at the early stages of learning classroom-management skills.

As indicated above, T3s2 responded that she was using a thematic curriculum approach using the Science, English, Technology, Health/PD/PE and The Arts KLAs to deliver certain astronomy, and other, concepts to students in her Years 1–3 composite class. Thus, T3s2 had not examined the resource materials provided with the Project that were aimed at developing her capability to design relevant teaching and learning programs as well as to improve student science learning outcomes. She did, however, agree to a request by the researcher to look at the materials.

T4s2, acknowledging he “was learning the teaching profession”, indicated that he was using the materials to structure teaching and learning experiences for concepts such as Day and Night, the seasons, stars and the planets. Interview data also revealed that T4s2 was using the materials to structure lessons around students using photographs of astronomical phenomena sourced on the Internet. This indicated that he was following the teaching steps suggested in one of the Projects (specifically, Chapter 3 and Missions 3.6 and 3.7). The same firewall problem teachers faced at Sites 1, 3 and 4 were present at Site 2. This meant that T4s2 was using the Internet to obtain photos of astronomical phenomena as a substitute for his students being able to do so directly using the remote telescope.

T4s2 identified two issues arising from using the Project materials he thought could be improved. The first was the literacy demands of the materials for students and the ability of teachers to modify materials to suit the literacy levels of their students. While acknowledging attempts had been made with the Student Workbook to match the literacy levels to middle year’s students, T4s2 commented:

*They’ve done that with this book but this is designed for my good Year 7s. This is the Primary Teachers’ Guide (2nd edition) and it is pretty good but my Year 7s are pretty good and they still read it and say “Well we can read*
it but what’s it all about?” I haven’t got the skills yet to simplify it for them, so this is part of the problem. I need more skills because I can’t deliver it to everyone. I can only deliver it to the kids who are smart enough to understand it.

T4S2 has identified a difficulty for his students in learning the astronomy concepts. He is asking for guidance on how to differentiate the materials so they can be understood without “dumbing down” the literacy expectations implicit in the materials. Providing this assistance will likely improve his science and literacy PCK.

The second issue concerned the use of technology to support teaching and learning as well as the professional learning of teachers. T4S2 expressed concern that apart from an initial test of Skype with Bathurst, NSW set up to facilitate professional learning support to implement the Project, when everything worked well, at later dates he was unable to “send and receive communications through Skype”. As T4S2 noted:

There is not one computer here we can use to get Skype in and out. There is only one computer we can get good Skype on. We can hear David and Lena but they can’t hear us. I bought new headsets, went through all the troubleshooting stuff but for some reason the computer just won’t work … it’s infuriating.

T4S2 was seeking additional IT support to implement the Project. Unfortunately, being so far away from IT help meant that considerable time passed before it became available.

T3S2 was not in a position to provide confidence ratings as she had elected not to implement the Project materials. T4S2 did not respond to the same question on applying self-rating confidence ratings, but when asked if the Project materials were improving his confidence to teach science, he indicated:

Slowly, it’s getting better but as I said before, I need a PD that is science based so I can learn more—so I know what I’m talking about. I will be able to deliver it better to the class but at the moment I can’t. I mean, I can, but only for a short while then it all falls apart as I haven’t developed those skills yet, but you only get three one-day PD days for the whole year and that’s not enough.

A researcher conclusion is that T4S2 is coming to grips with the notion of science PCK. He understands that he requires greater knowledge of the science content, hence his PD
comment. To build his science content knowledge skills, in addition to using the educative curriculum, T4s2 advised the researcher that he is using the CSIRO web site to download “...a heap of small and simple science projects so I can start small and build it up.” This will help him accumulate a suite of resources to assist with designing instructional strategies.

Student interview data from T3s2’s class was reflective of the integrated approach to teaching astronomy used to design their learning experiences. Students were able to talk about rockets, planets, their disappointment at not have the viewing night due to cloud cover, although this was partly compensated by the sleepover at the school going ahead, building a Moon buggy, watching the movies on “ET the Alien” and systems such as the Milk Way”.

Student interview data from T4s2’s composite Years 4–7 class contained evidence of their use of the Project materials to improve their content knowledge. Students were able to discuss astronomical concepts such as Day and Night with an explanation of causes, the production of their Moon-phase charts from one of the suggested projects, the use of computers to investigate the night sky, and the use of their Sun Spotter to view the Sun.

Teacher T4s2 relates the following story of a student engaged and motivated by the Project:

*When Lena and Rob came up, we did a night viewing and I had this Year 6 girl who still gets the order of her words mixed up but she was absolutely fascinated by what was going on out there. When we came in here [the classroom] and spent the next couple of weeks doing a PowerPoint presentation about it she was glued to it and really got into it. She could hardly read or write and hadn’t done anything like that [the PowerPoint presentation] so when you get things like that it’s great.*

An interview with a Year 10 student from Teacher T4s2’s composite class revealed an understanding of some astronomical concepts such as the size and scale of the planets, the size of the universe and sunspots. The student was keen to discuss the impact of sunspots on the Earth’s climate. Figure 5.5 shows two photographs of students engaged in Project activities at Site 2. The left hand photograph shows T4s2 and a student measuring sunspots. The photograph on the right shows students observing the Sun. The student in
the photograph at left referred to work sheets on sunspots and using computers to locate the planets. A key memory for this student was the viewing night along with the work in class.

![Figure 5.5: Using the Sun-spotter to view and record the position of sunspots](image)

While the teachers at this school had students complete the ADT pretest and forwarded the results, the posttest results were not forwarded to the researcher. Once again, this is likely to have been a result of heavy teacher workloads and competing priorities.

5.1.5.1 Comments about Site 2

Data from the principal interview, student interviews, teacher interviews, direct observations, documents, the ADT, and student work samples on display in classrooms indicate that the Project materials are assisting T4_{S2} as a new teacher to teach astronomy. IT restrictions hampered full implementation of the Project at this site as envisaged by its designers. There is evidence that T4_{S2} is starting to develop his science PCK and has the emotional attributes required to continue this development. T3_{S2} elected not to implement the project with her composite class preferring instead to use a cross-curriculum program developed by an inspirational science teacher educator to teach some basic astronomical concepts, although none of these were evident in the unit being employed nor mapped to the state’s science syllabus.

In summary, when applied to data from Site 2, the framework developed in Section 2.5.1 to map evidence for teacher science PCK improvement indicates that:
• There is emerging evidence to indicate T4_{S2} understands the need to develop by holistically and fluidly moving between PCK components. Currently, he is seeing the need to design strategies by taking account of his students’ literacy levels and content knowledge only. This may be linked to career stage as well as a need for support to develop further his science PCK;
• T4_{S2} is improving his knowledge and design of instructional strategies to teach astronomy from the base of a beginning teacher in his first appointment;
• There is some evidence of T4_{S2} beginning to develop knowledge of students’ alternative conceptions and designing instructional strategies to address these. There is evidence of his frank reflection on what he needs to do to develop further his science PCK. The inexperience of T3_{S2} and T4_{S2}, the lack of ongoing on-site support provided to the teachers and the IT problems are factors helping to account for this;
• T4_{S2} understands the need to adapt materials to differing levels of student literacy.
• There are early indications of T4_{S2} understanding his personal orientations to science, linked to what is required to improve his science PCK;
• T4_{S2} is improving his knowledge of assessment strategies in the context of improving overall strategies to deal with classroom management;
• T4_{S2} improved his knowledge of science (astronomy) content as well as the astronomy curriculum contained in the educative curriculum and continued to design teaching resources based on this knowledge throughout the Project;
• T4_{S2}’s confidence to teach astronomy is improving because of implementing the Project.
• In a site with difficult social and environmental factors affecting the school, T4_{S2} appears to be a reflective practitioner striving to improve his science PCK. He is able to assess accurately his needs for skill development and to take appropriate action; and
• There is evidence of students enjoying and engaging fully with the Project materials in T4_{S2}’s and with the activities designed by T3_{S2}. This does not include access to the remote telescope and associated activities.

The results for Phase 2 of the case studies are presented in Chapter 6 prior to presenting a summary and an analysis of results for both phases of the case studies in Chapter 7.
6  CHAPTER 6 Results—Phase 2

This chapter presents the results obtained from analyses of the various sources of data related to Phase 2 of the Type IV multiple-case, embedded mixed-methods design presented in Chapter 4 and whose context was described in Chapter 3. The chapter has two parts. The first part is organised around the same descriptive-analytic framework as for Phase 1 and which describes each of the case-study sites followed by an analysis of the data from that site. The organisational framework adopted is to present the results from case-study schools where implementation worked most successfully, concluding with sites where it was judged to have worked least successfully.

6.1  Results from the Phase 2 Case Studies

This section presents the results from the four case studies commencing with the sites where, in the researcher’s opinion, implementation worked most successfully and concluding with sites where it worked less successfully. As with the previous chapter, this one is organised in this way in order to investigate the issues related to the development of science PCK in relation to the teaching of the Middle Years Astronomy Project employing an educative curriculum structure. Organising the chapter in this way illuminates potential answers to Research Question 2: “If it does/does not have potential, what are the reasons for this?” where “it” refers to the Middle Years Astronomy Project.

6.1.1  Notes on naming participants

The same convention on naming participants has been applied in this chapter as in Chapter 5 with one exception; the concept of the small rural school Teaching Principal is introduced. These are principals of small rural schools who also have a teaching role. In Phase 2 of this study all principals at the four participating sites had teaching responsibilities. The same convention is used so that in Chapter 7 when results are amalgamated, interpretation of what was happening at the sites is clarified and a global picture developed. As illustrations:

- TP_{26} would indicate that this person is a Teaching Principal at Site 6
- T_{11}^{8} would indicate that this person is a Teacher at Site 8
• $S_{S8}$ would indicate that this person is a Student at Site 8

Each different Principal, Teacher or Student is indicated by a separate cardinal number.

6.1.2 Site 8 Rural School in Victoria

This site is located approximately 280 kilometres from Melbourne and 45 kilometres from the nearest regional population centre (population approximately 28,000 people). It is a small rural school situated in a predominantly farming community. The school, the focal point of its community, is a stand-alone complex set in the foothills of the Victorian Alps with students travelling to and from school by bus or by private transport. The nearest dwellings are on properties a few kilometres from the school. That is to say, "[the] school is stuck in the middle of a paddock in the middle of nowhere." (T11$_{S8}$).

At the time of the study, the school had an enrolment of 27 students across Years F–6 with Year 6 being the final year of primary school in Victoria. The teaching establishment comprised two teaching staff and a principal (TP4$_{S8}$) who taught part time as the special needs teacher. In common with most small rural schools in north-eastern Victoria with fewer than 50 enrolments, one teacher was allocated the Year F–2 class and the other the Year 3–6 class. TP4$_{S8}$ had been leading the school for eight years and the teaching staff tended to be stable with only one member new to the school in the last two years. This teacher had greater than five years teaching experience (T12$_{S8}$).

Private instrumental lessons are available to students at the school in guitar, keys, drums, flute and voice. Visiting teachers deliver Italian, Library and Art. An office manager also supports the students. The rural sites in this Phase formed a cluster of schools to provide support to each other in the shape of shared policies, programs and teaching and leadership expertise. As part of this arrangement, the leaders of the five schools agreed to fund a part time staff position to provide support to coordinate cluster activities (one day per week).

The school placed particular emphasis on the importance of developing Literacy and Numeracy skills using an integrated-curriculum approach. That is to say, themes that crossed curriculum boundaries were the norm rather than the more traditional subject-
centred approach. A key feature of the school was, and remains, the close interaction of the staff and students with the parents and other community members. This results in a truly whole-school community approach to providing a stimulating, sharing and positive learning environment.

This school is part of an unusual cluster of small schools that share curriculum activities, teachers, students and expertise. As an example, this school hosts the Stephanie Alexander Kitchen Garden program where students from the other school sites travel by bus two days per week to experience cooking lessons using the produce grown at their cluster school. Due to the joint nature of curriculum planning in the small schools, TP4S8 decided to implement the Project across Years F–6 rather than just with Year 5 and 6 students.

Prior to coming to the school, TP4S8 had been a small-schools science consultant travelling among several schools in rural Victoria to assist teachers in implementing the science curriculum. He attended the professional learning day conducted at the regional office and had been inspired by the activities to which he had been exposed during the day. The professional learning day, among other things, allowed TP4S8 to reflect on his science orientations and science preconceptions. He was heard at one point to remark explosively “… [expletive deleted], I’ve been teaching this wrong for 27 years!” when referring to the alternative conceptions he had about the seasons and the phases of the Moon.

On returning to school, TP4S8 allocated delivery of the Project to a part-time Year 3–6 teacher, T11s8, who had had over 20 years teaching experience with some of that time teaching science. She indicated that in her primary-teaching undergraduate degree she had undertaken a science-methods subject. She also said that she had attended several other professional learning courses but “none of that involved astronomy” (T11S8).

During his first visit to the school, enthusiastic students, eager to discuss their work on photographing planets, stars and nebula, greeted the researcher. Discussion was quickly curtailed, however, as the connection with Scott Mecca, the facilitator helping students to access the telescope in Wyoming USA, was about to take place. Scott is a trained teacher,
IT and physics specialist who lives in Laramie. With smiling students proudly leading the way, the researcher was escorted into the classroom set up as shown in Figure 6.1 to allow them to control the Wyoming telescope and to take pictures of various astronomical objects.

![Figure 6.1: Image showing teacher and students at Site 8 controlling the Wyoming system.](image)

The image in Figure 6.1 shows part of this particular group of Year 3–6 students controlling the telescope remotely in Wyoming. They have direct access to the actual computer that controls the telescope and its astronomical cameras. Simultaneously, they have both audio and video contact with Scott Mecca and can control the telescope and camera, with guidance if required. The numbers indicate:

1. Where the video image of Scott Mecca appears;
2. The image that they have just captured (a globular cluster called M15);
3. The control interface for the astronomical camera;
4. The Task Bar of the remote computer with *The Sky* planetarium telescope-control software and the camera interface; and,
5. The laptop computer that the student is using to control the Wyoming computer controlling the telescope and camera.

The student in the blue t-shirt had just finished telling the telescope to point to the object and had instructed the camera software to take an image of 45 seconds duration and which is now displayed on the large screen for all to see at number 2.

It is evident that concentration is deep. One can see the intense looks on two of the students’ faces, as well as that of their teacher as they watch their respective screens (the laptop and the large screen). It is also clear that the other two students are deeply focused on the screens although their full faces cannot be seen. It is also evident that T11\textsubscript{SS} is equally engrossed in the product that has appeared on the laptop screen, the photograph of the globular cluster. It should be remembered from above that T11\textsubscript{SS} had said that she had never experienced any professional learning involving astronomy, yet here she was standing as a spectator while her student had taken control to generate the image.

This image therefore reflects a number of processes that have happened successfully within her class prior to the researcher’s visit. They include the technical training in both telescope control and image processing activities contained within the Project materials. These, it could be inferred, had given her sufficient confidence as well as competence to undertake the investigation with her students and to allow them to assume the locus of control although she is there, nearby, to make sure that nothing goes wrong. This was reflected in her response to a later question by the researcher “Just on the issue of confidence to teach astronomy … how confident are you now to teach the units?”

Absolutely confident! And I’m hoping we can do this again next year and I’ve just starting to have a look around at that.

Expanding on the point above regarding T11\textsubscript{SS}’s confidence and competence to have her students control the telescope in Wyoming, she also had to undertake training to control the telescope to take and process images. Sufficient time had been allotted between the professional development day at the regional office in early August and the commencement of Term 4 in early October to allow teachers to plan for the implementation of the Project. During this time, T11\textsubscript{SS} was able to obtain this training from
the Teachers’ Guide, *A Journey through Space and Time: An integrated approach to teaching and learning* (McKinnon, 2012) contained in the suite of Project materials. The knowledge required to control the telescope, including how to use *Stellarium* software to locate astronomical phenomena of interest, is contained in Chapter 3 of the Teachers’ Guide. Chapter 3 also contains information guides and investigations on how to use the *Star Mx5©* software to process and enhance images taken by the telescope’s camera.

Using the Teachers’ Guide and with several years teaching experience, T11$_{S8}$ confided that she initially lacked confidence to manage the technological aspect of controlling the telescope. As she explained:

> I had confidence in teaching the content ... but because there was technology... that was new to me. I felt that if things had not gone to plan I would not have known where to start... I had never used the Elluminate program (a version of Blackboard Collaborate used to bypass Departmental firewalls) and I was very happy for the [Science] Consultant to come out and be a ‘trouble-shooter’ in case things didn’t go right, but we were very lucky and all things worked for us.

Thus, while the regional science consultant provided backup and psychological support for first contact with Scott Mecca to help build T11$_{S8}$’s confidence, everything went smoothly and the consultant’s presence was not required for future contact with Scott.

Using Chapter 3 of the Teachers’ Guide containing a series of missions to allow T11$_{S8}$ to teach students the skills necessary to control the telescope, and to enhance the images that they had taken with the telescope’s cameras, she was quickly able to develop the confidence in her students to use the technology. However, T11$_{S8}$ personalised the teaching activities in the Teachers’ Guide to suit her own style by placing them in an Engage, Explore, Explain, Elaborate and Evaluate (5Es) planning framework. T11$_{S8}$’s lesson plans using the 5Es planning framework are at Appendix 6.1.

Appendix 6.1 shows that T11$_{S8}$’s lesson plans are filled with activities taken from the Teachers’ Guide sequenced within the 5Es planning framework. Consequently, the lesson plan shows that prior to using the telescope the students had undertaken activities including:
Discussions with Scott Mecca;
Exploring and applying the Stellarium software;
Researching objects of interest from a mind map of space; and,
Identifying and agreeing on targets for the telescope.

From the tone and flow of the conversation between Scott Mecca and the students as they controlled the telescope, it was obvious to the researcher that a great rapport had been established facilitating highly effective two-way communication between them. This was important to the teacher who explained that the students could not always obtain the images of astronomical phenomena they had planned and agreed to observe. Some of their objects were either too low to observe, or not yet visible, which required sensitive explanation from Scott as to why the telescope would not always deliver their requests.

T11's response to the researcher’s question: How did the operation of the telescope work and how helpful was Scott? illustrates the level of interaction and the locus of control, which the students had been given permission to assume.

When they came up to their potential target, Scott explained whether or not they could view it and quite a few times he said he couldn’t do that one so the kids had to go back and pick something else and the kids understood why, so he was great.

We had quite a few weeks where we would have a chat with him. In the morning, we would set up a time by email and it would be one of the kid’s responsibilities to keep an eye on the emails to set up a time. So, they were very comfortable with it.

We developed such a strong relationship with him and we were quite happy for the kids to do those sorts of things.

On a subsequent visit to the school, the strength of the relationship between Scott and the students was made clear to the researcher when students expressed disappointment that Scott had not taken up their invitation to visit the school and community during the Christmas period. While the students’ understanding of the travel distances and costs involved in meeting their request to come from Wyoming to the school in NE Victoria for Christmas lunch was not quite right, their respect and appreciation of Scott certainly was!

Despite little disappointments on some days when they could not photograph their primary targets for reasons such as bad weather preventing the telescope’s use, the target
lying outside of the cameras field of vision or the atmospheric conditions not being conducive to taking photographs, the students experienced many good days when their primary targets were photographed. They proudly showed the researcher many successfully produced images such as the image in Figure 6.2.

