Case studies of excellent science teachers – factors influencing their beliefs and professional practice

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Abstract

This study involved an investigation of factors that influenced the development of the beliefs and professional practices of three excellent science teachers who teach in years 7-10 science classrooms in Victorian secondary schools. It provides new contributions to literature in this field, since previous studies have not examined the involvement of the teachers' personal contexts, knowledge and personal attributes, and their connection to the development of excellence within one study.

The research methodology involved qualitative case study approaches to data collection using multiple data sources including classroom observations, field notes, semi-structured interviews and analysis of the teachers' classroom artefacts. The data was analysed through thematic analysis with reference to factors related to excellence in the Australian Science Teachers Association's (ASTA) *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and the *Framework for examining beliefs* (Fives & Buehl, 2008).

Similar to the findings of other researchers (Bolshakova et al., 2011; Waldrip et al., 2009), the findings from the case studies provided evidence to conclude that having high levels of professional knowledge and certain personal attributes, are pivotal in the development of excellent science teachers. This includes having contemporary knowledge of the science disciplines and evidenced based approaches to teaching science. The teachers all demonstrated passion for science and for sharing the love of learning about science with their students. They were all able to engage in critical self-reflection about their approaches to teaching and learning.

My study also found evidence that these excellent teachers' beliefs influenced their perception of what kinds of classroom environments they wanted to create and how they could enact the curriculum in engaging ways. All three teachers believed that a positive, respectful environment is important to ensure students are motivated and prepared to take risks in their learning about science. Finally, I found that many of these teachers' beliefs were influenced by contextual factors in their past including their prior learning and work experiences. Their beliefs were reflected in ways they applied their pedagogical content knowledge in practice.

Recommendations from the findings include the need to consider the importance of pre-service teachers' beliefs about science education policies and practices in initial teacher education, and in the ongoing professional learning of science teachers. Recognition of the role of teachers' prior learning, personal attributes and existing beliefs can lead to insightful discussions about what matters in developing excellent teachers' practice, and how to integrate beliefs into further learning programs, so all teachers can reach their potential and maximise learning about science in classrooms.

Declaration

This thesis is an original work of my research and contains no material which has been accepted for the award of any other degree or diploma at any university or equivalent institution and that, to the best of my knowledge and belief, this thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

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Abbreviations

ACARA	Australian Curriculum Assessment and Reporting Authority
ADHD	Attention deficit hyperactivity disorder
AITSL	Australian Institute for Teaching and School and Leadership
APSTs	Australian Professional Standards for Teachers
ASTA	Australian Science Teachers Association
ASTA Standards	National Professional Standards for Highly Accomplished Science Teachers
ATAR	Australian Tertiary Entrance Ranking
CASPer	Computer-Based Assessment for Sampling Personal Characteristics
CRT	Casual Relief Teaching
EAL	English as an Additional Language
ELC	Early Learning Centre for three and four-year-old children
GTAC	Gene Technology Access Centre
ICSEA	Index of Community Socio-Educational Advantage
LBOTE	Language background other than English
NAP-SL	National Assessment Program – Scientific Literacy
NBPTS	National Board of Professional Teacher Standards (USA)
NIE	National Institute of Education, Singapore
PCK	Pedagogical Content Knowledge
PST	Pre-service teacher
SAC	School Assessed Coursework in VCE
SEAL	Select Entry Accelerated Program in Victorian schools
STAV	Science Teachers Association of Victoria
TOP	Tertiary Orientation Program
VCAA	Victorian Curriculum and Assessment Authority
VCAL	Victorian Certificate of Applied learning
VCE	Victorian Certificate of Education
VET	Vocational Education and Training
‘WIHITC’	‘What is happening in this class’ questionnaire

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Chapter 1 Introduction

> 'Without excellent teachers, any curriculum, no matter how it is framed, no matter what it contains, will remain aspirational and is likely to be consigned to history without its potential ever having been properly realized'. (Evans, 2014)

This is a study of excellent science teachers in junior secondary school (years 7 - 10, age 13 – 16 years) in Victoria, Australia. Numerous earlier works from all over the world about excellent science teachers have studied teachers' knowledge, personal attributes and beliefs independent of each other, and most have focused on preservice teachers or those teaching primary or senior years of science. In this study, the focus is on capturing and analysing factors influencing the knowledge, personal attributes and beliefs of excellent science teachers and the interplay within and between these factors for teachers of science in years 7-10. The teachers in this study were purposefully selected using a specific set of parameters outlined in a later section, 1.1.2. Throughout the study, I explored the traits and factors that have influenced the development of these teachers as excellent science teachers, using interviews and observations.