Figure 6.2: Image of nebula M27 taken from the Wyoming telescope by a student at Site 8

This image shows the planetary nebula M27, also known as the Dumbbell Nebula (a fine example of a Planetary Nebula and the dying phase of a Sun-like star), taken by one group of students. In order to produce this image, the students had to take three separate black and white images of the M27 using red, green and blue filters, and then use other software to colourise, overlay and align all three to produce the colour image shown in Figure 6.2. The fine-tuning of the final overlay was due to the 45-second exposure times involved in taking each image. This exposure time meant the telescope moved slightly relative to the night sky between when each a photo was taken. This resulted in students
needing to identify stars within each image and to align them in the three images to produce the ‘combined’ colour image of M27.

Returning to T11S’s lesson plans at Appendix 6.1, what is not immediately apparent to the reader is the important role played by the Project materials in helping her to understand any alternative conceptions her students held in relation to astronomical phenomena. The reference in the first row, third column of to the ‘Primary Diagnostic Test’, which is the *Astronomy Diagnostic Test* (Copy at Appendix 4.6a), is important as this 15-item test provided the means for T11S to assess any student alternative conceptions of astronomical phenomena. This assessment underpinned T11S’s lesson plan. Following assessment of alternative conceptions, T11S was able to choose or to design teaching activities using the missions contained in the Teachers’ Guide as a start to help her students to develop new conceptions of the astronomical phenomena that are more closely aligned to accepted science knowledge. With Chapter 2 of the Teachers’ Guide providing advice on commonly held student alternative conceptions of astronomical phenomena along with advice on how to assess and deal with them, T11S was able to select and design appropriate student-learning activities so that her students could develop new understanding and new explanations for these astronomical phenomena that are more scientific. Having knowledge on how to identify her students’ alternative conceptions also allowed T11S to anticipate and answer questions during the study for those astronomy missions that she had chosen to investigate with her class.

T11S’s lesson-plan overview in Appendix 6.1 shows a richness of activities designed to help guide student learning to acquire more accepted scientific explanations of the relevant astronomical phenomena. The design activities include content knowledge as well as ‘Activities’ or ‘Missions’ to allow students to accommodate or assimilate the new and often challenging concepts. In addition, the lesson-plan overview shows T11S using the support materials in the Teachers’ Guide as a scaffold then building on them to design learning activities appropriate to the context of her class. In that sense, she made the activities “her own”.
One of these activities was a stargazing night at the school where the entire community was invited and another activity involved a visit to the Melbourne Planetarium 300 kilometres away. This is suggestive of T11S8 applying her new knowledge of astronomy and of the astronomy curriculum provided in the Project materials, together with her knowledge of her students’ alternative conceptions, to design additional learning experiences to improve further students’ knowledge of astronomical concepts appropriate to their learning needs, i.e., the community stargazing event and the excursion to the planetarium. These activities were designed to assist her students to acquire and own the new scientific knowledge.

T11S8’s lesson plans at Appendix 6.1 also show how she is reinforcing the school’s focus on literacy by linking science to a range of literacy activities. The link to the English KLA included activities such as using Wordle, a tool for giving prominence to words that appear frequently in text, guided reading, descriptive and creative writing and story writing. This simultaneously reinforces the aims of the science and of the English curricula through an integrated curriculum approach and through integrated teaching and learning being driven by the science that was happening in the class as the students engaged in producing procedural and report writing texts. In a similar fashion, T11S8’s lesson plans show how she is linking the science activities to the Art and Music KLAs through the same integrated curriculum approach in order to achieve simultaneously the aims of the science, Art and Music KLAs as well as English.

T11S8 enjoyed the experience of planning and teaching the Middle Years Astronomy Project and spoke to the researcher about the differences in its approach compared to the one she had used previously when teaching elements of astronomy in her primary science classes. Illustrating this is the following response to the question from the researcher “...how do you find the materials?”

One of the things I found different about this program was its focus on deeper space objects, not just the planets. That is usually just the focus of primary school science; it also did the nebula and how stars were formed and the heat, and different stars. This was totally new territory.
TP4S8 echoed T11S8’s comments when he said in response to the same question:

*Even though we did a space theme [referring to their ‘traditional’ approach] in previous years, it [the Project] was different to anything we had done before.*

The traditional approach in this school involved a student researching a particular planet and creating a poster, or drawing maps and views of the Solar System. It also involved researching important events such as Moon landings or, engaging in creative writing approaches to imagine what it would be like to visit a particular place in the Solar System such as asteroids, moons and planets. One could ask what science was being learned in these “traditional” approaches aside from the skills of information gathering and presentation. Certainly, from talking with the students, they seemed to be excited by the science and by the technology in addition to the presentation skills.

From analysing T11S8’s lesson plans and viewing samples of her students’ work, it is obvious that she was able to traverse this “totally new territory” with the assistance of the support materials for the Project. As T11S8 indicated to the researcher when discussing the Teachers’ Guide:

*It’s a really useful document...I was able to pull out the relevant areas...the connections [hyperlinks] made it so much more interesting.*

T11S8’s ability to use the Project materials to traverse this “totally new territory” also came to the fore when, along with TP4S8 and T12S8 at the school, she organised a visit by parents to come to the school to view the students’ astronomy work and to explain the school’s new approach to teaching the astronomy content. As indicated above, on another occasion, she organised a stargazing night for the whole school community. This is referred to in her plans at Appendix 6.1 (p. 6) under the heading ‘Activities’ as ‘Stargazing night at school’. An image of the parents touring the Year 3–6 classroom is at Figure 6.3.

When discussing the purpose of organising these two activities with the researcher, T11S8 responded:

*We invited parents to the school and they were able to see the images produced by the students and heard the kids talk about their experiences. We also had a community stargazing night and one of the parents from*
[nearby town name deleted] had a telescope. He had a collection of them, and he made them available and we had every parent turn up.

This is illustrative of her growing confidence to teach the Project materials, to explain them to others and to let parents and community members view student astronomy work samples. Figure 6.3 shows some of the students and their parents and siblings on the night of the parent visit to the school. It shows attentive parents, siblings and fellow students listening carefully to the female student sitting in front of the computer screen wearing the grey jacket with the pink hood as she explains her work on the Project displayed on the computer screen. It is obvious that attention to the student’s explanation is deep with all eyes on her work that is being displayed on the computer screen.

Figure 6.3: Parents/community members visiting the Year 3–6 classroom at Site 8
Figure 6.4 shows a selection of parents and students actively engaged in using telescopes on the stargazing night. Parents and a student are using telescopes provided by a community member who had learned of the school’s work on astronomy from the School Newsletter. The community member volunteered his equipment and time on the night. TP4_{S8} and T11_{S8} were both extremely grateful and appreciative to have support from this valuable community member, a resource whose skill and passion for astronomy had hitherto been unknown by the school. A second amateur astronomer in another nearby town also emerged. She too had read about the students’ work in the school newsletters and made herself known to TP4_{S8} as an available and enthusiastic future resource. The stargazing night was described by both teachers and TP4_{S8} as an overwhelming success. All parents attended. Adding to the success of the night, a student-parent camp out and sleepover on the school oval followed the stargazing.

While the Year 3–6 class was highly engaged in the stargazing night and in completing their chosen Project’s missions, students in the Year F–2 class were also learning about
some of the astronomical phenomena the older students were studying. One of the interesting features in small schools such as this site is the integrated nature of curriculum planning across Years F–6. The implementation of the Project followed this practice with the Year F–2 teacher, T12S8, using some of the Project materials with her students. T12S8 said in response to the question from the researcher “Have you used any of the Project materials when she was working with the Preps, and Year 1s and 2s?”

One of the strong things about working with the Preps, Year 1 and Year 2 students was hearing others reading the Project materials and talking about them, which is one of the things I like about having content-based guided learning.

One thing we did was stand around the ‘Moon’ [a student holding a tennis ball], I asked them what sort of relative distance it would be from the Moon to the Earth, and they all clustered around pretty close to the Moon generally. Then we did the sums [calculations] about the distance and they found they should have been, like 7 or 8 meters away. That was a real eye-opener for all of us.

T12S8 is referring to Activity 4.5.4 of the Teachers’ Guide dealing with the concept of scale models of the Earth and the Moon in Chapter 4: Earth and Moon. As part of the activities in this chapter, students are required to form a hypothesis on the distance between the model Earth and Moon represented by a basketball and tennis ball respectively, and then to mathematically test that hypothesis by calculating the actual distance between the two objects using the scale model to represent that distance. Emphasis is made in the materials that the instructional strategy called Modelling using such 3D models requires that they be life like and for helping students not only “see” but also to demonstrate the relevance of mathematics.

T12S8 also indicated that her class had used the Moon chart to map the phases of the Moon from the Project materials. She had invited the parents of the F–2 students to participate in the classroom visits at the same time as the parents of the Year 3–6 students to view and discuss students’ work on astronomy as shown in Figure 5.5, a photograph of the F–2 classroom where students are presenting their work on the Project to parent and community members. It is evident from the mobiles on the left hand side of
Figure 6.5 that F–2 students have been engaged in learning about astronomical phenomena.

Figure 6.5: Parents and community members visiting the Year F–2 classroom at Site 8.

The numbers on Figure 6.5 relate to the following:

1. Shows a mobile of the planets comprising photos from the computer complete with explanatory text;
2. Shows a F–2 student deep in conversation with a parent explaining the work he is doing on astronomy;
3. Shows a F–2 student explaining the mobile to her siblings, two of whom are fully engaged in the conversation;
4. Shows a F–2 student looking at his astronomy work on the computer; and,
5. Shows a parent and sibling plus two additional parents (hidden), all engrossed in front of the computer screen them depicting students’ astronomy work.

During a second visit to the Site, one Year 4 student was eager to show the researcher, now known on a first name basis by the students at the school, the video that he had made to demonstrate his understanding of the topic ‘the seasons’. With the audio
recorder still switched off and in the researcher’s bag, the form of address was in words that approximate the following: “Hello Arthur. Has Miss showed you my video on the seasons?” In the conversation immediately following this personal exchange, TP4s8, on the researcher’s request, located the video to show the researcher. A link to the video is at Appendix 6.2.

In the video, the student demonstrates his understanding of the causes of the seasons. He uses a globe as a prop representing the Earth, a hula-hoop in the centre of the playground representing the sun and the playground’s width to position himself in four locations corresponding to the places of the Earth in its orbit in relation to the Sun during summer, autumn, winter and spring. The video demonstrates that he is confidently beginning to grasp the concepts that explain the seasons. He recognises two concepts in play to describe the causes of the seasons; the tilt of the Earth’s axis of rotation with respect to its orbit around the Sun and the impact this has on the amount of the Sun’s energy reaching different places on the Earth. The concept that the direction of the axis does not change as the Earth moves around the Sun and a deeper understanding of the effect this has on the amount of time during which the Sun is above the horizon heating the ground is just starting to be explored by the student. For a Year 4 student this is a good start. The researcher has worked with senior geography students in Year 11 who were unable to provide as detailed an explanation as this student.

Behind the explanation of the seasons by this particular Year 4 student exists the guidance and science PCK of T11s8 as the science teacher. She has used her developing science PCK to design an assessment strategy to assist the Year 4 student to display his preconceptions and to accommodate and assimilate any knew understandings on the cause of the seasons. She has done this by combining her knowledge of the astronomy content provided in the Project materials together with her knowledge of this student and her knowledge of any alternative conceptions this student may have had about the causes of the seasons. There is an apparent fluidity in the way T11s8 is able to design her instructional approach by combining the elements of PCK holistically to achieve successful student-concept-understanding. As T11s8 explained, his explanation is now quite different
to his previous conception that it was the Earth’s distance from the Sun that caused the seasons. In country areas, this alternative conception is quite natural and probably a consequence of students’ experiences with camping and campfires: when you get closer to the fire, it feels hotter.

The Project materials have provided a scaffold for T11_{S8} to be able to do this due to their educative nature. They have provided relevant content knowledge, assessment guidelines, guidance on identifying and addressing students’ alternative conceptions and instructional guidance on how to teach the concepts about the seasons contained in Activities 4.4.3.1 to 4.4.3.4 of the Teachers’ Guide. T11_{S8}, however, has used her science PCK to build on the advice contained in the Teachers’ Guide. She has designed an additional pedagogical and assessment strategy: the production of a video to allow the student both to check his preconceptions on the causes of the seasons as well as to demonstrate his knowledge on their causes to others in a stimulating way using ICTs. This shows her increasing confidence and the growth in her science PCK.

In addition to educating teachers on common student astronomical alternative conceptions, the ADT can be used as a pretest and posttest. The number of students in the Year 3–6 class at Site 8 was small given the fact that the total enrolment at the school at the time of the study was 27 students. The ADT was administered to students in the Year 3–6 class only with data being available only for those students who were still attending the school. Records for the other students who had sat the ADT are with their school records in their new high schools. These are not available to the researcher because of Privacy Legislation. Table 6.1 shows ADT data available for six students still enrolled at the school at the time of the study.
Table 6.1: ADT data for students still enrolled at Site 8

<table>
<thead>
<tr>
<th>Student</th>
<th>Grade when ADT administered</th>
<th>ADT Pretest /15</th>
<th>ADT Posttest/15</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural 1</td>
<td>Grade 3</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Rural 2</td>
<td>Grade 3</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Rural 3</td>
<td>Grade 3</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Rural 4</td>
<td>Grade 4</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>Rural 5</td>
<td>Grade 4</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Rural 6</td>
<td>Grade 4</td>
<td>0</td>
<td>12</td>
</tr>
</tbody>
</table>

Mean=2.5  
SD= 1.52

Mean = 11.5  
SD= 0.84

While this sample is much too small on which to base any strong conclusions, it nevertheless is suggestive of the six students having had many of their alternative conceptions changed. Between the pretest administered in Week 1 of the Project and the posttest administered in Week 10, students experienced a major change in their conceptions of those astronomical phenomena tested in the ADT to become more aligned with accepted scientific concepts. Indeed, if statistical analysis was possible then the effect size would be greater than 7-sigma (Cohen’s d).

As a further illustration, growth in student astronomy knowledge can be found in the two sets of pre- and post-videos made by TP4S8 and located in, Appendix 6.3a, b, c, and d. Prior to the Project commencing, TP4S8 asked students questions concerning their knowledge of space. Student responses were videoed. At the end of the Project students were asked the same questions with the responses again being videoed. The students’ responses show greater identification of astronomical phenomena and a greater richness in vocabulary between the first and second occasion.

6.1.2.1 Comments about Site 8

During the second visit to the school, TP4S8 opened an unprompted conversation with the researcher with the following anecdote:

*You know Arthur, I had a student say to me when we were first going to do the science unit about space “I knew I wasn’t going to like this, it was going to be for the boys and it was going to be boring really”. And then, after we’d been doing the space unit for a while, and just after astronomy night at school and we had a guy come and show us the telescopes, she said later...*
that her opinion had changed completely to “This is the best thing we have done at school”. She went from “Oh this is going to be boring” and “This is for the boys” to “I learned so much”.

The ADT data, student work samples, student-made videos and researcher observations confirm that other students too learned a great deal about astronomy and did so in an engaging and enjoyable way. In addition, the Project also helped an experienced primary teacher learn to improve her science teaching by improving her science PCK (Shulman, 1986a) and the students were the beneficiaries of this. T11_S8’s lesson plans coupled with data from interviews attest to this. They show that T11_S8 gained new content knowledge on astronomical phenomena as she worked through the curriculum materials designed to facilitate an inquiry-based, integrated-curriculum approach to teaching and learning; an approach different from the more traditional project-based approach to teaching astronomy.

They also show T11_S8 building on the suggested instructional strategies in the Project designed to move students’ conceptual knowledge about astronomical phenomena from the current and usually alternative conceptions to more accepted scientific knowledge and explanation of these phenomena by designing her own pedagogical approaches armed with knowledge of her students’ context and where their alternative conceptions lay. This improved T11_S8’s skill as a science teacher, and her science PCK (Shulman, 1986a). Due to the integrated nature of the curriculum design used in the Project, the data from this site suggest that the Project also made a contribution to improving T11_S8’s skills in technology, mathematics, literacy and art.

As the Science Consultant, a teacher with many years’ experience in helping teachers implement science curriculum, commented when referring to her observations of T11_S8 in the classroom implementing the astronomy units:

The materials were great. They were well written and well researched and what teachers did use was really good. T11_S8 had done some homework. She gave me her work on the unit and it followed the 5Es and was well stepped out. It was really good. She just grabbed it with both hands. So someone like T11_S8 at Site 8 was just sensational.
The interview data with the Year F–2 teacher, T12S8, and photographic evidence, indicate that she too found the Project materials useful in designing teaching approaches for students in her class. While this group of students lay outside of the intended scope of the present study, it nevertheless raises an interesting question on the year level at which the Project may be introduced. Of course, the teachers’ contextual knowledge of their students has to be taken into account. This issue is further discussed in Section 8.4.4.

In summary, when applied to data from Site 8, the framework developed in Section 2.5.1 to evidence teacher science PCK improvement indicates that:

- There is evidence of T11S8 holistically and fluidly moving between the components of science PCK identified by Magnusson et al. (1999) to improve instructional strategies and student learning outcomes;
- T11S8 and T12S8 improved their knowledge of (astronomy) science instructional strategies and their implementation;
- T11S8 and to a lesser extent T12S8 improved their knowledge of areas of science students find difficult to understand together with strategies to remedy this;
- There is some evidence of T11S8 improving knowledge of her personal orientation to teaching science and her preparedness to try an alternative inquiry-based investigative approach (the Project);
- T11S8 and T12S8 improved their knowledge of the science (astronomy) and the astronomy curriculum contained in the educative curriculum as a result of implementing the Project;
- T11S8 improved her knowledge of science assessment strategies, particularly those identifying students’ astronomy alternative conceptions;
- T11S8 improved her confidence to teach astronomy as a result of implementing the Project;
- T11S8, an experienced science teacher but with little technology or astronomy experience, demonstrated the personal attributes of willingness to try new approaches and ‘sticking at it’ with the initial support from a science consultant; and,
- There is evidence of student alternative conceptions of astronomical phenomena approaching accepted scientific understandings of these phenomena, of students enjoying and engaging with the Project’s approach, and of students’ science vocabulary improving.
Finally, there is also evidence of the Project engaging the wider school community in science education, a feature of the ideal picture for science education developed by Goodrum et al. (2001).

6.1.3 Site 5 Rural School in Victoria

This site is a small rural school of 36 students located approximately 300 kilometres from Melbourne and 50 kilometres from the nearest rural centre (population approximately 28,000 people) with enrolments being drawn from the small town in which the school is situated and from surrounding hamlets. Tourism, viticulture, forestry and agriculture are the economic mainstays of the area.

The school is a focal point and resource for this small rural town. School facilities include a library, performance space, art room and an Outside Schools Hours student-care facility. The school employs various education technologies including laptops and iPads, and has interactive whiteboards in all classrooms. Sustainability is a focus of the curriculum, with the school being self-sufficient in both water and power. The school has excellent grounds including a large vegetable garden, fruit trees, a chicken shed, a sports oval and an undercover, as well as an open, sports area.

The school is part of a cluster with four surrounding schools who all share programs, students, teachers and their general expertise. Cluster initiatives include the Stephanie Alexander Kitchen and Garden program, a range of camps and sporting activities including Personal Best athletic sports, cultural days and professional learning initiatives.

The school is staffed by a Year F–2 teacher (T1055), a Year 3–6 Teaching Principal (TP155), a part-time Literacy/Numeracy intervention teacher (one day per week) as well as a part-time music teacher (two days per week). Private instrumental lessons are also available to students at the school in guitar, keyboard, drums, flute and voice. Visiting teachers support Italian, library and art. An Office Manager and Integration Aide (two days per week) also support the students. The school also employs the services of a Cluster Coordinator for one day each week.
As is the case with many small schools in Victoria, this school organises its curriculum, pedagogy and assessment on a ‘junior primary’ (Years F–2) class and a ‘senior primary’ (Years 3–6) class basis with joint planning occurring across Years F–6. Thus, while the focus of implementing the Middle Years Astronomy Project was initially on Years 5–6 at this school, implementation also extended to years F–4 because of the joint nature of whole school curriculum planning.