In this introductory chapter, I explain how my interest in excellent science teachers developed, then discuss the concept of excellent science teachers and describe the background research in this area. I also consider the significance of the study, the research methodology and an outline of the structure of my thesis.

1.1 Background

1.1.1 Researcher's background

My reasons for choosing this research focus stem from both personal and professional interest. During my twenty-five-years of teaching science in secondary schools, I continually tried to improve my practice based on feedback from my students, their parents and my peers. I always had questions and searched for answers through professional learning opportunities and reading current research for ideas. In addition, through leadership roles in schools both in Victoria and overseas, it was often my responsibility to mentor new teachers, appraise teachers' practice, lead pedagogical innovations and deal with classroom concerns raised by teachers, students and parents. I often felt conflicted when working through these issues with staff, but especially when the teachers' practices did not align with what I knew of them as a colleague or did not align with the beliefs I had about excellent practice. Additionally, I have often heard anecdotal stories from friends and family about how they hated science when they were at school, about poor science teachers and how their science education was meaningless in their current lives. This caused me frustration, since I love science and teaching science and recognise the importance of the field of learning. The opportunity to choose an area of research for my PhD aligned with the first implementation of the *Australian Professional Standards for Teachers* (APSTs) (AITSL, 2011) and the announcement of the *Australian Prime Minister's Awards for Excellence in Secondary Science Teaching* (2011) (Australian Government - Department of Industry, 2013). This piqued my interest in identifying how 'excellence' was defined since my understanding of excellent teachers was limited. I wanted to know what it was about these teachers' and their work that compelled members of their school community to go to the effort to nominate them for such a prestigious award. Thus, my PhD journey began. First, I needed to ascertain what being an excellent teacher involves and then identify excellent teachers for my investigation.

1.1.2 Background to identifying excellent teachers and teaching

In reviewing the literature, I found different terminology used to describe aspects of excellent teachers. Expert, exemplary, effective and highly accomplished are all descriptors that have been used in the literature rather than excellent. There is however, strong agreement that professional knowledge is an essential aspect of quality teachers' work (Goldhaber & Anthony, 2007; Hattie, 2003; Tobin & Fraser, 1990). Indeed, the APSTs (AITSL, 2011) provide a description of the essential professional knowledge expected of a teacher, including knowledge of content, curriculum, students and pedagogy. There is also a growing body of literature about the role of teachers' personal attributes in education (Linda Hobbs, 2012; Walker, 2008). Bolshakova, Johnson and Czerniak's (2011) findings indicate that both professional and personal attributes are important in teaching so my study examines both these factors. In addition, my exploration of excellent teachers considers the impact of length of classroom experience since research indicates it does not necessarily equate to excellent teachers' practice (Berliner, 2001; Marshall, 2008). Since Schaefer, Long and Clandinin (2012) describe teachers in the first five years of teaching as early career or novice teachers, where they are transitioning from being students to professional teachers, in my study, I decided to choose teachers who had been teaching for five or more years.

A review of the literature revealed discussion of the reality that teaching is complex, and being an excellent teacher is not just a matter of knowledge, personal traits or experience. To better understand why and how excellent science teachers employ their professional and personal traits in their work, my research also examined the beliefs, contexts and other factors that influenced these teachers. Hutner and Markman (2016, p. 675) state that beliefs are, 'mental representations that influence the practice of a teacher'. Fives and Buehl (2011) noted that teachers hold a range of beliefs which act as filters to knowledge and experiences and Jones and Carter (M. G. Jones & Carter, 2007) argued that more experienced teachers tend to have more complex beliefs. Levin, He, and Allen (Levin et al., 2013) added that teachers' beliefs are formed from past personal contexts – extending from when they were students through to their experiences as teachers. In addition, current contexts, such as government and school policies can influence teachers' beliefs and practices. Results from the OECD *Teaching and Learning International Survey* (TALIS) for example indicate that year 7-10 classes in Australia have more students with special needs, more non-native English speakers and more disadvantaged students than the OECD average (Thomson & Hillman, 2019). This diversity of student population and different school systems means that excellent science teachers in Victorian schools work in very different contextual conditions.

I set the following parameters for selecting three excellent teachers to participate in this study, based on the findings of my review of the literature (see full discussion of this in chapter 2 and chapter 3):

- They currently teach year 7-10 science
- Have more than 5 years teaching experience
- Are highly respected by school leadership, parents and students in teaching middle school science
- Are enthusiastic about teaching science and students learning science
- Know science content and can communicate it clearly
- Know their students and cater for their diverse learner needs

In conjunction with the findings from my literature review, I drew on the expertise of three experienced science teacher educators to assist in recommending excellent science teachers who would meet these parameters.

1.2 Purpose and scope of this research

My intention at the outset of this study was to explore factors involved in how excellent science teachers' knowledge and beliefs about science education developed; and to consider the influence of their personal attributes on their teaching practices. I also wanted to investigate the extent to which contextual factors are involved in the alignment of teachers' beliefs about science education with their teaching practices in years 7-10 science classrooms.

Three research questions were formulated:

1. How do personal and contextual factors influence the development of excellent teachers' knowledge, personal attributes, beliefs and practices?
2. What do excellent science teachers believe about teaching and learning in science in years 7-10?
3. How are the beliefs of excellent science teachers demonstrated in their professional practices and classroom teaching?

The importance and originality of this study are twofold. Whilst there is previous research about science teachers' knowledge or personal attributes or beliefs, no single study was identified in the review that investigated all these factors and examined the complexity of their influence on teaching. Further, this study focusses on excellent science teachers in what is called junior secondary or the 'middle years' (7-10). Past studies have examined pre-service teachers, teachers in the primary years and teachers in the senior year levels thus, there is a need for a better understanding of 'middle years' teachers and their practice.

The findings will be of interest to a range of stakeholders. With the increasing importance of personal attributes and beliefs in selecting and educating preservice teachers, those involved in initial teacher education will certainly be interested in the outcomes of this research. School leaders, parents, students and the media will also benefit from understanding factors involved in the complexity of excellent teachers' work. Additionally, the findings have the potential to contribute to improvements in science teaching, as the Australian Federal government has recognized the importance of improving science education for an improved economy (Dinham, 2013).

The scope of this study has limitations. Given that the focus is only on three case studies in three different schools in Victoria, Australia, during a short period of time, there was no attempt made to generalize. Rather, the focus was on developing deep understanding and ‘thick description’ that is a feature of qualitative research (Creswell, 2013).

1.3 Research methodology

In order to investigate the three research questions, it was necessary to gain an in-depth understanding of the participating teachers’ knowledge, personal attributes, beliefs and contexts. An interpretive case study analysis was conducted. Three science teachers who were highly regarded by their school community, and by science teacher educators in a Melbourne University, were approached to participate.

The methodology involved qualitative approaches to data collection through semi-structured interviews with the three teacher participants: an initial extended interview followed by pre- and post-lesson interviews during a teaching sequence. I observed and made field notes of the participating teachers during a series of four lessons of teaching science to one of their year 7-10 class. The participating teacher and I collaboratively selected a representative group of four students from the class to form a focus group with whom a semi-structured interview was conducted. The findings from the interviews and class observations were checked by participating teachers to ensure a true representation. Relevant teaching artefacts (such as lesson plans and student work) were also collected, coded and analysed. These multiple forms of data collection allowed for triangulation of evidence to confirm the findings from my study.

A pilot study was conducted with one teacher to test and refine the data gathering techniques and to uncover potential problems (Creswell, 2013). Themes arising from the research questions were identified and coded for using NVivo™, a computer software tool. The case study data were analysed through thematic analysis with reference to the Australian Science Teachers Association’s (ASTA) *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and the *Framework for examining beliefs* (Fives & Buehl, 2008) and a descriptive narrative was constructed for each case study. After examination of the evidence, it was possible to build a case for each teacher, which exemplified excellence in science teaching and to highlight the similarities and differences of the factors involved between the case study teachers.