At the time of the study, the teacher of the Years 3–6 class of 14 students, who was also the principal (TP1SS), had fifteen years teaching experience with five of those years as a Teaching Principal in his current role at the school. When asked by the researcher what training or experience he had in teaching science, TP1SS responded that while he had studied environmental science as part of an outdoor education degree, which equipped him to teach at the primary and secondary levels, he had had no experience or training in teaching astronomy.

School newsletters in small schools like this one kept the school community informed, not only of school events but also of community events. The school newsletters devoted increasing coverage to teacher- and student-produced articles on the Middle Years Astronomy Project as the term progressed. The following articles at Figure 6.6 are taken from one newsletter at the time of the study illustrate this. A copy of the complete school newsletter is at Appendix 6.4.
**SPACE**

**Numeracy Corner**

A real life reference point is important to help students understand some of the big distances, speeds, and numbers that they encounter as they learn about space. Facts such as a rocket launching into space at 11kms per second, is the same as getting from here at school to [local landmark deleted] in 1 second. The real life reference point helps students understand just how fast that is.

Today we linked up via Skype with Professor David McKinnon, at Charles Sturt University in Bathurst, and learnt how to use the remote telescope software for tomorrow night’s astronomy night. While we were doing this we learnt that the ‘Pluto Express’ is a satellite that was launched in 2006 and should arrive at Pluto in 2015. The Pluto Express is the fastest thing humans have created—travelling at 16.4 kms per second. Travelling at this speed it will take 8 years all up to get to Pluto. This gives students an idea of just how far away we are talking (rather than just knowing it is 5,500,000,000km away).

**Literacy Corner**

Past, present and future are concepts that we have been encountering when discussing our topic of ‘Space’. We have been looking at language in our reading and writing in the grade 3–6 class and been focussing on ‘past, present & future tenses. The articles in this edition of the newsletter are (hopefully) written in the ‘future’ tense, as the grade 3–6 students are writing about some of the upcoming, exciting events at [Site 5] School. This is quite different to the student’s normal reflections on ‘past’ great learning activities.

**Figure 6.6: Site 5 School Newsletter Articles—Extract**

These newsletter articles show that the teachers and students at this site are engrossed in implementing the Middle Years Astronomy Project. The Numeracy Corner article reveals that teachers are using the materials to help students derive a sense of ‘real distances and times’ by linking the astronomy work with students’ work in numeracy. The Literacy Corner article reveals that teachers are using the Project materials to help Year 3–6 students develop further their use of past, present and future tenses. The complete newsletter at Appendix 6.4 shows Year 3–6 student-designed questions and answers on astronomical phenomena written using the future tense.
The Numeracy Corner article also mentions the forthcoming astronomy night, a viewing night for the whole school community using the Telescope in Bathurst. This well publicised culminating event for the Project in December was well advertised in the School Newsletters, which carried invitations for the parents and community members to attend. It was the final community event for the school year designed by the teachers to celebrate the learning that had been happening.

Preceding this viewing evening was all of the learning in class and an afternoon viewing session with the students using the telescope in Wyoming, which provided them with access to the night skies above North America. Thus, they experienced, and had to learn about, what objects were visible at both of these locations, with one in the northern hemisphere and the other in the southern, to locate and photograph astronomical phenomena that were visible. During a visit to the school, a proud TP1SS presented the researcher with a number of photographs of stars, planets and nebulae taken by students on the viewing afternoon and evening to demonstrate their proficiency in using the equipment shown in Figure 6.7.
Figure 6.7: The equipment used for the CSU Telescope viewing evening.

The numbers indicate:

1. T1055 assisting a student using a laptop to control the program operating the Bathurst telescope;
2. A student using a laptop to control the program operating the telescope;
3. The view from the Bathurst telescope. Professor McKinnon also has this view on his computer screen in Bathurst;
4. The Polycom Video Conferencing unit used by the teachers and students, facilitating the viewing evening to communicate with Professor McKinnon (overexposed);
5. Screen to display the Wide-Field Camera Output showing where the telescope is pointing in the sky;
6. A larger screen version than the laptop image of the telescope at Bathurst showing the viewing audience its movements in response to commands entered into the laptop by the student described in 2; and;
7. A laptop with the screen described in 6.
TP1\textsubscript{55} describes the event and equipment ‘set up’ for the viewing evening shown in Figure 6.7 in the following way:

> It was a great night with the Polycom [video-conferencing unit] outside and I had two desktop computers, so one had planetarium software, one had the webcam for watching the telescope and we had David (Professor McKinnon) on the Polycom and we had the interactive whiteboard with what the kids were actually doing and taking photos of: the moons of Uranus or a type of star. The kids would come up and David would talk them through and say, ‘Now put this into the search’ and he was able to field questions about little technical glitches and other things that happened.

This demonstrates that TP1\textsubscript{55}, who indicated he had had no previous experience teaching astronomy, could lead the viewing evening for the school community with T10\textsubscript{55} and took the technological aspects involved in setting up the equipment in his stride. An observation, confirmed by the Cluster Coordinator and Science Consultant, is that TP1\textsubscript{55} revealed in the technology aspects of setting up the viewing evening. He enjoyed a reputation in the cluster of small schools as someone who saw each technology challenge as an opportunity to problem solve.

When asked by the researcher to describe the reaction of parents to the viewing night, TP1\textsubscript{55} provided the following enthusiastic response:

> They thought it was great! They were ‘wrapped’! I still get questions like ‘Can we have another space night? It was amazing how many people in the community started talking about it. I think it went through to 11.00pm and we started just on dark (about 8.00pm).

The evening certainly captured the attention of the parents and students as Figure 6.8 shows.
Figure 6.8: The audience watching with rapt attention

Figure 6.8 shows a selection of parents and students deeply engaged in viewing the screens described in Figure 6.8 on the Astronomy Night at Rural Site 5. With the exception of the female student seated fourth from the right hand side in the second row, who appears to be watching the photographer, every pair of eyes is focusing intently on the viewing screens.

As with Rural Site 8, much preparation by the teachers and the students had taken place prior to the afternoon and evening to ensure its success. For the teachers, Chapters 1 and 3 of the Teachers’ Guide provided guidance on how to use the telescopes to view and take pictures of the stars and other astronomical phenomena. Chapter 2 had prepared the teachers by allowing them to understand common student alternative conceptions on astronomical phenomena by providing an assessment instrument (the ADT) for diagnosing and analysing any alternative conceptions their students may have held. This knowledge of their alternative conceptions positioned the teachers to structure the learning experiences to allow students to test their alternative conceptions, and to accommodate
and assimilate the new scientific conceptions in line with those accepted by the scientific community. The ADT also provided teachers with a means of measuring changes in students’ conceptions over the course of the Project. Chapter 3 of the Teachers’ Guide provided guidance on allowing students to undertake controlled experiments with the image processing software using images supplied with the learning materials. This allowed students to apply the techniques to their own images taken when controlling the telescopes.

Chapter 2 of the Teachers’ Guide prepared students by helping them to identify any alternative conceptions they may have held as a precursor to testing those conceptions and accommodating and assimilating new conceptions more in keeping with those of the scientific community at that time. For the students, with the assistance of their teachers, Chapters 1 and 3 had prepared them by:

- Holding discussions with Scott Mecca (Wyoming) and Professor McKinnon (Bathurst) prior to the evening;
- Exploring and applying the Stellarium planetarium software;
- Researching objects that interested them;
- Identifying and agreeing on targets for the telescope; and,
- Taking and enhancing photographs of astronomical objects.

Prior to the viewing evening, TP1SS had been building his science PCK. This, he claimed, allowed him to be more effective in designing learning experiences for his students in his context by facilitating their learning to accommodate and assimilate conceptions more in keeping with those held by the scientific community. Several examples of TP1SS using the Project materials to enhance his own science PCK were observed by the researcher. One example, contained in the video at Appendix 6.5, illustrates this. This video shows the outcome of TP1SS’s students ‘conceptual wrestling match’ with the problem of simultaneously representing sizes of the planets and their distances from the Sun on the same scale in a way that had real meaning for them.

Under the guidance of TP1SS, the students explored a number of scales to construct scale models of the solar system. The video shows the students applying three scales. The students found their first scale, where 1 mm on their model equals 1 million kilometres in
real life, suitable only for representing the distances of the planets in a reasonable space but not their relative sizes to each other. This is the typical ‘toilet-roll’ scale model.

Similarly, the students found the next scale they tried, where 1 cm on their model equals one million kilometres in real life, was also suitable for representing the relative distances of the planets but, again, not their relative sizes. They now had to move outside to their school playground to represent the Solar System. The third scale agreed by the students, where 1 metre on their model now equals 1 million kilometres in real life, while proving useful for representing both size and distances of the planets proved difficult for the students to conceptualise. To assist students in understanding this scale TP155 began by applying the learning and teaching approach described in the School Newsletter article at Figure 6.6 by providing:

* A real life reference point [is important] to help students understand some of the big distances, speeds, and numbers that they encounter as they learn about space.

The video shows TP155 providing this ‘real life reference point’ students require. In the final sequence of the video, he does this by first locating a scale model of the Sun that students have made out of Paper Maché in the centre of the community. Next, he positions the students holding models of their planets designed to the same scale along a nearby straight road. Each distance is a scaled distance to represent the distance of each planet from the model Sun located in the centre of their town. The video shows TP155 driving his car at 20 kilometres per hour past the students, each holding one of the planets modelled to scale, and after several (15) minutes finally reaching the student holding the scale model of Pluto, 2 mm in diameter, located 5.9 kilometres from the (model) Sun.

Those students not positioned along the road are producing the video footage while TP155 drives his car. By providing accompanying sound and text, these students get the opportunity to use science to develop their literacy and ICT skills. This video sequence also involved the community who drove their cars out in advance of the video-car where parents in their cars dropped each child with their scale-model planet at the relevant distance informed by a student who watched the odometer and told the driver when to stop to deposit the model planet holder at the correct distance from the town centre. The
middle vehicle contained the driver, an odometer spotter and the cameraperson. The car carrying the camera operator travelled at a constant 20 km/h. Other parents in their cars followed to pick up the children after they had been filmed. It must have been quite a sight.

From the perspective of developing science PCK, the video shows that TP155 used the Teachers’ Guide to help students calculate the relative distances to the planets from the Sun and their relative sizes using three agreed-upon and different scales. This knowledge is found in the Teachers’ Guide Section 4.5 containing knowledge and scaffolding advice on designing instructional approaches on Scale Models of the Earth and Moon; Section 5.3 on Scale Models of the Planets and Section 5.4 on Scale Models of the Solar System.

Realising from in-class observations that his students were having difficulty in conceptualising and representing the distances of planets from the Sun and the size of the planets on the same scale, TP155 designed an instructional approach to help his students work through their conceptual difficulties. At first TP155 followed the pedagogical approach suggested in the Teachers’ Guide by having his students agree on their first scale (1mm = 1 million kilometres.), calculate distances then draw their scale model on continuous-roll paper placed on the floor of a large area (classroom floor). When the students found it difficult to represent the sizes of the planets and their distances from the Sun using this scale, TP155 helped them agree upon a second scale and again followed the advice contained in the Teachers’ Guide. This advice resulted in students creating a model of the solar system outside in the school grounds. They measured the scale distances using a trundle wheel with his students placed at the calculated distances.

However, the students still found it difficult to represent the size of the planets and their distances from the Sun on this scale (1 cm on their model equals 1 million kilometres in real life). TP155 guided the students to select a third scale (1 metre = 1 million kilometres) and again sought guidance from the Teachers’ Guide. It recommends locating the closest planets to the Sun in an area within the school then working with a local map to plot the remaining planets beyond Mars on that map. TP155 considered this suggested instructional approach problematic for his (my emphasis) students. So he used the following:
• The content from the Project curriculum materials on creating scale models of the solar system;
• His knowledge of his students’ alternative conceptions around representing distances and sizes of the planets on the same scale; and,
• His knowledge of the context of his students in their rural setting.

He then devised a more appropriate instructional strategy to enhance his students’ science conceptual development of representing sizes and distances of the planets on the same scale based on real life reference points’. This approach of agreeing on a scale then producing a video using local landmarks to allow his students to conceptually understand the distances and size of the planets on the same scale, demonstrates that TP1SS used the Project materials to increase his own science PCK. Equally, in using scale models of the solar system in this way, TP1SS is also improving his own mathematical PCK, which in this case is derived from the science investigation.

Another illustration of TP1SS building his science PCK from implementing the Middle Years Astronomy Project occurs with him creating the learning and teaching environment for teaching the astronomy units modelled by Professor McKinnon at the professional development day conducted early in the previous school term. The professional development day, held in the nearby regional centre approximately two months prior, gave participants time to plan their approach. TP1SS found this day very useful, especially the concept of creating a dark room to teach astronomy, as his following response to a researcher question on how useful he found the professional learning day indicates.

I think that session we did in [regional centre name deleted] was a pretty essential part. It drove the passion and gave the base understanding. It was a crucial element, I reckon. It gave us confidence to have a go and bring it alive. The modelling [by Professor McKinnon] brought it alive. The resource materials we got, there seemed to be tonnes of it.

That PD we did with you [two months prior to implementing the project] ...was just brilliant and there was stuff we didn’t get to. But it helped me to shape it and say “Well these are the key aspects, this is what we need to learn”, whereas [without the PD day] I would have gone about it differently.
At the professional development day, Professor McKinnon had arranged for the room to be in darkness to help the teachers see what the modelling activities were designed to show. On returning to his school, TP1SS constructed a *dark room* to facilitate the teaching of key astronomical concepts and in the process developed further his science PCK. Figure 6.9 shows students during one astronomy lesson in the *dark room*, named The Planetarium by the school.

![Figure 6.9: The Planetarium room](image)

Figure 6.9 shows the *dark room* or *The Planetarium* set up by TP1SS being used to teach the seasons. The lamp in the bottom left hand corner of the photograph represents the Sun shining on the globe in the centre right of the photograph representing the Earth. The Earth is propped on a movable chair to facilitate the movement or orbit of the Earth around the Sun. TP1SS is off to the left hand side of the photograph with another globe describing the Earth’s axis and the effect this has on creating the seasons. Students can be seen giving TP1SS their attention as he explains the Earth’s axis. (The out-of-focus image is due to the long exposure in the darkness and the photographer’s inexperience.)
TP1SS’s confidence to teach astronomy was also improving, furthering his science PCK. He demonstrated this in his response to the researcher’s question about how he would rate his confidence to teach astronomy prior to and after implementing the Project.

Before, I would have been a 2 or a 3 [out of five with five being very highly confident to teach astronomy] … and now about a 4.5. It just helped my confidence. It was great. I have great interest in it but the skills I got from it [the Project] and the support materials that we had, helped a lot … The learning for this is just so rich, so my confidence just rose. I cannot wait to teach it again next year.

The students were the beneficiaries of TP1SS’s increasing science PCK. This was evident to the researcher in a number of ways. One indication was student performance in the ADT pretest and in the posttest. TP2 informed the researcher that Year 3–6 students had completed the ADT pretest and posttest but that he was not able to locate the document for forwarding to Professor McKinnon detailing student results. In an email to the researcher, TP1SS provided the following information on student performance on the ADT.

I have managed to find the blank pre– and posttest booklets for the space unit in my resources files (getting closer), but alas not the student ones or my results (referring to his copy of the results). But in summary and from memory, 12 students from the 3–6 class completed both pre– and posttests. Pretesting indicated 9 students knew about how day and night happen, 2 knew how the Earth, Moon, Sun orbits, 2 knew of Moon phases and 1 gave a good response to why summer and winter happen. I honestly don’t remember much about the students’ responses to the remaining questions.

Posttesting, … however, it was pleasing to report that all 12 students could explain day and night, 9 students could explain the orbit of the Moon, Earth and Sun, 11 students could explain the phases of the Moon, 10 could explain why summer and winter happen. In addition, I do remember question 14; all 12 students got correct that the full Moon will still have the full-Moon phase in 6 hours.

One can infer from this recollection that for those questions listed by TP1SS, the total score on the pretest was 14 correct for the 12 students while on the posttest for the same items, the total score was 44. While question 14, there is no explicit reference to it in the pretest, the total score correct may be as high 54 if no one got it correct on the pretest. The sample of 12 students is small and TP1SS is providing the information on test scores
from memory. However, his recall is suggestive of a major improvement in the 12 Year 3–6 students’ knowledge of certain astronomical concepts between the ADT pretest and posttest, a period of about ten weeks.

A further indication of students benefiting from TP1’s improved science PCK is the expansion of students’ astronomical vocabulary to include terms that he may not have used prior to reading the Project materials, such as nebula. As he indicated:

_Had I not done the training_ [referring to the professional development day], _I would not have gone near those sorts of things [concepts] and terms._

In addition to improving student science outcomes, student literacy outcomes were also improving at this school. Further documentary evidence, researcher observations and interview data from both teachers provided many examples of teachers linking the science Project materials with the English KLA to improve student literacy outcomes. Examples include:

- The P–2 students practising open-ended questions and active listening. This was necessary to create effective communication with Professor McKinnon prior to and during use of the Bathurst telescope;
- Know, Wonder, Learn (KWL) exercises on astronomical phenomena involving students researching materials and writing complete sentences on what they had learned, and what they would like to learn more about; and,
- Guided reading for students on astronomical phenomena involving students using research skills to identify suitable materials to complement their in-class work and for use with guided-writing exercises to build their astronomy knowledge. Figure 6.10 illustrates this with two students wearing earphones at their computer.
In a further illustration of the apparent positive impact the Project had on stimulating student-literacy development, T10SS indicated to the researcher that demand for texts on astronomy from the mobile library van that visited the school each fortnight had increased dramatically as a result of students studying the Project. T10SS, the F–2 teacher with 10-years teaching experience, no science qualification or science-methods training but some experience in teaching science, was also experiencing growth in science PCK. T10SS described the more traditional project-based approach she had used for teaching astronomy to Year 6 students in the past in sharp contrast to the inquiry-based approach employed in the Middle Years Astronomy Project. When describing the impact the Project was having on her ability to teach astronomy T10SS said:

*It’s just a fantastic topic. Kids just love astronomy and when TP1SS was able to get on to the people with the telescope that added an extra dimension. We had the globe and we shone the lights on it and we talked about the seasons and then we had models of the Moon and things like that ... My previous approach was more that we would have models of the planets hanging in the room and we made models of the Earth etc.*
When asked by the researcher if student understanding of astronomical concepts improved because of implementing the Project T10 responded:

*Definitely! And the understanding of the movement of the Earth in relation to the Sun and the Moon. Because they were studying and looking at where we recorded the Moon and where it was for the whole month ... That helped definitely to improve their language and knowledge.*

### 6.1.3.1 Comments about Site 5

In response to a question from the researcher on how student use of the Wyoming telescope to obtain photographs of astronomical phenomena was going, TP1, while showing the researcher some of the great photographs of planets and nebula the students had taken, responded:

... *we'd look on a scale of how far away Uranus was and here we were using a telescope and taking photos of moons and even just one of the planets, (it) was great!*

This response, in a small way, helps capture the excitement and fascination that teachers and students in this small rural school in northeast Victoria experienced in using a telescope on the *other side of the world* to explore space through the Middle Years Astronomy Project. Teacher-interview data, student-work samples, student-made videos, reported ADT data, reports in school newsletters and researcher observations confirm that students at this site learned a great deal about astronomy in an engaging and enjoyable way. These data also indicate that the Project helped TP1 to develop his science PCK, to the extent that he is looking forward eagerly to teaching the units again next year. The data also show the integrated nature of the curriculum design used in the Project contributing to the growth in TP1’s PCK in mathematics, literacy and ICT skills.