1.4 Chapter outline

- **Chapter 1** introduces the rationale, scope and framework followed by the methodology for my study.

- **Chapter 2** explores literature related to science teaching to develop a conceptual framework of excellent science teachers for the study. The review critically discusses knowledge, personal attributes, contexts and beliefs held by science teachers and the role of these factors in their practice.

- **Chapter 3** is the methodology chapter, which explains the research approaches and data collection and methods of analysis. The validity of the study is also discussed.

- **Chapters 4 and 5** discuss case study teacher one, Lindy [pseudonym]. This includes an examination of her past experiences, knowledge and beliefs and analysis of her teaching practice in year 8 science class.

- **Chapters 6 and 7** follow the same format at 4 and 5, but with case study teacher two, William.

- **Chapters 8 and 9** present the analysis of case study teacher three, Hannah.

- **Chapter 10** is a comparative analysis of themes that emerged from the three teachers investigated.

- **Chapter 11** presents the conclusions from my study. The significance of the research is discussed, and recommendations are made regarding further research in this area.

In this chapter I have introduced the motivation for my study, the data collection strategy and outlined the structure of my thesis. In the next chapter, I review the literature in relation to excellent science teachers and my methodology.

Chapter 2 Literature Review

2.1 Introduction

> 'It is what teachers think, what teachers believe, and what teachers do at the level of the classroom that ultimately shapes the kind of learning that young people get.' (Hargreaves, 1994, p. ix).

To establish the place of my study in the field, this review explored contemporary Australian and international literature related to the research focused on excellence in science teaching. The concept of excellent teachers is contentious, so developing an understanding of what constitutes 'excellence' and how it is framed was an important part of my review. In the first section, to assist in forming a framework of the attributes of excellent science teachers for my study, I explored how 'high-quality teachers' have been identified through accolades including award schemes, and via the collection of evidence against teacher standards and the recognition of students' learning outcomes. Since the participants of my study were viewed as excellent science teachers by the criteria I set, I examined two systems of teacher standards. First, the *Australian Professional Standards for Teachers* (APSTs) (AITSL, 2011) which provided a framework for identifying highly accomplished and leading teaching is discussed. Second, the *National Professional Standards for Highly Accomplished Teachers of Science* (ASTA Standards) (ASTA, 2002, 2009) was reviewed, since they were written specifically to describe highly accomplished secondary school science teachers in Australia. The next section of the review examined literature discussing teachers' beliefs about science teaching, students' learning and the purpose of middle school science, as well as the relationship between teachers' beliefs and their classroom practice as another dimension in identifying excellence. I also examined contextual factors which could be involved in the beliefs and practices of excellent science teachers, such as the curriculum, the school context and the diversity of learners. All of these areas of the review were critical, since they provided insights into previous research relevant to my study and helped to identify how my study of excellent science teachers' knowledge, personal attributes, beliefs and practices would add to current understanding in this field.

2.2 Excellent science teachers' knowledge

Defining an excellent teacher is more complex than identifying one. The *Oxford English Dictionary* defines excellence as a state of being in 'possession chiefly of good qualities in an eminent or unusual degree; surpassing merit, skill, virtue, worth' (Oxford English Dictionary, 2015b). Thinking of excellence through consideration of the 'good qualities' of excellent teachers is dependent upon the perspective and the criteria set by the stakeholders; teachers, school leaders, students, parents, policy makers or teacher educators and researchers. The literature on quality teaching extends debates about how excellence can be defined, as it includes a broad range of descriptors such as effective, experienced, excellent, exemplary, expert, accomplished and good. Tobin and Fraser (1990, p. 8) studied seven 'above standard' teachers in Western Australian schools who had been identified as such by 'Education Department personnel and university staff'. They then made four assertions about *exemplary* science teachers saying that, 'they manage and facilitate student engagement; increase student understanding of science; encourage students to participate in learning activities; maintain a favourable learning environment' (Tobin & Fraser, 1990, p. 3). Marshall (2008) views *exemplary* science teachers as those who use inquiry, are enthusiastic about science and promote curiosity. Marshall (2008) also states that these *exemplary* teachers use excellent questions to explore topics in depth and to challenge students' thinking.