The interview data with T10, as well as photographic evidence and student work samples, indicate that she too found the Project materials helpful in designing learning experiences to improve student understanding of key astronomical concepts. She was able to make favourable comparisons between the inquiry-based approaches used in the Project and the more traditional approaches she had used in the past to teach astronomy, an approach based mainly on project work involving students modelling the Earth and the
Moon and having mobiles of planets hanging from the class ceiling. As with students at Site 8, the Year F–2 students lay outside of the scope of this study. The issue of their inclusion in any future implementation of the Middle Years Astronomy Project is discussed more fully in Chapter 8.

In summary, when applied to data from Site 5, the framework developed in Section 2.5.1 to analyse the potential science PCK improvement indicates that:

- There is evidence of TP1ss holistically and fluidly moving between the components of science PCK identified by Magnusson et al. (1999) to improve (astronomy) science instructional strategies and student learning outcomes;
- TP1ss and T10ss improved their knowledge of designing and implementing a wider range of instructional strategies;
- There is evidence of TP1ss improving his knowledge of students’ alternative conceptions and designing instructional strategies to address this, particularly in the video provided in Appendix 6.5;
- In terms of knowledge of personal orientations to teaching science, there is some evidence of T10ss being aware of her previous approaches to teaching astronomy and preparedness to change to the inquiry based approach employed in the Project. There is also acknowledgement from TP1ss that without exposure to the Project he would have gone about teaching astronomy in a different (traditional) project-based manner;
- TP1ss and T10ss improved their knowledge of science (astronomy) content and the astronomy curriculum contained in the educative curriculum as a result of implementing the Project;
- TP1ss improved his knowledge of science assessment strategies, particularly those related to identifying students’ alternative conceptions;
- TP1ss and T10ss improved their confidence to teach astronomy, if not science more generally, as a result of implementing the Project;
- While there was no specific evidence indicating TP1ss and T10ss improved their personal attributes, a researcher observation is that TP1ss and T10ss have a mature professional relationship where constructive feedback is sought and well received and the desire to achieve great outcomes for students drives persistent resilience; and,
- There is evidence of student alternative conceptions of astronomical phenomena approaching accepted understandings of these phenomena, of students enjoying the engagement with the Project’s approach, and of student science vocabulary improving.
Finally, as with Site 8, there is evidence of the Project engaging the wider-school community in science education, which is a feature of the ideal picture for science education developed by Goodrum et al. (2001).

6.1.4 Site 7 Small Rural School in Victoria

The enrolment of 14 students in Years F–6 for this primary school, located approximately 310 kilometres from Melbourne and 50 kilometres from the nearest rural centre (population approximately 28,000 people), is drawn from nearby rural properties and a small hamlet. The school has an integrated approach to curriculum with a strong emphasis on the teaching and learning of literacy and numeracy. Information and Communication Technology (ICT) skills are integral to the school’s programs, with access for students to computers at all times to use as a learning tool. Italian language lessons, integrated into the curriculum, occur once per week. A visiting tutor teaches singing on a fortnightly basis.

The school’s staffing component consisted of one full-time and one part-time teacher, with the former being the Teaching Principal (TP3s7), as well as a part time business/administrative support staff member. In addition, the school benefitted from fortnightly visiting Art and Library Teachers as well as a monthly visiting Technology Assistant. The Cluster Coordinator is located at the school. As with the previous two case studies for Sites 8 and 5, for reasons of joint curriculum planning, the school principal elected to implement the Project for all students across Years F–6.

Set in a valley of vineyards and hop fields, the school is located in a small hamlet of about ten buildings, perched above the valley with outlooks to the Victorian Alps. Arriving at the school in this picturesque setting and walking to the school office from the car park, the first thing that catches the eye is the large brightly tiled pizza oven located in the playground next to the main classroom. This construction, built by students and volunteers, symbolises the very close links between the school and its community with the oven being used regularly by the school to provide catering for school-community evenings and by the community for social functions.
Across from the pizza oven is a very large undercover workshop area used by students to construct student-designed articles with the assistance of community members. The pizza oven and the workshop symbolise TP3_{57}’s philosophy of teaching by placing great emphasis on what he describes as practical learning. By this, he means designing instructional strategies that provide every opportunity for students to learn by doing, e.g., designing and constructing, building scale models, and acting out roles. TP3_{57} describes himself as a very practical person. Accordingly, each Thursday morning, community members work with students in the school workshop to produce student-designed articles which, in TP3_{57}’s words, give students

... the opportunity to use the computer and their ICT skills for searching, researching, writing and communicating as well as inventing and making and using their literacy.

As a very practical person, TP3_{57} with over ten years experience leading this school and over 25 years teaching experience, admitted at first to finding the Project units difficult to learn and to teach. As he pointed out to the researcher when questioned on his experience teaching astronomy:

No, I did not have a background in astronomy. I’ve got a Phys. Ed. and Outdoor Ed. background. A lot of that [referring to implementing the Project units] was difficult learning for me, and certainly reading through the extended work that was going with it [referring to the Teachers’ Guide and materials provided on the memory stick] was challenging for me personally.

However, TP3_{57} did have experience and training in environmental education from previous years where teaching one aspect of astronomy, the planets, was a feature. The emphasis, however, had been on using the planets as a guide to navigating by the stars.

Yet, as he was implementing the Project, TP3_{57} expressed increasing confidence to the researcher to teach astronomy and this confidence was discernible in his instructional delivery. When asked by the researcher to rate his confidence to teach the astronomy units at the conclusion of the Project compared with at the commencement on a scale of one to five, with one being barely confident and five being very highly confident, TP3_{57} replied:
I would have been about a 2 [at the commencement of implementation]. In my outdoor education, stars were something [we studied] so I had some knowledge but not the technical knowledge. It was all look and see knowledge. But as I read through the mountains of notes that he [Professor McKinnon] had provided, it put me in a much better place and certainly in my learning of space and in my outdoor education. Now I am maybe a 4 or a 5.

How did a Teaching Principal with very little background in astronomy, who found the Project materials personally challenging, significantly improve his confidence to teach astronomy to the extent that he rated himself as a four or five in confidence? One possible explanation is that TP3\textsubscript{57} found the practical aspects of the Project materials easy to implement and therefore confidence boosting, e.g., the construction of models, experiments to investigate craters on the Moon, and the hands-on use of software programs like Stellarium. After all, as a practical person, these units aligned nicely with his general philosophy of teaching. In addition, there is interview data from TP3\textsubscript{57} emphasising the practical nature of the Project units that supports this line of argument. For example, in response to a researcher question on whether the Project materials had provided him with any guidance on how to teach astronomy, TP3\textsubscript{57} responded:

\begin{quote}
I think the method of the practical side of it; working from the physical side of things, then putting in the knowledge and investigation ... [provided guidance]. So many people start with the knowledge, which the kids totally miss, and once they become disengaged with the body of knowledge, then the rest of it is lost because you have lost them at the start.

The one [unit] that was most successful was the actual practical thing of the solar system, the planets and setting it up in the classroom and having a scale and looking at the sizes. That was a beautiful thing because they gave us the Sun as a one-metre ball, used Pluto as this size [TP3\textsubscript{57} is using his fingers to show the size of about a pea] and a tennis ball for Jupiter. So they made a direct link to the sizes [of the planets] for the children.

And we did the Moon study. It’s a beauty because you go up each night and you see the shape and that’s really engaging. Then [in class] you put the ball up to the light and you see the shape and that’s really engaging. Then you put the ball up and get a projector and ask ‘Where is the light coming from?’ They are lovely practical things. But even the teachers [at the Professional Learning day] were saying ‘Well where is the light coming
from?‘ [Testing their preconceptions]. It promoted deep-thinking processes that challenges [the teacher].

This response is illustrative of TP3$\text{S7}$ enjoying using the beautiful practical teaching approaches suggested in the Teachers’ Guide to help his Year F–6 students to understand two key concepts: the first involves the relative sizes of the planets and their distances from each other and the second, the phases of the Moon. The suggested practical-teaching approaches to which TP3$\text{S7}$ is referring, suggested in Missions 5.3, 5.4 and 4.1 of the Teachers’ Guide, also provide content knowledge on the relative sizes and distances of the planets as well as phases of the Moon and how to go about introducing the ideas inside the classroom.

However, an examination of all of the available data for this site provides a deeper explanation for TP3$\text{S7}$’s newfound confidence to teach the astronomy units and his enjoyment in doing so. Consider, for example, the student video at Appendix 6.6. This video shows students at Site 7 in costumes that they have designed to represent each of the planets and the dwarf planet Pluto in our Solar System. As a precursor to making the video on the day, the students have:

- Worked through Mission 5.3 to calculate the relative sizes of the planets/dwarf-planet and distances from each other;
- Developed a scale model of the solar system understanding the difficulties in representing the planets/dwarf-planet on the same scale;
- Developed an understanding of the orbits of the planets/dwarf planet around the Sun. That is to say, the students have developed an understanding of representing the orbits of inner and outer planets on the same scale; and,
- Calculated the relative timing of the orbits of the planets around the Sun to be able to represent this in a model of the orbits of the planets in the solar system on the school oval.

To help his students get to the stage in their learning where they can model the orbits of the Solar System, TP3$\text{S7}$ has:

- Used the Teachers’ Guide to gain content knowledge on the relative sizes of the planets, their distances from each other and their orbital periods;
- Assisted students to calculate the relative orbits of the planets using the table in Section 5.3.3 of the Teachers’ Guide. This involves expressing each of the orbits on
a common scale to obtain a big picture view of the planets orbiting in the Solar System, then having students calculate their particular planet’s orbit relative to the next planet nearest the Sun to assist with the timing of their planet’s orbit;

- Considered the suggested instructional strategies in the Teachers’ Guide to develop a scale model of the Solar System showing the orbits of the planets, particularly the photo in Activity 5.4.5 showing students at Charles Sturt University, Bathurst, with their scale model of the Solar System and a CD playing Gustav Holst’s “The Planets Suite”; and,

- Used the content knowledge contained in the Teachers’ Guide, his knowledge of the students in the context of his school, including any alternative conceptions they hold, along with the aims of the Project mission, to design a pedagogical approach that best meets the needs of his learners.

The video shows the product of his approach is an enjoyable practical learning experience for the students that involves them acting as planets while modelling the orbits of the planets in our Solar System. The video shows students engaged intently in watching the feet of their fellow students nearer to the Sun and counting their steps to time their own orbit as they have calculated the timing and distances for each planet’s orbit relative to other planets. The dance of the orbit of the planets the students have produced with the inner planets rotating quickly following by the more slowly orbiting outer planets has allowed the students to understand a difficult concept. TP357 has thus designed an instructional approach to facilitate his students’ learning based on his knowledge of the astronomy content, knowledge of his students’ learning, including any alternative conceptions they have, and knowledge of the Project curriculum that all align with his personal teaching philosophy. The Project materials have supported him in doing this. One might conclude that TP357 has used the Project materials to enhance his science PCK.

Getting his students to model the planets and individually design a representation of a planet is a further illustration of TP357 applying science PCK to increase student learning about the planets and their orbits by immersing and engaging students in their learning. TP357 is also employing literacy strategies whereby students develop and recite poems, dressed as planets, to describe their planet. Videos showing the poems developed by students for ‘their’ planet are at Appendix 6.7.
Could the growth in TP3\textsubscript{S7}'s science PCK account for his growth in confidence to teach astronomy? Is it reasonable to assume that the growth in TP3\textsubscript{S7}'s skill to teach astronomy improved his confidence to do so? Assisting TP3\textsubscript{S7} to increase his confidence and enjoyment in teaching astronomy was the support he received from colleagues throughout implementation of the Project. The five schools comprising the cluster to which Site 7 belongs have developed into a formal community of practice (Lave & Wenger, 1991) that displays many features of a mature self-improving school system (Hargreaves, 2012). The cluster schools share innovative ideas, personnel, students, and teacher expertise when they come together for professional learning. One tangible manifestation of their commitment to support each other is the appointment of a Cluster Coordinator to plan and implement joint cluster activities. During the implementation of the Project, the Cluster Coordinator helped with the planning for the viewing evenings as well as providing IT services to set up each school’s viewing evening. As TP3\textsubscript{S7} explained:

\textit{We had the Cluster Coordinator to help set up and our IT technician comes once a month, or once a fortnight if we are lucky, so getting the IT technician to come on the night you are setting up [for viewing] is a difficult concept. TP1\textsubscript{S5} [the Teaching Principal at site 5] is one who is good [with technology] and he went up to Site 6 as TP2\textsubscript{S6} needed lots of support. But it’s investing in someone in the cluster, so our model with a support person who is technically minded in the cluster is a powerful thing to do.}

For TP3\textsubscript{S7}, who acknowledged ‘\textit{My skills are not in that [IT] area’}, knowing instant IT support was at hand to help in implementing the Project from either the Cluster Coordinator or colleagues in other schools who were facing the same implementation issues was a great benefit. In addition, support for instructional ideas for the Project was also available to TP3\textsubscript{S7} from the cluster community of practice. The Cluster Coordinator had created a \textit{Dropbox} for teachers to share innovative implementation ideas and this was available for TP3\textsubscript{S7} to use and to contribute to in order to support other members in their community of practice. Finally, in addition to the Cluster Coordinator and like-minded colleagues, TP3\textsubscript{S7} could call on the regional Science Consultant for implementation assistance. Support for teachers to implement the Project from these sources is considered more fully in Section 8.4.3.
The data reveal a number of additional supporting factors at work that appear to have improved TP357’s science PCK and his confidence to teach astronomy, and provided him with an enjoyable experience in doing so. These include:

- First, the Project’s educative curriculum provided a range of support to build curriculum content knowledge, to understand his students’ astronomy alternative conceptions, help to assess students’ understanding and to design or to modify instructional strategies. Magnusson (1999) indicates that improved knowledge of each separate element as well as improved knowledge in combining the elements holistically and stimulating movement between them fluidly, improves science PCK. Improved confidence to teach the Project’s missions is one manifestation of the development of TP357’s science PCK.
- Second, the professional learning day on the Project conducted by Professor McKinnon (prior to implementation), helped model the inquiry-based approach embodied in the Project’s materials. By placing TP357 in the position of student on the day, the professional learning day allowed TP357 to reflect on his orientation to teaching astronomy, as well as any alternative conceptions he held, in a very non-threatening way.
- Finally, a range of implementation support assisted TP357 to deliver the Project to his students. This support came from the Cluster Coordinator, a like-minded community of practice, a regional science consultant and Professor McKinnon. The improved confidence to teach astronomy assisted TP357 to conduct highly successful telescope viewing sessions. The first was a viewing evening using the remote telescope in Bathurst with assistance from Professor McKinnon where parents were ‘blown away’ with the work their students were doing. This evening involved the school’s parents and community members who camped out on the school oval. A second viewing session occurred on the following day with Scott Mecca in Wyoming. The success of the viewing sessions were built on TP357’s ability to develop students’ skills to the point where they were able to use the telescopes to photograph astronomical phenomena and to take that work back into their classroom to stimulate inquiry into those phenomena. As with students at Site 5 and Site 8, the Project’s educative curriculum had given the teachers the confidence and competence to conduct successfully the viewing evening and day.

The Project was also an enjoyable learning experience for the students. Students were observed to be engaged eagerly in their work during visits to the site by the researcher.
where they presented their work with pride showing the researcher images of planets, nebula and stars and indicated how much they were looking forward to the viewing evening and observation afternoon.

Only one of the students at the school was qualified by age to sit the ADT. The Cluster Coordinator reported a pretest score of 2 from the 15 questions and a posttest score of 10. This single case is far too limited to build any definitive conclusions but it is suggestive of growth in this student’s understanding of key astronomy concepts over the course of the Project.

6.1.4.1 Comments about Site 7

Teaching principal, Cluster Coordinator and Science Consultant interview data, student work samples, student-made videos, reported ADT data, reports in school newsletters and researcher observations confirm that the Project helped TP3_{S7} to develop his science PCK, one indication being his improved confidence to teach astronomy. As with Site 8 and Site 5, the joint nature of curriculum planning meant that non-middle-school aged students also participated in the Project at Site 7. The same data indicate that the whole group of 14 students spanning Years F–6 engaged fully with the Project materials, enjoyed doing so and learned a lot about astronomy.

In summary, when applied to data from Site 7, the framework developed in Section 2.5.1 to assess science PCK improvement indicates that:

- There is evidence of TP3_{S7} holistically and fluidly moving between the components of science PCK identified by Magnusson et al. (1999) to improve science instructional strategies and student learning outcomes, especially in the ‘orbit of the planets’ video;
- TP3_{S7} improved his knowledge of (astronomy) science instructional strategies and their implementation;
- TP3_{S7} improved his knowledge of areas of science students find difficult to understand together with strategies to remedy this;
- There is some evidence from TP3_{S7} of his preferences for practical approaches to teaching and learning that overlap with some of the educative curriculum as well as a preparedness to try an inquiry, investigative approach to teaching astronomy (the Project);
• TP3_{S7} improved his knowledge of the science (astronomy) content as well as the astronomy curriculum contained in the educative curriculum as a result of implementing the Project;
• TP3_{S7} improved his knowledge of science assessment strategies, particularly those identifying students' alternative conceptions;
• TP3_{S7} improved his confidence to teach astronomy as a result of implementing the Project;
• There was no specific evidence indicating TP3_{S7}'s personal attributes improved other than his preparedness to persist with the materials he personally found difficult to learn; and,
• There is evidence of students enjoying and engaging fully with the Project’s approach, of student science vocabulary improving. There is also evidence for the one student assessed using the ADT of her alternative conceptions of astronomical phenomena changing to align more with accepted understandings of these phenomena.

Finally, there is also evidence of the Project engaging the wider school community in science education, a feature of the ideal picture for science education developed by Goodrum et al. (2000).

6.1.5 Site 6 Rural School in Victoria

This site had an enrolment of 30 children across Years F–6 with the great majority of children travelling to school from surrounding properties and hamlets on one of two buses. The school is located approximately 280 kilometres from Melbourne and 30 kilometres from two rural centres, with populations of approximately 9,500 people and 28,000 people respectively. Serving the community for over one hundred years, the school is a standalone facility located at the intersection of three rural roads with the nearest dwellings being several kilometres away.

The school is in a competitive drawing area for students with enrolling Prep students having attended one of nine kindergartens in the two regional centres or nearby small towns located within 40 kilometres of the school. Year 6 students exiting the school travel to attend secondary schools in both the regional centres and the school’s families reside in one of the two adjacent local council areas.
Family demographics are a blend of farming families, employees commuting to regional centres, manual labourers, contractors, tradesmen and local family businesses members. The school receives extra funding because of the low socio-economic circumstances of the families of the enrolled students. Outdoor Education is a major feature of the school’s curriculum that links the six KLAs. Visiting teachers provide weekly lessons in Music and Italian and fortnightly lessons in Art and Library. The school is one of five schools in the cluster that shares planning and expertise in sport, camps and excursions, curriculum enrichment, planning and professional development. Together with the other sites in this study, the school is part of the Stephanie Alexander Kitchen Garden program, the Country Education Project, the Farm Stay program and the Melbourne University—Rural Schools of Excellence Pre-Service Teacher Training Program where trainee teacher education students engage in practicum placements.

The school had two full-time teachers with one being the part-time Teaching Principal and two part-time teachers, two integration aides and a part-time Office Manager at the time of the study. The Teaching Principal TP2S6, elected to teach the Project to the students in Years 3–6. TP2S6 advised the researcher that she had taught science, including astronomy, to Years 3–6 for several years but had no science methods in her teacher training. TP2S6’s experience in teaching astronomy to Years 3–6 was not continuous. For a number of years TP2S6 had employed T11S8, now at Site 8, to teach science at the school.

TP2S6 implemented the Project but not at the same time as TP1S5, TP3S7 and TP4S8. As TP2S6 indicated:

*I thoroughly enjoyed the PD ... and the reason I didn’t go back and apply it immediately, and I know TP1S5, TP3S7 and TP4S8 did, was at that particular time we were right in the middle of some other science unit, so we put it off for a little while.*

TP2S6 found the Project materials useful and they helped increase her astronomy content knowledge. As she pointed out:

*It was my knowledge they [referring to the Project materials] enhanced the most. That was the most useful part for me. I became much more of an authority and had more confidence in what I was saying because of those*
materials. And because, ... I guess, ... because it did that, it broadened the scope of the lessons.

TP2s6 rated herself as a two point five to three on a scale of zero to five for confidence to teach astronomy prior to teaching using some of the Project materials. After having taught using the materials, she rated herself at 3.5 to 4. She indicated that she felt her confidence had increased as a result of implementing the Project materials. During a site visit, there was evidence of TP2s6 and the students using the materials to guide their study of aspects of the Solar System (Missions 5.3, 5.4 and 5.5). Students appeared to be enjoying the learning experience.

During the implementation of the Project, however, TP2s6 had elected not to have the students control the telescopes in Bathurst or Wyoming. TP2s6 attributed this to the delay in timing the implementation of the Project due to students studying the previous science unit. As she indicated:

*Because we put it [the Project] off we missed the opportunity to link with the telescope in the USA, so I didn’t do that part of it.*

Here, TP2s6 is expressing the belief that the Wyoming telescope was available to be accessed only for a certain time of the year when, in fact, it is available throughout the whole year. This was made clear at the Professional Learning day. Interview data from the Science Consultant indicate that the reasons for TP2s6 not accessing the Wyoming or Bathurst telescopes are a little more complex and require further consideration when implementing projects of this nature on a voluntary basis.

First, TP2s6 had timetabled the Project at 10.00am in the morning to suit the school’s busy schedule. The time difference between Victoria and Wyoming of 17 hours for local daylight-saving time meant it was only 5.00pm on the previous day in Wyoming. That is to say, the time in Wyoming was at sunset when the northern sky was still too bright to take images, and thus was not an ideal time for viewing the night sky in that time zone of the USA. Restrictive enforcement of the timetable thus rendered it impossible for the students at this site to use the Wyoming telescope. Yet, that aspect was under the complete control of TP2s6.
Second, technology use within the cluster had been somewhat problematic. While the schools had Polycom video-conferencing units, their use was not widespread and those that were in use were often slow with poor acoustics. A researcher observation was that some teachers in the region, including TP26, were weary of technology failures having had many difficult experiences with the video-conferencing technology in the past.

Third, interview data from the Science Consultant supports the notion that lack of confidence with the technology requirements for the Project was an important factor affecting implementation for some teachers, including TP26. As the Science Consultant indicates:

I found it was a confidence thing [the reason TP26 did not access the telescopes]. Even when I was prepared to work with TP26, behind and in some cases in front of the classroom teacher, they [referring to TP26 and a teaching principal from a site who elected not to implement the Project] weren’t prepared to take it up at all.

The astronomy units definitely helped with student and teacher engagement [in science and scientific method] but the technical aspect tended to derail the whole thing at Site 6 and ... [at the site electing not to implement the Project materials]. It was like ‘Oh my God, that’s too hard’ and ‘We can’t do that’ and it was just too hard and it was just pushed aside. They had the swimming sports [a carnival] and they had ‘this’ and they had ‘that’ and it was just too hard to do it. It was unfortunate that people allowed their fear of the unknown to put them off implementing the Project.

E lecting not to control the remote telescopes did not prevent TP26 and her Years 3–6 students from continuing to implement aspects of the Project using small locally-sourced conventional telescopes. A friend of a relieving teacher at this site provided his telescope for a viewing evening. Students, parents and community members participated in the viewing evening complete with a sleepover at the school. This supported elements of Missions 5.3, 5.4 and 5.5 allowing students to study astronomy by using some of the Project materials and some traditional approaches to study the planets in the Solar System.
6.1.5.1 Comments about Site 6

Data from an interview with the Teaching Principal direct observations, documents, and interview data from the Science Consultant supporting the Project provide some evidence of the Project materials improving teacher subject knowledge and confidence to teach astronomy. While improvement in both areas are indicators for improvement in TP2_{S6}'s science PCK, the inability of the Project to make a greater contribution to that growth appears to lie in ensuring teachers such as TP2_{S6}, who are not confident in using technology, have the necessary technological support to implement the Project more fully.

In summary, when applied to data from Site 6, the framework developed in Section 2.5.1 to evidence science PCK improvement indicates that:

- There is no evidence to indicate TP2_{S6}'s science PCK is developing. She does not holistically and fluidly move between components to help assess and reassess the impact of instructional activity to generate desired learning outcomes during implementation of the Project;
- There is some evidence that TP2_{S6} used the Project materials to augment a more traditional instructional approach to teaching astronomy;
- There is insufficient evidence from the data to indicate TP2_{S6} is improving her knowledge of areas of astronomy students find difficult to understand together with strategies to remedy this;
- There is no direct evidence from the data showing TP2_{S6}'s increasing understanding of her personal orientations to science;
- There is insufficient evidence to show TP2_{S6}'s knowledge of science assessment improving;
- TP2_{S6} elected not to administer the Astronomy Diagnostic Test;
- TP2_{S6} improved some of her knowledge of astronomy content as well as the astronomy curriculum, contained in the educative curriculum by using materials supplied in the Project;
- TP2_{S6} experienced an increase in confidence to teach astronomy because of implementing the Project’s materials;
- There is evidence of TP2_{S6} continuing to implement the Project despite not accessing the telescopes in Bathurst or Wyoming. She did use a telescope provided by a community member;
- There is evidence of students enjoying and engaging with the Project materials. This does not include access to the remote telescope and associated activities; and
• Finally, there is evidence that the Project engaged the whole school community. Chapter 7 presents a separate summary of the results for Phase 1 and Phase 2 of the study before presenting a combined summary of both phases to allow a ‘helicopter’ view of the results of the Project to be developed. An analysis of similarities and difference between the results for Phase 1 and Phase 2 of the study is also presented in Chapter 7 together with suggested explanations for those differences.
7 CHAPTER 7 Summary and Analysis of Results for Phase 1 and Phase 2

The purpose of this chapter is to present a separate summary of the results for Phase 1 and Phase 2 of the study before presenting a combined summary of both phases to allow a ‘helicopter’ view of the results of the Project to be developed. In addition, an analysis of similarities and differences between the results for Phase 1 and Phase 2 of the study is presented together with suggested explanations for those differences.

The chapter is organised in three sections. Section 7.1 presents a separate summary of the data for Phase 1 and Phase 2 of the study. Section 7.2 then presents a summary of the data for the combined phases of the study. Similarities and differences in the data for each phase are identified in Section 7.3 followed by an analysis of possible reasons for differences in the data.

7.1 Summary of data for Phase 1 of the Study

This section presents a summary and comment on the data for Phase 1 Sites 1, 2, 3 and 4, designated as remote sites. The summary for this Phase uses the framework developed in Section 2.5.1 (Kind, 2009b; Magnusson et al., 1999; Shulman, 1986) for analysing data for evidence of the development of science PCK as the result of implementing the Project.

7.1.1 Summary of Data for Phase 1 Remote Sites—Sites 1, 2, 3 and 4

Applying the framework developed in Section 2.5.1 (Kind, 2009b; Magnusson et al., 1999 and Shulman, 1986) to analyse data from Phase 1 sites for evidence of development of science PCK as a result of implementing the Project can lead to the conclusion that the Project had made positive impacts on those who adopted either all or some of its elements. The extensive evidence emerging from the case studies includes the following:

With respect to the first indicator of PCK growth; Holistically and fluidly moving between the components of science PCK identified by Magnusson et al. (1999) to improve instructional strategies and student learning outcomes as a consequence of continuous scanning of the teaching and learning environment, there is suggestive of emerging evidence that indicates T4S2 is developing this ability for some, but not all, PCK
components. This relates to his recognition of the need to design instructional strategies taking into account students’ literacy levels, his need for content knowledge provided from the materials and his use of alternative materials from other websites to enhance his content knowledge. There is evidence indicating T7s4’s science PCK is developing because of her ability of holistically and fluidly moving between knowledge of curriculum, knowledge of assessment, knowledge of students’ difficulties and her orientations to science teaching and learning to help assess and reassess instructional activity to generate the desired learning outcomes during implementation of the Project.

As far as the PCK growth indicator Knowledge of science instructional strategies and their implementation is concerned, the data suggest that T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4 improved their knowledge and design of instructional strategies to teach astronomy as a result of implementing the Project. That is to say, eight of nine teachers improved their knowledge of this element of PCK.

For Knowledge of areas of science students find difficult to understand together with strategies to remedy this, the data reveal that T1s1 and T2s1 redesigned materials to accommodate students’ literacy levels but did not use knowledge of students’ alternative conceptions or redesign instructional strategies to address these. There is some evidence of T4s2 beginning to develop knowledge of students’ alternative conceptions and designing instructional strategies to address these. The data show T7s4 and T9s4 improving their knowledge of areas of astronomy that students find difficult to understand and using that knowledge to help design instructional strategies to help students move their understanding to more accepted understandings of astronomical concepts.

As far as developing Knowledge of one’s personal orientation to teaching science is concerned, the data suggest T4s2 is beginning to understand his personal orientations to science and which is linked to what is required to improve his science PCK. There is evidence T7s4 is improving her knowledge of her orientations toward a constructivist approach to teaching and learning Project activities and designing instructional strategies that take account of students’ prior learning.
For the PCK growth indicator *Knowledge of science assessment*, the data suggest T7s4, T8s4 and T9s4 are improving their knowledge and of using that knowledge to help design appropriate instructional strategies.

As far as *Knowledge of astronomy science content knowledge and the astronomy curriculum* is concerned, the data suggest that T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4 and T9s4 are improving their knowledge of astronomy content knowledge and the astronomy curriculum content contained in the Project.

The data for *Improved teacher confidence to teach science* suggest that the confidence of T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4 and T9s4 to teach astronomy improved quite markedly and in varying degrees while implementing the Project. The personal assessment made by teachers in response to the question of how confident they felt all showed increases.

For the PCK growth indicator *Improved personal attributes* the data suggest that at the sites with difficult social and environmental factors affecting classroom teaching and learning, T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4 and T9s4 are working enthusiastically to improve their personal attributes to improve student science learning outcomes. At issue is the type and level of support required to harness this enthusiasm to develop further their science PCK.

As far as *Improved student science learning outcomes* is concerned, the data show students at all sites enjoyed and engaged fully with the Project materials. This does not include access to the remote telescope and associated activities for some of these sites. All sites, involving T1s1, T2s1, T3s2, T4s2, T5s3, T6s3 and T8s4, held viewing evenings using their telescopes. Students particularly enjoyed these evenings. Students commented favourably on engaging with projects such as investigating and measuring crater impacts and keeping a Moon journal. Delivering the Project by establishing the Astronomy Society at Site 3 was a novel approach that provided an enjoyable experience for the students.

In addition, there is evidence of the Project involving the school community in astronomy through the viewing nights conducted at Sites 1, 2, 3 and 4. Where the ADT was
administered and pretest and posttest data returned (site 4), the evidence is suggestive of students having had many of their alternative conceptions changed.

A summary of these descriptive data showing PCK growth for Phase 1 sites is presented in Table 7.1

**Table 7.1: Summary of data showing growth by PCK**

<table>
<thead>
<tr>
<th>Indicator of PCK growth</th>
<th>Teachers involved</th>
<th>Number of Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Holistically scanning and fluidly moving between components</td>
<td>T4s2 and T7s4 beginning to do so</td>
<td>2</td>
</tr>
<tr>
<td>2. Knowledge of science instructional strategies and their implementation</td>
<td>T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4, T9s4</td>
<td>8</td>
</tr>
<tr>
<td>3. Knowledge of areas of science students find difficult to understand together with strategies to remedy this</td>
<td>T1s1, T2s1, T7s4 and T9s4</td>
<td>4</td>
</tr>
<tr>
<td>4. Knowledge of one’s personal orientation to teaching science</td>
<td>Partially for T4s2 and T7s4</td>
<td>2</td>
</tr>
<tr>
<td>5. Knowledge of science assessment</td>
<td>T7s4, T8s4 and T9s4</td>
<td>3</td>
</tr>
<tr>
<td>6. Knowledge of science (astronomy) content knowledge and curriculum</td>
<td>T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4 and T9s4</td>
<td>8</td>
</tr>
<tr>
<td>7. Improved teacher confidence to teach science</td>
<td>T1s1, T3s2, T4s2, T5s3, T6s3, T7s4, T8s4 and T9s4</td>
<td>8</td>
</tr>
<tr>
<td>8. Improved personal attributes</td>
<td>T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4 and T9s4</td>
<td>8</td>
</tr>
<tr>
<td>9. Improved student science learning outcomes</td>
<td>All teachers for: • enjoyment; • engagement; and, • content knowledge and skills</td>
<td>9</td>
</tr>
</tbody>
</table>

**Notes**  
* T3s2 implemented her own program at Site 2

Table 7.1 shows, for example, that as a result of implementing the project, T1s1, T2s1, T4s2, T5s3, T6s3, T7s4, T8s4, T9s4, improved their science PCK by improving their Knowledge of (astronomy) science instructional strategies and their implementation (Kind, 2009b; Magnusson et al., 1999; Shulman, 1986). Similarly, as a further example, Table 7.1 shows that as a result of implementing the project, T4s2 and T7s4 were beginning to move holistically and fluidly between knowledge of curriculum, knowledge of assessment,
knowledge of students’ difficulties and orientations to science teaching and learning to help assess and reassess instructional strategies to generate desired learning outcomes for the Project.

7.1.1.1 Comment on Table 7.1

There are a number of inferences that can be made from Table 7.1 in relation to the potential of the Project to improve the middle-year teachers’ science PCK. First, the data suggest that the Project’s educative curriculum improved the science PCK on five of nine growth indicators for half or more of teachers involved in implementing the Project. For all nine growth indicators, the data suggests two or more teachers improved their science PCK for that particular indicator. For the PCK indicator *Improved student-science learning outcomes* the data suggest student engagement and enjoyment with astronomy at all sites improved and at some sites suggested that students’ alternative conceptions moved towards more accepted scientific explanations for particular phenomena. There is evidence of improved science knowledge, skill and vocabulary at most sites.

Second, measured by the number of teachers showing improvement in a PCK growth indicator, the data suggest that for teachers at the remote Phase 1 site, the Project’s educative curriculum had the greatest impact on improving the following components of science PCK:

- Knowledge of science instructional strategies and their implementation;
- Knowledge of science content and the science curriculum;
- Improved teacher confidence to teach science;
- Improved personal attributes; and
- Improved student science-learning outcomes.

This was followed by:

- Knowledge of areas of science that students find difficult to understand together with strategies to remedy this; and,
- Knowledge of science assessment.

Third, measured by number of teachers showing improvement in a PCK growth indicator, the data suggest the Project’s educative curriculum had the least impact on improving the following components of science PCK:
• Knowledge of one’s personal orientation to teaching science; and,
• Holistically scanning and fluidly moving between components.

However, being able to scan holistically the teaching and learning environment and move fluidly between PCK components to adjust teaching strategies in response is the hallmark of the ‘expert’ science teacher and takes time to develop. The fact that many of the teachers in Phase 1 of the study were at an early career stage may have been a mitigating factor to acquiring this integrative component of PCK. This is discussed further in Section 7.4.2.

It is also suggested that career stage of participating teachers may have been a major factor influencing the results on Knowledge of one’s personal orientation to teaching science where teachers in the beginning stages of their careers are still developing their knowledge of their orientations to teaching science and how that can affect their choice of instructional strategies.

7.2 Summary of the Data for Phase 2 Rural Sites in Victoria—Sites 5, 6, 7 and 8.

This section presents a summary and comment on the data for Phase 2 Sites 5, 6, 7 and 8 designated as rural sites. The summary for this Phase uses the framework developed in Section 2.5.1 (Kind, 2009b; Magnusson et al., 1999; Shulman, 1986) for analysing data for evidence of the development of science PCK as the result of implementing the Project.

7.2.1 Summary of Data for Phase 2 Rural Sites—Sites 5, 6, 7 and 8

It is important to recognise that T10S5 and T12S8, as teachers of Years F–2 students, were not the direct focus of this study. However, data for both teachers have been included due to the joint nature of curriculum planning at Phase 2 sites and to illuminate the effects of implementing the Project with Years F–2 students at Sites 5 and 8 respectively. Applying the framework developed in Section 2.5.1 (Kind, 2009b; Magnusson et al., 1999; Shulman, 1986) to investigate Phase 2 sites for evidence of development of science PCK indicates a number of things.

In terms of the first PCK growth indicator, teacher ability to scan holistically the teaching and learning environment to assess and reassess the effectiveness of teaching and
learning approaches and to make fluid in the moment modifications in response to changes occurring in any of the five components of science PCK described by Magnusson et al. (1999), TP1s5, TP3s7 and T11s8 appeared to move holistically and fluidly between knowledge of curriculum, knowledge of assessment, knowledge of students’ difficulties and orientations to science teaching and learning to help assess and reassess their instructional strategies to generate the intended learning outcomes during implementation of the Project.

As far as knowledge of (astronomy) science instructional strategies and their implementation is concerned, TP1s5, TP3s7, T10s5, T11s8 and T12s8 improved their knowledge and design of instructional strategies to teach astronomy because of implementing the Project. There is also some evidence to show that TP2s6 improved her knowledge and design of instructional strategies to teach astronomy because of implementing the Project.

With respect to knowledge of areas of science students find difficult to understand together with strategies to remedy this, TP1s5, TP3s7, T11s8 and T12s8 improved their knowledge and used it to help design instructional strategies to help students move their understanding to more accepted understandings of astronomical concepts.

For the PCK growth indicator knowledge of one’s own personal orientation to teaching science, TP1s5, TP3s7 and T11s8 improved this personal knowledge and the effect this has on their choices of instructional strategies.

As far as knowledge of science assessment is concerned, the data suggest that TP1s5, TP3s7 and T11s8 improved their knowledge of assessment strategies, particularly those identifying students’ astronomy alternative conceptions.

For the PCK growth indicator knowledge of science (astronomy) content knowledge and knowledge of the astronomy curriculum contained in the educative curriculum, TP1s5, TP2s6, TP3s7, T10s5, T11s8 and T12s8 appear to have improved their knowledge of the astronomy component of the science curriculum.
In terms of *improved teacher confidence to teach science*, the confidence of TP1S5, TP2S6, TP3S7, T10S5, T11S8 and T12S8 to teach astronomy improved because of implementing the Project.

For the PCK growth indicator *improved personal attributes*, there are data to indicate T11S8 improved her perseverance to teach astronomy.

Finally, as far as *improved student science learning outcomes* is concerned, students’ alternative conceptions of astronomical phenomena changed to align better with accepted science understandings at Sites 4, 5, 7 and 8. At all sites the data show students enjoyed and engaged with the Project’s approach, and of student science vocabulary improving.

The data show the Project involved the school communities in the viewing nights conducted at Sites 5, 6, 7 and 8. The data also show the Project going beyond the immediate school community of parents and students to attract members into their schools from the wider community in the form of amateur astronomers and other interested people to engage with the Project thus bringing *science to life* for these groups.

Table 7.2 summarises the data for Phase 2 of the Project.
## Table 7.2: Phase 2 summary of data showing growth by PCK indicator

<table>
<thead>
<tr>
<th>Indicator of PCK growth</th>
<th>Phase 2</th>
<th>Number of Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher Codes: TP1\textsubscript{55}, TP2\textsubscript{56}, TP3\textsubscript{57}, T10\textsubscript{55}, T11\textsubscript{58}, T12\textsubscript{58}***</td>
<td>Maximum 6</td>
<td></td>
</tr>
<tr>
<td>1. Holistically scanning and fluidly Moving between components</td>
<td>TP1\textsubscript{55}, TP3\textsubscript{57} and T11\textsubscript{58}***</td>
<td>3</td>
</tr>
<tr>
<td>2. Knowledge of science instructional strategies and their implementation</td>
<td>TP1\textsubscript{55}, TP3\textsubscript{57}, T10\textsubscript{55}***, T11\textsubscript{58} and T12\textsubscript{58}</td>
<td>5</td>
</tr>
<tr>
<td>3. Knowledge of areas of science students find difficult to understand together with strategies to remedy this</td>
<td>TP1\textsubscript{55}, TP3\textsubscript{57}, T11\textsubscript{58} and T12\textsubscript{58}***</td>
<td>4</td>
</tr>
<tr>
<td>4. Knowledge of one’s personal orientation to teaching science</td>
<td>TP1\textsubscript{55}, TP3\textsubscript{57} and T11\textsubscript{58}</td>
<td>3</td>
</tr>
<tr>
<td>5. Knowledge of science assessment</td>
<td>TP1\textsubscript{55}, TP3\textsubscript{57} and T11\textsubscript{58}</td>
<td>3</td>
</tr>
<tr>
<td>6. Knowledge of science (astronomy) content knowledge curriculum</td>
<td>TP1\textsubscript{55}, TP2, TP3\textsubscript{57}, T10\textsubscript{55}<em><strong>, T11\textsubscript{58} and T12\textsubscript{58}</strong></em></td>
<td>6</td>
</tr>
<tr>
<td>7. Improved teacher confidence to teach science</td>
<td>TP1\textsubscript{55}, TP2\textsubscript{56}, TP3\textsubscript{57}, T10\textsubscript{55}<em><strong>, T11\textsubscript{58} and T12\textsubscript{58}</strong></em></td>
<td>6</td>
</tr>
<tr>
<td>8. Improved personal attributes</td>
<td>T11\textsubscript{58}</td>
<td>1</td>
</tr>
<tr>
<td>9. Improved student science learning outcomes</td>
<td>All teachers for:</td>
<td>6</td>
</tr>
<tr>
<td>• enjoyment;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• engagement; and,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• content knowledge and skills</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Notes

** TP4\textsubscript{58} did not implement the Project at Site 8 and is not recorded in the table. T11\textsubscript{58} and T12\textsubscript{58} did this.

### Table 7.2 shows, for example, that as a result of implementing the project, TP1\textsubscript{55}, TP3\textsubscript{57}, T10\textsubscript{55}***, T11\textsubscript{58} and T12\textsubscript{58}*** improved their science PCK by improving their knowledge of science instructional strategies and their implementation (Kind, 2009b; Magnusson et al. (1999). As a further example, Table 7.2 shows that as a result of implementing the project, TP1\textsubscript{55}, TP3\textsubscript{57} and T11\textsubscript{58} were able to move holistically and fluidly between knowledge of
curriculum, knowledge of assessment, knowledge of student’s difficulties and orientations
to science teaching and learning to help assess and reassess instructional strategies to
generate desired learning outcomes for the Project.

There are a number of inferences that can be made from Table 7.2 in relation to the
potential of the Project to improve the middle-year teachers’ science PCK. Firstly, the data
suggest that the Project’s educative curriculum improved science PCK on eight of nine
growth indicators for half or more of teachers and teaching principals involved in
implementing the Project. For the PCK indicator *improved student science learning outcomes*, the data suggest high student engagement and enjoyment with astronomy at all sites and at some sites also suggested that students’ alternative conceptions moved towards more accepted scientific explanations for particular phenomena.

Secondly, measured by the number of teachers and teaching principals showing
improvement in a PCK growth indicator, the data suggest that for Phase 2 sites, the
Project’s educative curriculum had the greatest impact on improving the following
components of science PCK:

- Knowledge of science content and the science curriculum;
- Improved teacher confidence to teach science;
- Improved student science learning outcomes; and,
- Knowledge of science instructional strategies and their implementation.

This was followed by:

- Knowledge of areas of science that students find difficult to understand
together with strategies to remedy this;
- Knowledge of science assessment;
- Knowledge of one’s personal orientation to teaching science; and,
- Holistically scanning and fluidly moving between components.

Thirdly, measured by number of teachers and teaching principals showing improvement in
a PCK growth indicator, the data suggest the Project’s educative curriculum had the least
impact on improving the following components of science PCK:

- Improved personal attributes.

A possible reason for this last result is discussed in Section 7.4.1.
7.3 Summary of the Results from Phase 1 and Phase 2 of the Case Studies

Table 7.3 presents a summary of results from Phase 1 and Phase 2 of the case studies.

Table 7.3: Summary of data showing growth by PCK

<table>
<thead>
<tr>
<th>Indicator of PCK growth</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Number of Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Teachers involved</td>
<td>Teacher Codes: T1, T2, T3, T4, T5, T6, T7, T8, T9</td>
<td>Teacher Codes: TP1, TP2, TP3, TP10, TP11, TP12</td>
</tr>
<tr>
<td></td>
<td>T4s2 and T7s4 beginning to do so</td>
<td>TP1s5, TP3s7 and T11s8</td>
<td>5</td>
</tr>
<tr>
<td>1. Holistically scanning and fluidly moving between components</td>
<td>T1s5, T2s5, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4</td>
<td>T11s8 and T12s8***</td>
<td>13</td>
</tr>
<tr>
<td>2. Knowledge of science instructional strategies and their implementation</td>
<td>T1s5, T2s5, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4</td>
<td>TP1s5, TP3s7, T11s8 and T12s8***</td>
<td>8</td>
</tr>
<tr>
<td>3. Knowledge of areas of science students find difficult to understand together with strategies to remedy this</td>
<td>Partially for T4s2 and T7s4</td>
<td>TP1s5, TP3s7 and T11s8</td>
<td>5</td>
</tr>
<tr>
<td>4. Knowledge of one’s personal orientation to teaching science</td>
<td>T7s4, T8s4, and T9s4</td>
<td>TP1s5, TP3s7 and T11s8</td>
<td>6</td>
</tr>
<tr>
<td>5. Knowledge of science assessment</td>
<td>T1s5, T2s5, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4</td>
<td>TP1s5, TP2, TP3s7, TP10s5, T11s8 and T12s8***</td>
<td>14</td>
</tr>
<tr>
<td>6. Knowledge of science (astronomy) content knowledge and curriculum</td>
<td>T1s5, T3s2, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4</td>
<td>TP1s5, TP2s6, TP3s7, TP10s5***, T11s8 and T12s8***</td>
<td>14</td>
</tr>
<tr>
<td>7. Improved teacher confidence to teach science</td>
<td>T1s5, T3s2, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4</td>
<td>T11s8</td>
<td>9</td>
</tr>
<tr>
<td>8. Improved personal attributes</td>
<td>T1s5, T2s5, T4s2, T5s3, T6s3, T7s4, T8s4, and T9s4</td>
<td>T11s8</td>
<td>9</td>
</tr>
<tr>
<td>9. Improved student science learning outcomes</td>
<td>All teachers for: enjoyment; engagement; and, content knowledge and skills</td>
<td>All teachers for: changing alternate conceptions; enjoyment and engagement; science vocabulary; knowledge and skills</td>
<td>14</td>
</tr>
</tbody>
</table>

Notes

* T3s2 implemented her own program at Site 2
** TP4s8 did not implement the Project at Site 8 and is not recorded in the table. T11s8 and T12s8 did this.
*** T10s5 and T12s8 were teachers of F–2 students who technically lay outside of the scope of this study but who were included due to the joint nature of curriculum planning in small rural schools. TP3s7 also included the whole school from F–6 when implementing the Project for the same reason.
Table 7.3 shows, for example, that as a result of implementing the project, T1\textsubscript{S1}, T2\textsubscript{S1}, T4\textsubscript{S2}, T5\textsubscript{S3}, T6\textsubscript{S3}, T7\textsubscript{S4}, T8\textsubscript{S4}, T9\textsubscript{S4}, TP1\textsubscript{S5}, TP3\textsubscript{S7}, T10\textsubscript{S5}, T11\textsubscript{S8} and T12\textsubscript{S8} improved their science PCK by improving their *Knowledge of science instructional strategies and their implementation* (Kind, 2009; Magnusson et al., 1999; Shulman, 1986). Similarly, as a further example, Table 7.3 shows that as a result of implementing the project, T4\textsubscript{S2} and T7\textsubscript{S4} were beginning to move holistically and fluidly between *knowledge of curriculum, knowledge of assessment, knowledge of student’s difficulties and orientations to science teaching and learning to help assess and reassess instructional strategies to generate desired learning outcomes for the Project*. The data for TP1\textsubscript{S5}, TP3\textsubscript{S7} and T11\textsubscript{S8}, in contrast, show that rather than beginning to do so, these educators were able to move *holistically and fluidly among PCK components* to make in-the-moment decisions to achieve major student learning outcomes.

### 7.3.1 Comment on Table 7.3

A number of inferences can be made from Table 7.3 in relation to the potential of the Project to improve the middle-year teachers’ science PCK. First, the data suggest that the Project’s educative curriculum improved science PCK on six of nine growth indicators for half or more of teachers and teaching principals involved in implementing the Project. For all nine PCK growth indicators, the data suggests five or more teachers improved their science PCK for that indicator. For the PCK indicator, *improved student science learning outcome* the data suggest student engagement and enjoyment with astronomy at all sites improved and at some sites suggested that students’ alternative conceptions moved towards more accepted scientific explanations for particular phenomena. There is evidence of improved science knowledge, skill and vocabulary at most sites.

Second, measured by the number of teachers and teaching principals showing improvement in a PCK growth indicator, the data suggest that for teachers at remote (Phase 1) and rural (Phase 2) sites combined, the Project’s educative curriculum had the greatest impact on improving their *knowledge of science instructional strategies and their implementation, knowledge of science content and the science curriculum, improved*
student science learning outcomes and improved teacher confidence to teach science. This was followed by improved personal attributes, knowledge of areas of science that students find difficult to understand together with strategies to remedy this; and, knowledge of science assessment.

Third, measured by number of teachers and teaching principals showing improvement in a PCK growth indicator, the data suggest the Project’s educative curriculum had the least impact on improving knowledge of one’s personal orientation to teaching science’ and holistically scanning and fluidly moving between components. As indicated above, possible reasons for these two exceptions are discussed in Section 7.4.1 and Section 7.4.2 respectively.

7.4 Similarities and Differences between the data for Phase 1 and Phase 2 Case Studies

In terms of similarities in the data for Phase 1 and Phase 2 sites, the data indicate that all or all bar one of the teachers/teaching principals in both phases improved their PCK in the areas of knowledge of science instructional strategies and their implementation, knowledge of science (astronomy) content knowledge and the ‘astronomy’ science curriculum contained in the Project, improved teacher confidence to teach science, and improved student science learning outcomes. The single biggest difference in results between Phase 1 and Phase 2 of the study is in improved personal attributes where this PCK growth indicator was present for eight of nine teachers in Phase 1 sites and only one of six teachers/teaching principals in Phase 2 sites. A possible explanation for this is discussed in Section 7.4.1.

Equal numbers of teachers/teaching principals at sites in both phases of the study showed growth in the PCK indicators knowledge of areas of science students find difficult to understand together with strategies to remedy this, and knowledge of science assessment (four teachers and three teachers respectively in each phase). It should be noted, however, that given the numbers of teachers/teaching principals participating in each of the phases these numbers represent a higher proportion of teachers/teaching principals
showing growth in the PCK indicator at the Phase 2 sites. Given that PCK development takes time and the teachers in the rural Phase 2 sites had more teaching experience than teachers in the Phase 1 remote sites, a reasonable inference is that the difference is due to their greater experience. A further factor accounting for this, it can be argued, is that the greater engagement at the Phase 2 sites lies in the fact that the participants were able to access the remote telescopes in Wyoming and Bathurst allowing them to be more fully immersed in the Project. Yet another factor accounting for the engagement difference may have been the greater relative stability of teachers at the Phase 2 rural sites compared with the more short-lived nature of their tenure at the remote sites. The more experienced teachers had, for example, established themselves with their students and and with the school communities, which resulted in fewer difficult classroom management issues. Improvements made to the Project’s resources between the phases may offer further explanation for the differences in the engagement data.

For knowledge of one’s personal orientation to teaching science and holistically scanning and fluidly moving between components, relatively fewer teachers/teaching principals (two and three teachers respectively in Phases 1 and 2) showed growth in this PCK indicator. Differences in the data between Phase 1 and Phase 2 sites for the PCK indicator improved personal attributes are discussed in Section 7.4.1. Section 7.4.2 examines differences between the phases for the PCK indicator holistically scanning and fluidly moving between PCK components.

7.4.1 Accounting for the differences in improved personal attributes

One possible explanation for the difference in the numbers of teachers showing improvement on the PCK indicator improved personal attributes between Phase 1 and Phase 2 sites may lie in the career profile of the teachers participating at each of the two locations. The great majority of teachers in Phase 1 sites were early-career graduate teachers who needed to develop quickly the skills of resilience and perseverance as well as skills in giving and receiving feedback as part of learning the profession. To this extent a culture of needing to bounce back during the early stages of their careers as they
attempted to learn the profession in challenging remote locations was constantly present with participating teachers showing high degrees of resilience and a thirst for help on how to develop as professionals. At issue for these teachers was that their desire for feedback and the opportunity to network with colleagues in other schools to give and receive feedback on their teaching was not being met through either internal or external support mechanisms.

In contrast, the career profile of Phase 2 teachers showed more experience with many more years of teaching experience in relatively stable teaching and learning environments. T11s8, TP1s5 and TP2s6, already had well-developed personal attributes including strong reflective practitioner skills, high levels of resilience and the ability to provide and receive constructive feedback often as part of a professional learning network of colleagues in a highly functioning cluster of schools. It was, therefore, more difficult for the data to show evidence of growth in these personal attributes for these teachers/teaching principals although T11s8 did demonstrate a willingness to try the Project’s integrated inquiry-based, investigative approaches using technology when she had initially felt uncomfortable in using the technology.

7.4.2 Accounting for the differences in holistically scanning and fluidly moving between components of PCK

This study suggests the development of PCK takes time, and more particularly in developing the capacity of being able to holistically and fluidly move between elements of PCK to continually assess and reassess the effectiveness of instructional strategies. This study suggests that this attribute is one hallmark of effective and experienced teachers of science. The different career profile for the teachers/teaching principals in each phase of the study it is argued is likely to be a factor in accounting for the differences in this indicator in each phase of the study. To illustrate this, consider representing the career profile of teachers on a continuum from Trainee Teacher to Expert or Lead Teacher on a horizontal axis. Career descriptors would include Trainee Teacher, Graduate; Proficient; Highly Proficient; Accomplished and Lead or Expert Teacher. On the vertical axis is placed
the elements of PCK (Kind, 2009b, Davis & Krajcik, 2005, Magnusson et al, 1999). This is shown in Table 7.4 together with indicator of PCK growth for teachers T2_{S1}, T9_{S4} and T11_{S8} as examples with evidence of their PCK growth by PCK indicator represented by a ‘tick’ symbol.

Table 7.4: Indications of PCK growth for T2_{S1}, T9_{S4} and T11_{S8}

<table>
<thead>
<tr>
<th>Elements of PCK</th>
<th>T2_{S1}</th>
<th>T9_{S4}</th>
<th>T11_{S8}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Holistically and fluidly apply Science curriculum</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Areas students find difficult</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Instructional strategies</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Improved confidence</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Science assessment</td>
<td></td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Personal Orientation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Student outcomes</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
<tr>
<td>Personal attributes</td>
<td>√</td>
<td>√</td>
<td></td>
</tr>
</tbody>
</table>

Table 7.4 shows that teacher T2_{S1} at Site 1, a remote site, is a Graduate Teacher with *Zero experience with science and no experience in teaching astronomy*. Teacher T2_{S1} is representative of remote teachers in the early stages of their careers in Phase 1 of this study with little or no qualifications or experience to teach astronomy. Teacher T9_{S4} at Site 4, a remote site, is a Proficient Teacher with five years teaching experience and has a science major in Biology but no methods training or experience in teaching astronomy. Teacher T9_{S4} is representative of Proficient Teachers with several years teaching experience who have qualifications and experience in teaching science but little or no methods training or experience in teaching astronomy. Teacher T11_{S8} in Table 7.4 at Site 8, a rural site, is a Lead Teacher with over 20 years teaching experience with some of that
time being spent teaching science and some science methodology training that occurred in her primary teaching degree. T11_{s8} is representative of the leading teachers and teaching principals with many years of teaching experience, including teaching science.

The career profile of Phase 1 teachers, overwhelmingly in the Graduate category, means by necessity they are engaged in learning the profession. If we take T2_{s1} as an example of this group of teachers, prior to implementing the Project, T2_{s1} had little qualification or experience in teaching science or astronomy in particular. This understandably resulted in T2_{s1} having little if any knowledge of science instructional strategies, science content knowledge, knowledge of astronomy students have difficulty in understanding and low confidence to teach astronomy at the commencement of implementing the Project. Thus, T2_{s1} gave herself a rating of 1 on a five point rating scale for confidence to teach astronomy, indicating that she was not confident to teach astronomy. As a result of implementing the project, T2_{s1} improved her PCK in each of the six areas listed above. However, T2_{s1}’s knowledge of areas students have difficulty in learning is only beginning to develop and is focused on the literacy demands of the materials and the extent to which students understand the text rather than key astronomy concepts students find difficult to learn. The instructional strategies T2_{s1} selects to help address this situation focus on modifying the text in the materials together with teacher reinterpretation of the text to make it understandable to students.

T2_{s1}’s personal orientations to science are still developing. She did not articulate her beliefs about science and science teaching and learning. For example, she has not articulated or demonstrated a theory of student science learning and the responses this elicits when designing instructional approaches to help her students learn astronomical concepts do not take this element of PCK into account. In addition, T2_{s1}’s knowledge of science assessment is still developing. She has not articulated or demonstrated those parts of student learning that are the most important to assess or how to go about assessing these important areas using proven methods of assessment.
Unsurprisingly, this results in T2s1 not being able to demonstrate holistically and fluidly moving between components of PCK to continually assess and reassess the effectiveness of instructional strategies when taking into account knowledge of areas students have difficulty in understanding, her knowledge of the curriculum, knowledge of assessment and knowledge of her personal orientations to science. As stated above, T2s1 is still developing her knowledge of areas of PCK and how to move fluidly between PCK components. As T2s1 develops further her knowledge of instructional strategies, knowledge of areas students find difficult to learn, knowledge of her personal orientation to science, knowledge of assessment, personal attributes and confidence to teach science and with support from educative curricula, face-to-face professional learning and experienced colleagues, it can reasonably be anticipated that she will develop the skill of moving holistically and fluidly between PCK elements.

Compared to T2s1, Table 7.4 shows improvements in PCK for all indicators for T11s8. Key differences in PCK improvement for T11s8 and T2s1 are in the areas of knowledge of personal orientations to teaching science, knowledge of science assessment, and ability to scan holistically the teaching and learning environment to assess and reassess the effectiveness of teaching and learning approaches and to make fluid in the moment modifications in response to changes occurring in any of the five components of PCK described by Magnusson et al. (1999).

One possible explanation for the differences relating to personal orientations is that T11s8, through greater experience, support and professional learning in teaching science, has reached a point in her career where she can articulate and demonstrate her beliefs and views on science teaching. This has allowed T11s8, for example, to develop an implementation plan for the Project based on a 5Es approach (Bybee, 2005) employing an inquiry-based approach using a constructivist model of student learning. T11s8’s unit plan shows the instructional strategies she selects are influenced by her beliefs about the inquiry-based, constructivist theory of student learning.
In relation to science assessment strategies, T11’s experience and qualifications for teaching science have led her to use the ADT to diagnose areas where students are likely to hold alternative conceptions. With her knowledge of science assessment strategies and areas of the curriculum where students are likely to hold alternative conceptions, T11 is able to plan a variety of assessment approaches to assess student-learning progress as well as to diagnose how well her instructional strategies are being implemented.

T11’s existing PCK, which has been developed over time, allow her to move holistically and fluidly between the components of PCK to continuously assess the effectiveness of her instructional strategies when taking account of the context of her students and any alternative conceptions they may hold, her knowledge of the astronomy curriculum, her knowledge of student assessment and her knowledge of her beliefs about science, as illustrated in her work with students on explaining the causes of the seasons. This results in T11 being able to continuously monitor her science teaching and learning environment to be able to adjust her instructional approaches in response to changes in any of the PCK components.

However, this is not to suggest that the skill of *holistically scanning and fluidly moving between components* is rigidly fixed to a teacher’s career stage. As Kind (2009b) and others have pointed out, while experience is a likely indicator for PCK growth and teacher effectiveness there are no doubt science teachers in the Accomplished and Highly Accomplished stages of their careers that excel in moving holistically and fluidly between components of PCK to help students learn effectively and there are no doubt teachers with many years’ experience who cannot achieve this. This study does suggest, however, the development of the *holistic and fluid* component of PCK requires an initial strong foundation of PCK to build on with further developments that can be initiated over time. At issue is the support provided to teachers to assist their ability to acquire this element of PCK growth because of its association with ‘master’ or ‘lead’ teacher capability and effectiveness.
Importantly for science teachers, visualising PCK improvement as occurring along a career continuum reinforces the view that existing PCK can be refined and improved over time. Questions concerning how long it takes to develop teachers’ ability to *holistically scan and fluidly move between components* and how this process can be accelerated are areas for further investigation. These questions are considered in Chapter 8.
8 CHAPTER 8 Discussion

This chapter has four purposes. First, the results are briefly summarised and interpreted and the findings of the research explained. Second, the limitations of the study are discussed. Third, the implications for practice are discussed. Finally, further areas for research are suggested.

At the individual level, the study of science plays an important role in equipping students with scientific literacy, a key skill required to thrive in today’s world. At the national level, the study of science contributes to the development of conceptual, creative advances, technology, information literacy and higher-order thinking skills (Australian Chamber of Commerce and Industry, 2007; Business Council of Australia, 2014; Johnson, 2005) all of which are key skills required of knowledge workers in interconnected global knowledge economies.

In Australia, teaching Science to students in Years F–10 is mandatory with an expectation that the subject will be taught well (ACARA, 2011). However, an examination of school science education literature as well as national and international assessment data reveals two areas where improvements to the teaching of science can be made. The first lies in the middle years of schooling where student aspirations toward the study of science are formed. The evidence generated in this study indicates much can be done to shift the science-achievement curve to the right while simultaneously closing the gaps in performance for equity cohorts (ACARA, 2011; ACER, 2013; Chadbourne, 2001; Chubb, 2012; Dinham & Rowe, 2009). In the middle school years, the evidence also indicates that more can be done to achieve the ideal picture of science (Goodrum et al., 2001) by providing curriculum relevant to the needs and personal experiences and interests of students; by providing inquiry-centred teaching and learning opportunities, which allow students to investigate and test ideas by providing a teaching and learning environment characterised by fun; engagement in learning, by building mutual respect between teacher and students in the learning environment; and, by ensuring assessment serves highly effective science teaching (Goodrum, et al., 2001; Marginson et al., 2013).
The second area for improvement lies in rural and remote regions, where the data and literature show students experience education disadvantage due to a range of factors impacted by their geographic isolation. This rural educational disadvantage adversely affects their ability to experience the ideal picture of science education (Goodrum et al., 2001) or to achieve at the same level of performance as their metropolitan counterparts on a range of education indicators (Australian Senate, 2009; COAG, 2013; National Assessment Program for-Scientific Literacy, 2003–2012; Sidoti, 2000; OECD–PISA, 2012; Trends in International Mathematics and Science Study, 2011; VAGO, 2014).

The literature provides strategic guidance on how to implement approaches to improve school science education in the middle years in rural and remote areas, commencing with improving the effectiveness of science teachers by enhancing their training and by providing ongoing support to achieve this ideal picture of science education (Australian Productivity Commission, 2007, 2010; Dow, 2003a; Goodrum et al., 2001; Goodrum et al., 2012; Marginson et al., 2013). Improving the effectiveness of science teachers requires improving their Pedagogical Content Knowledge (PCK) which, in turn, improves their ability to achieve the key components of the ideal picture of science education. The focus of this study has involved exploring the development of PCK for teachers of science in the middle years of schooling in rural and remote schools so that science is part of the curriculum and is taught well.

The literature discussed in Section 2.2.8 and Section 2.2.9 shows that improving teachers’ science PCK in the middle years of schooling in rural and remote areas using traditional face-to-face professional learning activities presents a number of challenges. These include lack of availability of casual relief teachers to release teachers to engage in professional learning and difficulties in attracting and retaining science teachers to teach in middle schools resulting in, for example, fewer experienced science teachers to assist the less experienced ones to develop their PCK though activities such as analysing 360-degree-data from their classrooms. Further challenges arise for teachers of science in middle schools in rural and remote areas because they experience significantly fewer professional learning opportunities than their metropolitan counterparts (ACDS, 2005;
ASPA, 2006; Lyons, 2006), lack science content knowledge and experience limited exposure to science PCK development in their teacher training. This adversely affects teacher confidence to teach science (Appleton, 2003, 2005) with one consequence being a reduction in the frequency of science lessons in the school curriculum, especially in primary schools (Goodrum et al., 2001; NAP-SL, 2011).

Educative curricula designed to improve teacher PCK provide an alternative to traditional face-to-face professional learning for science teachers. Educative curricula embed professional learning for teachers within the curriculum materials and can help to improve PCK while simultaneously providing a structure to improve student-learning outcomes (Davis & Krajcik, 2005). One educative curriculum currently in use in some schools in rural and remote areas is the Middle Years Astronomy Project (McKinnon, 2005). This educative curriculum provides access to telescopes in NSW, Australia and in Wyoming, USA for students to control remotely to take photos of astronomical phenomena that form the basis of further investigation. This educative curriculum also includes a Teachers’ Guide designed to improve teachers’ PCK by providing them with guidance on designing and using appropriate instructional strategies for astronomy projects. These materials take into account knowledge of students’ difficulties in learning particular concepts, the most appropriate assessment strategies to employ, the curriculum content, and knowledge of teachers’ personal beliefs and orientations regarding science teaching and learning. This thesis has explored the potential for this Project, with its educative curriculum, to improve the PCK of teachers of science in the middle-school years located in rural and remote settings in Australia.

8.1 Overview of the Research and Data Collection

This research project set out to explore answers to the following three questions:

1. Does the Middle Years Astronomy Project (the Project) have any potential for improving teacher science PCK in the middle years of schooling in rural and remote areas with the concomitant potential to improve rural education disadvantage?

2. If it does/does not have potential, what are the reasons for this?
3. What, if any, are the implications from this study for supporting middle-years science teachers in rural and remote areas to improve their PCK?

The study employed a Type IV multiple-case, embedded mixed-methods design (Yin, 2014) over two phases in two states of Australia to explore answers to these research questions. Eight sites implementing the Project elected to participate in the research with four sites in remote Western Australia and four sites in rural Victoria. Participants were those specifically involved in implementing the Project and comprised 12 teachers, four principals, four teaching principals, one Science KLA consultant, one Cluster Coordinator and in excess of 200 primary and secondary students in the middle years of schooling. Data from the eight sites were assembled from interviews with teachers, principals, students, a Science KLA Consultant, a Cluster Coordinator and a Middle Manager; archival records; researcher direct observations; an astronomy diagnostic test; student artefacts and documents.

Data were analysed first at the site level and then by Phases of the research to look for emerging patterns. The descriptor ‘remote’ was used for Phase 1 sites and ‘rural’ for Phase 2 sites. Convergent and divergent patterns emerged from the data. The process of triangulation tested each pattern. In this way, explanation building (Yin, 2014) occurred to account for patterns emerging from the data at the individual and aggregated site levels for Phases 1 and 2 of the study. The process of explanation building by triangulating the data involved developing rival explanations (Yin, 2014). Incorporating emerging propositions to create new explanations occurred where data supported this.

A framework developed from the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986) was applied to the data to examine evidence for PCK growth. This framework indicated PCK growth if the data provided evidence of improvements in any of the following nine components:

1. Teacher ability to holistically scan the teaching and learning environment to assess and reassess the effectiveness of teaching and learning approaches and to make in the moment modifications in response to changes occurring in any of the five components of PCK described by Magnusson et al. (1999);
2. Knowledge of science instructional strategies and their implementation;
3. Knowledge of areas of science students find difficult to understand together with strategies to remedy this;
4. Knowledge of one’s personal orientation to teaching science;
5. Knowledge of science content knowledge and curriculum;
6. Knowledge of science assessment;
7. Improved teacher confidence to teach astronomy as a consequence using the educative curriculum;
8. Improved personal attributes; or,

The literature indicates that PCK growth can be conceptualised along a continuum. At one end of this continuum is improvement in one or two components of PCK. At the other end of the continuum is improvement in the ability to scan holistically the teaching and learning environment to assess and reassess the effectiveness of teaching and learning approaches and to make fluid in-the-moment modifications in response to changes occurring in any of the first five components listed above by Magnusson et al. (1999). This research supported the notion of PCK occurring along a continuum and suggests that the continuum could represent the career classifications of teachers as defined by the Australian National Professional Standards for Teachers (AITSL, 2011), i.e., trainee, graduate, proficient, accomplished, highly accomplished and lead teacher.

8.2 Summary of Results and Discussion

Section 8.2.1 summarises and discusses the results for the first research question. The results for the second research question are summarised and discussed in Section 8.2.2. Finally, Section 8.2.3 summarises and discusses the results for the third research question.

8.2.1 Research Question 1

Does the Middle Years Astronomy Project have any potential for improving teachers’ science PCK in the middle years of schooling in rural and remote areas with the concomitant potential to improve educational disadvantage?

Table 7.3 is reproduced here as Table 8.1. Table 8.1 presents a summary of data for the teacher participants’ science PCK improvement during Phases 1 and 2 by indicators of PCK.
growth developed based on the literature of Kind (2009b), Magnusson et al. (1999) and Shulman (1986).

Table 8.1: Summary of Data Showing Growth by PCK Component (From Table 7.3)

<table>
<thead>
<tr>
<th>Indicator of PCK growth</th>
<th>Phase 1</th>
<th>Phase 2</th>
<th>Number of Teachers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. Knowledge of areas of science students find difficult to understand together with strategies to remedy this</td>
<td>Teacher Codes: T151, T251, T351, T452, T553, T653, T754, T854, T954</td>
<td>Teacher Codes: T155, T255, T355*, T457, T557, T657, T757, T857, T957, T1057, T1157, T1257</td>
<td>13</td>
</tr>
<tr>
<td>6. Holistically scanning and fluidly moving between components</td>
<td>Teacher Codes: T452 and T754 beginning to do so</td>
<td>Teacher Codes: T155, T255, T355*, T457, T557, T657, T757, T857, T957, T1057, T1157, T1257</td>
<td>14</td>
</tr>
<tr>
<td>8. Improved personal attributes</td>
<td>Teacher Codes: T151, T251, T351, T452, T553, T653, T754, T854 and T954</td>
<td>Teacher Codes: T155, T255, T355*, T457, T557, T657, T757, T857, T957, T1057, T1157, T1257</td>
<td>9</td>
</tr>
<tr>
<td>9. Improved student science learning outcomes</td>
<td>All teachers for: enjoyment; engagement; and, content knowledge and skills</td>
<td>All teachers for: changing alternate conceptions; enjoyment and engagement; science vocabulary; knowledge and skills</td>
<td>14</td>
</tr>
</tbody>
</table>

A reasonable conclusion that can be drawn from examination of Table 8.1 is that the Middle Years Astronomy Project (McKinnon, 2005, 2012) has strong potential for improving teachers' science PCK in the middle years of schooling in rural and remote areas together with the concomitant potential to help redress rural education disadvantage.

Table 8.1 indicates that out of the total of 15 teachers/teaching principals listed in Table
8.1, there was growth in PCK on six of the nine growth indicators for half or more of the participants. A full analysis of the results, including similarities and differences between the outcomes for Phase 1 and Phase 2 of the Project together with possible reasons accounting for these, were presented in Chapter 7, Section 7.4.

8.2.2 Research Question 2

If it (the Project) does/does not have potential, what are the reasons for this?

As discussed in Section 8.2.1 above, the Project does have potential for improving teachers’ science PCK in the middle years of schooling in rural and remote areas with the concomitant potential to help redress rural disadvantage. It appears that this potential derives from two sources. The first lies in the Project materials conforming to the design principles for educative curricula to simultaneously elicit teacher and student learning, and the second lies in the Project having a well-conceived implementation plan. Each of these is discussed below.

The Project materials conform to the design principles to educate teachers to develop their PCK by adhering to the nine principles developed by combining the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986) as well as the design heuristics developed by Davis and Krajcik (2005) as discussed in Section 2.6.1.1 and Section 2.6.1.2. In addition, the Project materials conform to the design principles for student curriculum developed by Bybee (2006) and Donovan and Bransford (2005). Further, both teacher and student learning materials are of a high quality as well as extensive, and offer high levels of support in both in a face-to-face and in an ICT mediated fashion.

The second point, concerning the Project having a well-conceived implementation plan is achieved by delivering an intense face-to-face professional development session. This session is designed to provide an overview of the Project, to model use of the materials to teach students and, in a very subtle and non-confronting way, to allow teachers to examine and understand their science orientations so they may identify any alternative conceptions they may hold regarding key concepts covered in the Project’s curriculum. In
addition to face-to-face professional learning support, the Project provides a Teachers’ Guide containing embedded professional learning to develop teachers’ PCK including advice on designing and modifying a number of instructional strategies to teach astronomy, astronomy content knowledge to help teachers build their astronomy subject-matter knowledge, knowledge of students’ alternative conceptions in astronomy, information on students’ beliefs about astronomy and, advice on assessment practices. Details of the Teachers’ Guide are provided in Section 3.1.2.1.3.

In addition to the face-to-face and embedded professional learning support, the Project provides an Astronomy Diagnostic Test (ADT) and guidance on the alternative conceptions students are likely to have and how to deal with them. The test is administered on pre- and post-occasions to assess any changes in students’ alternative conceptions.

Further, as part of the well-conceived implementation plan, teachers are provided with high-quality resources on a USB or DVD as well as ease of access to these resources in the Teachers’ Guide through extensive hyperlinks within the materials. Finally, the Project also provided access to telescopes to control remotely with accompanying cameras to take photos of astronomical phenomena to use for further investigatory work as well as access to ongoing support at any time from the Project’s author, Professor McKinnon or from Scott Mecca in the USA during the online observation sessions.

8.2.3 Research Question 3

What, if any, are the implications from this study for supporting teachers of science in the middle years of schooling in rural and remote areas to improve their PCK?

This study identifies a number of implications for supporting teachers of science in the middle years of schooling in rural and remote areas to improve their PCK. These are dealt with in more detail in Section 8.4 as well as being summarised below.

First, the development of PCK takes time, particularly being able to holistically and fluidly move between elements of PCK to continually assess and reassess the effectiveness of instructional strategies (e.g., Loughran, Mulhall, & Berry, 2006). Visualising PCK
improvement as occurring along a career continuum reinforces the view that new PCK can be developed and existing PCK refined and improved further. Developing and improving the PCK of teachers of science in the middle years of schooling in rural and remote areas requires an integrative combination of educative curricula and face-to-face professional learning to develop both the quantity and quality of the nine PCK components identified in Section 2.5. The quality of PCK refers to teachers improving their effectiveness in applying each PCK component, especially the skill of holistically and fluidly moving between different PCK components leading to high-level student conceptual development, a characteristic of ‘master’ or ‘lead’ science teachers.

Second, given the criticality of science teachers to achieving the ideal picture for science education, this research indicates that the development of PCK cannot be left to chance. Rather, PCK development requires a planned and systematic approach for each teacher supported by the employer. In addition, teachers are time poor when it comes to developing educative curricula and they require support from education systems to develop or to have supplied high-quality educative curricula to build their PCK. Further, teachers in the middle years of schooling in remote areas face a number of significant challenges to develop their science PCK, especially graduate and proficient teachers, who require additional in-school and external support in addition to support from such educative curricula to meet these challenges.

Finally, introducing educative curricula in Years F–4 in rural and remote schools provides an opportunity to improve early primary school teachers’ science PCK. The approach identified in the Project, and investigated in this research, has important implications for the design of other educative curriculum materials and for the role of particular forms of face-to-face professional support for teachers of Years F–4 to develop their PCK. This is an area worthy of further investigation.

8.3 Limitations of the study

This section discusses the major limitations of this research. The limitations are organised around the design of the study, time and instrument selection and the timing of
researcher involvement in Phase 1 of study. Each of these limitations is discussed in the sections that follow.

8.3.1 Design

The first limitation is concerned with the case-study design of the research given the threats to validity and reliability identified and discussed in Chapter 4. However, a Type IV multiple-case, embedded mixed-methods design was suited to this study due to the need to collect multiple sources of data from participants in real-life settings as they implemented the Project. Attempts to reduce threats to construct validity, internal validity, external validity and reliability included using data from multiple sources to develop findings, triangulating data in explanation building and, accounting for divergent results.

The largest threat introduced by the case-study design lies in where it was conducted with its focus on teachers of science and students in the middle years of schooling in rural and remote settings. Thus, any attempt to generalise findings to other year levels and students in other locations requires great caution. In addition, each school is unique and generalising findings from this study to other rural and remote sites also requires caution.

8.3.2 Time and instrument selection

The second limitation concerns the time the researcher could devote to the study given the demands of his employment and its interaction with the location of the schools. Ideally, the researcher would have preferred to spend three one-week blocks at each site: one at the commencement, one in the middle and one near the end of implementation. This would have required a total time commitment at eight sites of 24 weeks. Meeting this time requirement was not possible due to employment conditions and travelling times and distances to the remote sites in Western Australia and due to employment conditions in Victoria. In addition, the fact that schools in both phases of the study were implementing the Project at the same time meant that, organisationally, it was not possible for the researcher to physically be in four separate locations at the same time.
during both Phase 1 and Phase 2. Had the researcher been able to find additional time that fitted in with both his employment situation and the organisational demands of the schools in this study, then there would have been more scope to use additional instruments, such as video equipment, to gather data on PCK development by teachers as they engaged with students in their teaching and learning environment.

8.3.3 Timing of researcher involvement in Phase 1 of the study

The third limitation concerns the stage at which the researcher became involved in the study. His involvement began when the design for the Project had been determined for Phase 1 of the study and the initial face-to-face professional development day had been conducted so that schools had commenced implementing the Project. Problems with the Western Australia Department of Education (WA DET) IT security measures prevented students and teachers using the Internet to access the CSU Remote Telescope in Bathurst to take photographs of astronomical phenomena at an early stage of implementation. The inability to control the telescope through the Internet meant, in effect, that teachers and students could not participate fully in the Missions set out in the Teachers’ Guide. Controlling the telescope was a significant additional student-motivating factor for the Project as well as a key tool with which to conduct scientific inquiries. If one were to undertake this study again and had control over timing of involvement, then participation in the study would occur well before implementation. This would enable greater time to be devoted to risk managing any potential threats to the study, including early discussion with the WA DET concerning the IT threats to the implementation of the program, and mitigating those threats. This happened in Phase 2 of the study.

8.4 Implications for practice

The results of this research suggest four implications for science education practice in rural and remote middle schools outlined in the subsequent sections. The first, that the development of PCK components takes time and requires support to be nurtured using a planned and systematic approach is discussed in Section 8.4.1. Second, there is a need for education systems to develop educative curricula to improve the PCK of teachers of
science, which is discussed in Section 8.4.2. The third implication, that teachers in remote areas require more support to develop their PCK, is discussed in Section 8.4.3. Finally, the implications for developing the science PCK of Year F–4 teachers are discussed in Section 8.4.4.

8.4.1 Development of PCK takes time

This study has shown that the development of PCK takes time, and more particularly the element of being able to holistically and fluidly move between elements of PCK to continually assess and reassess the effectiveness of instructional strategies, which this study suggests is one hallmark of effective and experienced teachers of science. This study suggests that as teachers develop along a career continuum they need first to acquire the elements of PCK and then to apply them fluidly, moving between those elements to generate high-level student conceptual development. Visualising PCK improvement as occurring along a career continuum reinforces the view that existing PCK can be refined and improved with more sophisticated PCK developing over time. This provides guidance to those who support and nurture the development of PCK by teachers of science when developing educative curricula or face-to-face professional learning experiences to catalyse its growth and development.

Allied to the notion that PCK development takes time, while noting that PCK may develop along a continuum defined, for example, by career classification, and taking into account the importance of teachers’ science PCK to achieving the ideal picture for science education for rural and remote students in middle schools, the question naturally arises as to whether or not the development of PCK can be left to chance. This study infers not. Rather than leaving PCK development to chance, this study advocates a planned and systematic approach to PCK improvement for each teacher of science. Kind (2009a) argues that PCK development needs to commence in teacher training with trainee teachers being provided with knowledge of PCK together with suggested processes for developing and recording their PCK development throughout their career.
Williams and Lockley (2012) agree with Kind (2009b) as well as Loughran, Berry and Mulhall (2006) that the use of CoRes and PAP-eRs will assist in promoting PCK development in trainee and graduate teachers and occur more efficiently if expert teachers work with beginning teachers during this process. Rural and remote students, in particular, stand to be major beneficiaries compared to what is extant now if science were to be delivered by teachers with highly developed PCK.

As teachers gain experience in teaching science, questions arise concerning the processes for developing the PCK of Trainee, Graduate, Proficient, Highly Proficient, Accomplished and Lead or Expert Teachers. This research suggests that professional learning to develop teachers’ science PCK for Trainee, Graduate and Proficient should focus on developing a strong foundation of PCK then continuously improving that foundation in the areas of:

- Knowledge of science instructional strategies and their implementation;
- Knowledge of areas of science students find difficult to understand together with strategies to remedy this;
- Knowledge of science curriculum;
- Knowledge of science assessment;
- Improving teacher confidence to teach science;
- Improved personal attributes; and,
- Improved student learning outcomes.

Once a strong foundation exists, this study suggests the focus of PCK development, while including an emphasis on continually improving these components of PCK, should include for Accomplished, Highly Accomplished and Lead Teachers:

- Knowledge of one’s personal orientation to teaching science, and
- Holistically scanning the teaching and learning environment to assess and reassess the effectiveness of teaching and learning approaches to fluidly make in the moment modifications in response to changes occurring in any of the five components of PCK described by Magnusson et al. (1999).

However, it can be anticipated that each teacher is likely to have different PCK strengths and areas that require support, and that some teachers will not conform to the career stage model alluded to above, i.e., they may demonstrate an ability to holistically scan and fluidly move between PCK components very early in their teaching careers. Thus,
personalised individual professional learning plans designed to develop each teacher’s PCK will be required. Improving teachers’ knowledge of their personal orientations to teaching science means improving their knowledge and beliefs about the purposes and goals for teaching it both in general, and at particular grade levels. This may allow teachers to understand better their personal committed beliefs about the teaching and learning of science that influence their selection of instructional approaches to teach the subject. In turn, this may further allow teachers of science to understand and evaluate alternative approaches to teaching the subject putting them in a stronger professional position to choose those that work. This should help to improve teacher PCK by improving knowledge of instructional strategies with the expectant flow-on benefits into teacher confidence and student outcomes.

The Lead Teachers and Teaching Principals in this study had the ability to scan holistically the teaching and learning environment to assess and re-assess the effectiveness of instructional strategies, as well as to make fluid in-the-moment modifications in response to changes occurring in any of the other components of PCK described by Magnusson et al. (1999). The added value obtained by being able to do this is a hallmark of the Lead Teacher and Teaching Principals in Phase 2 of this study, when compared to the less-experienced teachers in Phase 1. Developing this component of PCK requires approaches focused on helping teachers in the context of their learning environment with their students to scan, assess, implement and reassess instructional strategies, knowledge of areas of content students have difficulty in understanding, knowledge of curriculum and the science content and knowledge of assessment.

Helping teachers to develop each component of PCK and to bring them all together in the learning environment context then to read and react to signals from students to make in-the-moment adjustments by moving between PCK components requires a professional-development approach that gathers data from students and teachers, and analyses teacher reactions to those data. While the data from students may be analysed for the teacher by each PCK component (instructional strategy, curriculum knowledge,
understanding of students’ alternative conceptions, orientations and assessment), the data for the teacher needs to be analysed holistically by teacher movement amongst these PCK components. This places the emphasis on the teacher recognising changes in of the PCK components by continually scanning the learning environment then responding holistically and fluidly to these changes.

An analogy from sport provides a content representation to help, perhaps, illustrate this fluidity of movement. Thus, the coach (Lead Teacher) ensures players in a team have mastered not only the individual techniques of the game (the components of PCK) but also how to read the game and to react accordingly. Reading the game requires the player to understand what is happening at each moment of the game then to select the correct technique(s) at the right time and to implement them effectively during the time they, as a player, are involved in the game. Having done this, the player continues to read the game, ready in anticipation of having to react again by selecting the appropriate techniques at the right time and implementing those effectively (and so on) in a recursive fashion until the end of the game. In analogous fashion, for each teacher of science, each component of PCK needs to be developed as does the teacher’s ability to read the learning environment and to holistically and fluidly apply the right instructional strategy in the right way at the right time to achieve the goals of the lesson.

This raises four points. The first is that if teachers of science need to develop each component of PCK to a ‘high level’, this requires ongoing professional learning and support. This study suggests that educative curriculum can provide some of this support along with other forms of support such as face-to-face professional learning and coaching.

The second point is that the literature defining what mastery of each PCK component to a ‘high level’ looks like for science teachers is scant. A career-long approach to developing PCK would benefit from development of a rubric that describes each component of PCK by career classification—Trainee, Graduate, Proficient, Highly Proficient, Accomplished,
and Lead Teacher. This rubric is required to be more explicit than the National Professional Standards provided (AITSL, 2012) and linked by a conceptual framework that helps explain and define the holistic and fluid movement amongst the components of PCK characteristic of Accomplished and Lead Teachers. The rubric would help teachers of science to self-evaluate their PCK development in a non-threatening manner as well as provide an indication of PCK development needs by career classification assisting career planning.

The third point is that professional learning approaches are required that focus on helping teachers to read the game and react effectively during the game to support them to holistically and fluidly move between PCK components in learning environments with their students. One approach is to use video camera technology that records the entire 360-degree view of learning environments to gather data on students and teacher reactions to instructional strategies. Teachers can self-reflect on the data gathered from the video evidence with assistance from a rubric describing the PCK components in detail. While this, at present, has to happen after the teaching event and involve critical reflection, it may be that in the near future global classroom information could be provided in real-time by the advances in technology currently being implemented in other domains such as engineering design. With increasing confidence, teachers may choose to supplement their self-reflection with comments and coaching from trusted peers and/or Lead Teachers.

The final point is that educative curricula have a place in professional learning approaches designed to improve the PCK of teachers of science. This research suggests that, where possible, the processes for developing PCK should include both face-to-face professional learning experiences and embedded professional learning from educative curricula. Where face-to-face professional learning is not possible, such as in rural and remote communities, this research suggests educative curricula should be used to develop the PCK of teachers of science. A caveat here is that professional and geographical isolation in remote communities would require, where possible, some face-to-face professional
learning to supplement that provided in educative curricula and to overcome any negative impact of professional and geographical isolation on teacher morale. This will allow teacher PCK development to occur with support from colleagues.

8.4.2 Education systems need to develop educative curricula

The results of this study indicate the Project has potential to improve teachers’ science PCK in the middle years of schooling in rural and remote areas. This potential derives from the Project materials meeting certain minimum design principles for teacher and student learning (Bybee, 2005; Davis & Krajcik, 2005) together with a well-conceived implementation program.

It had been hoped by the researcher that the design components and implementation process would provide a model for participating teachers to use to develop, individually or collectively, additional science educative curricula. However, this study showed that the demands of the profession result in virtually no time for teachers to engage in curriculum development. Thus, while participating teachers commented very favourably on the quality and usefulness of the materials, they requested similar educative curricula on a range of science topics from the researcher. T11s8, for example, made the comment to the researcher that the standard had been set by the Project materials and could the researcher please provide her with materials of a similar standard for all of the other Australian Curriculum: Science F–10 topics she would teach over the next few years.

This is indicative of the time demands that the participating teachers faced in meeting the requirements of teaching. They are understandably time poor when it comes to finding time for activities such as developing their own curriculum materials, preferring instead to have someone else design the materials for them. Education systems have the capacity to do this through their curriculum design functions usually located in Curriculum Directorates or Distance Education Learning Material Design Directorates. Education systems need to be encouraged to develop and make available educative curricula to all teachers requesting support, and most notably for those in rural and remote areas. One
way this may be achieved is to promulgate this research on the benefits of educative curricula for teacher PCK development to education systems.

**8.4.3 Teachers in remote areas require more support to develop their PCK**

Five of the nine participating teachers in Phase 1 of this study who were teaching in remote areas of Western Australia were in their first or second year of teaching with very little science content knowledge in their degrees, very little science methodology training and very little (if any) experience in teaching science. For two of these teachers, science was *out-of-field* as their qualifications were in music and languages. All teachers of science in remote areas face challenges in growing their science PCK and relate their difficulties to a lack of casual-relief teachers to support their engagement in professional learning activities, difficulties in attracting and retaining science teachers resulting in fewer experienced science teachers to support those less-experienced ones to develop their PCK and, fewer science professional learning opportunities than their metropolitan counterparts. However, teachers new to the profession face additional challenges in learning their vocation, particularly classroom management techniques, and in the case of primary teachers, developing their PCK in all of the Key Learning Areas of the Australian Curriculum. They have to face these challenges often in very difficult personal circumstances caused by isolation from family and other support structures. These challenges can be acute if teachers lack content knowledge, which further adversely impacts on their confidence to teach science (Appleton, 2005).

Graduate teachers of science in remote areas require additional in-school support to meet these challenges. Ideally, this should come from experienced teachers of science. Where experienced teachers of science are not available, as was the case at remote Sites 1, 2 and 3, then support should come from school principals. Principals are able to provide additional in-school support by facilitating the establishment and nurturing of subject-specific and teacher and leader networks as occurred with Phase 2 sites. Principals can jointly fund a cluster coordinator position to help organise cluster activities, as was shown in the Phase 2 sites. Such a position can provide organisational support for time poor
teachers who are in the early stages of their careers coming to terms with behaviour management techniques as well as learning subject-specific PCK. This was especially the case for the teachers in Phase 1 of this study who were beginning to develop their understanding of PCK needs across all KLAs and not just the Science KLA.

The five participating teachers in the remote sites also lacked external support from their education system to teach science. In addition to the provision of educative curricula described in the previous section, system support could include a Science Consultant with a highly developed PCK skill-set coupled with experience in meeting the needs of teachers of science in remote areas, and more particularly those in the early years of their career. A Science Consultant would, therefore, be able to assist teachers to develop their science PCK by, for example, coaching, mentoring, providing online support, establishing and nurturing teachers of science networks and supporting professional learning.

The teachers from the remote sites who participated in this study showed great personal attributes, particularly resilience and commitment, in implementing the Project in the face of the above challenges. They, and those teachers who follow them to teach in remote schools, deserve better external support from their education system to develop their PCK than the beginning teachers in this study received.

8.4.4 Include development of Year F–4 teachers’ PCK

The results of this study indicate that all teachers of science require an individually planned and systematic approach to their development of improved PCK. This raises a question concerning the development of PCK for the F–4 teachers of science in this study. While the focus of this study was on science PCK development in middle schools, in those sites where joint curriculum planning operated teachers of Year F–2 students became involved with the Project. For the same reason, the Year 3–4 students became involved in the Project where they were part of a Year 3–6 class at Sites 5 and 8 or forming part of the Year F–6 class at Site 7. Data from this study indicate that teachers of Year F–2 students as well as the Year 3 and 4 students found the Project an enjoyable and engaging experience. The Project increased four components of PCK for the two F–2 teachers. Year 3 and 4
students attended observation evenings and engaged with the Project materials improving their astronomy knowledge and skills.

This study has shown that science in rural and remote schools is a concern that can be addressed by improving teachers’ science PCK by using educative curricula. If the adage solve the concern early in the life of the problem and in the life cycle of the child applies, then introducing educative curricula provides an opportunity to improve both teacher science PCK for F–4 primary teachers as well as F–4 student science learning outcomes. The implications of such an approach for the Project and the design of educative curricula materials, and for face-to-face professional support for teachers of Years F–4 to develop their PCK, is an area worthy of further investigation.

8.5 Suggestions for further research

This research found that development of PCK takes time, and particularly in being able to holistically and fluidly move between elements of PCK to continually assess and reassess the effectiveness of instructional strategies. This research conceptualised PCK improvement along a continuum using the career classifications of Trainee Teacher, Graduate, Proficient, Accomplished, Highly Accomplished and Lead Teacher and reinforced the view that new PCK can be developed and existing PCK refined and improved further. It proposed a career-long individualised approach to developing PCK but found that the description of PCK by teacher classification was lacking.

Given the criticality of science teachers to achieving the ideal picture for science education, this research indicates that the development of PCK cannot be left to chance. It is therefore suggested that further research into the development of a rubric describing PCK by teacher would be helpful. This would provide a conceptual framework to help course designers of educative curricula and professional development experiences to plan specific activities based on the individual needs of teachers at different stages of their careers. The rubric would be especially helpful in designing professional learning activities to assist teachers to holistically and fluidly move between components of PCK, a characteristic of experienced Lead Teachers. The rubric would also help teachers of
science self-evaluate their PCK development in a non-threatening manner as well as assist teachers with career planning by providing an indication of the development needs by career classification.

Helping teachers to improve their PCK to reach the level of skill embodied in holistically and fluidly moving between components of PCK requires approaches to data gathering that capture and interpret student and teacher reactions to components of PCK in the context of the learning environment. One example is the use of video technologies that capture 360-degree views of learning environments and gathering data on student and teacher reactions to instructional strategies. It is suggested that additional research be conducted into the application of technologies that capture the learning environment for later collaborative analysis of the teaching and learning data related to PCK in-action. Also required are better practice processes for interpreting and applying that data to improve PCK. These better practice processes could include self-reflection, peer-supported reflection and Lead Teacher supported reflective practices.

The literature concerning better practice principles for designing educative curricula is scant. It is comprised mainly of the works of Joseph Krajcik usually in collaboration with a few other researchers. It is suggested that additional research into better practice design principles for educative curricula would supplement this literature base. This research would inform designers and writers of educative curricula in the development of materials to improve simultaneously teacher PCK and student learning outcomes. A focus for this additional research could be the conjoint generation of design principles for educative curricula that lead to improved teachers’ science PCK and student learning outcomes in Years F–4.

8.6 Conclusions

This thesis has investigated the potential for the Middle Years Astronomy Project to improve teachers’ science PCK in the middle years of schooling in rural and remote areas, along with any reasons for this and any implications arising from the research for supporting teachers of science in rural and remote areas to improve their PCK. The study
employed a ‘Type IV’ multiple case, embedded mixed-methods design (Yin, 2014) over two phases in two states of Australia to explore answers to these research questions. Eight sites implementing the Project elected to participate in the research with four sites in remote Western Australia and four sites in rural Victoria. Data from the eight sites were gathered from interviews with teachers, principals, students, a Science KLA Consultant, a Cluster Coordinator and a Middle Manager; archival records; researcher direct observations; an astronomy diagnostic test; student artefacts and documents. Data were analysed at site level then by phases of the research to look for emerging patterns. The descriptor ‘remote’ was used for Phase 1 sites and ‘rural’ for Phase 2 sites. Convergent and divergent patterns emerged from the data. The process of triangulation tested each pattern. In this way, explanation building (Yin, 2014) occurred to account for patterns emerging from analysis of the data at the individual and aggregated site levels for Phase 1 and Phase 2 of the study. The process of explanation building by triangulating the data involved developing rival explanations (Yin, 2014). Incorporating emerging propositions to create new explanations occurred where data supported this. In addition, a framework developed from the works of Kind (2009b), Magnusson et al. (1999) and Shulman (1986) was used to analyse the data for evidence of PCK growth.

The results of this research indicate that the Middle Years Astronomy Project, with its educative curriculum design, has strong potential for improving teachers’ science PCK in the middle years of schooling in isolated areas with the concomitant potential for redressing rural disadvantage. This educative curriculum achieves this by conforming to better practice design principles as well as having a well-conceived implementation plan. The results support the view that new PCK can be developed and existing PCK refined and improved further along a continuum, based on career classifications from trainee teacher to experienced teacher. The study provides guidance to teachers and designers of professional learning experiences on areas of PCK to target when seeking to develop the attributes possessed by experienced teachers.

This research has shown that if science education in rural and remote settings in the middle years of schooling is to be effective then the development of science teacher PCK
is critical and cannot be left to chance. This requires an individualised, planned and systematic approach to PCK development for each teacher, supported by the employer. This research has also shown that educative curricula with embedded teacher professional learning should form part of a suite of professional support activities for teachers of science in rural and remote areas to assist the development of their PCK. In addition to educative curricula, this study suggests that the suite of support should include other forms of external support such as science consultants, cluster-schools support and face-to-face professional learning as well as in-school support from the principal and experienced teachers.

Teachers in the middle years of schooling in rural and remote areas face many challenges to develop their science PCK to improve their students’ learning outcomes, which appear to decrease in proportion to their remoteness from metropolitan centres. These teachers, especially graduate and proficient teachers in remote schools, require support from educative curricula as well as in-school and external support to meet these challenges. The moral imperative for improving science teaching and learning in rural and remote areas stems from the need to ensure that rural students (and teachers) do not experience another layer of disadvantage relative to their metropolitan peers by receiving a poorer science education or worse, no science education at all. If this disadvantage continues, it could potentially result in poorer scientific literacy skills for rural and remote students and a reduced ability to contribute to and thrive in the national and international knowledge economy.
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