The guidelines for the *Australian Prime Minister's Award for Excellence in Science Teaching* seek evidence of the teacher's 'knowledge of science, science education and students' and 'innovative and imaginative approaches ... to achieve high quality outcomes' (Australian Government Ministry of Industry and Science, 2014, p. 9). Finally, Berliner (2004b) suggests another dimension of excellence is *expertise* that is 'specific to a domain, and to particular contexts in domains, and is developed over hundreds and thousands of hours' (p. 15), suggesting that *experience* is required. These examples demonstrate that literature about quality or excellent science teachers contains variations in terminology, perspectives and contexts. However, there are similarities in the traits identified and examined. As a result, I used these varied ideas from the literature to refine the description of excellence for my study. However, it became clear that I needed to consider wider questions about what constitutes an excellent teacher through for example, being 'knowledgeable' about content and pedagogy, meeting standards and achieving quality learning for students, in particular to achieve the goals of the *Victorian Curriculum: Science* (VCAA, 2017e).

Thirty years ago, in a landmark publication, Shulman (1987) conceptualised the 'knowledge' held by teachers. He developed seven categories to describe teachers' knowledge:

- content knowledge,
- general pedagogical knowledge,
- curriculum knowledge,
- pedagogical content knowledge (PCK),
- knowledge of learners and their characteristics,
- knowledge of educational contexts,
- knowledge of educational ends, purposes, and values and their philosophical and historical grounds.

(p. 8)

The following section provides an examination of literature related to these complex dimensions of teachers' knowledge related to excellent science teachers.

2.2.1 Knowledge of science and science curriculum

Education researchers have been investigating science teachers' knowledge since the 1960s (Abell, 2007). The findings about the significance of teachers' content knowledge in influencing student learning makes a distinction between the quantity and quality of teachers' content knowledge. Darling-Hammond's (2000, p. 3) meta-analysis of studies that investigated teacher quality and student achievement found that there is 'no consistent relationship between [teachers' test scores] of subject matter knowledge and teacher performance as measured by student outcomes'. However, Tobin and Fraser's (1990) case studies of science teachers raised the concern that if teachers do not have the depth and breadth of content knowledge, they are less likely to diagnose alternative conceptions or be able to assist students in making a correction. Furthermore, the teachers who do not have deep content knowledge might also hold alternative conceptions. Abell (2007, p. 1111) reported that, 'alternative conceptions that had been reported for children persisted into adulthood', raising the concern that alternative conceptions could be perpetuated by teachers and passed on to future generations. These findings raise the necessity to distinguish between the *quality* of content knowledge rather than the *quantity* of that knowledge.

There is agreement in the literature that teachers require a 'basic level of competence of the subject' (Darling-Hammond, 2000, p. 4). In support of this, graduate teachers in Australia must have completed higher education study to third-year Bachelor's degree level in at least one subject, preferably two, in addition to accredited studies in teaching methodologies (AITSL, 2018a, p. 15). However, in Australia, except for the state of New South Wales, teachers are registered as qualified teachers, rather than teachers of a particular subject (Price et al., 2019). As a result, teachers can be appointed to teach subjects where they do not have formal qualifications. As evidence of this, in 2013, a survey of Australian teachers showed nearly 14% of year 7-10 general science teachers had no qualifications in the field of science – having neither a tertiary unit or science teaching method (Weldon, 2016). These teachers are considered to be teaching 'out-of-field'. Childs and McNicholl (2007) interviewed 'out-of-field' science teachers of varying experience in the UK with mixed responses. They found some teachers reported that their lack of content knowledge gave them, 'much greater awareness of what it's like to learn this material …as you've learnt it more recently yourself, you've got a much better handle on what are the difficult concepts' (p. 10). Whereas other teachers reported that better (deeper) knowledge of the content, 'allowed them to give a broader range of alternative explanations particularly for lower attaining students … that do not compromise the integrity of the scientific meaning' (Childs & McNicholl, 2007, p. 11). More recently in an Australian study, Crisan and Hobbs (2019) contended that strong content knowledge allowed teachers to be more intuitive in their practice and they did not need as much planning and research to teach a topic. It should be noted that even if a teacher has majored in science at tertiary level, it might be in a very specialised area such as molecular biology, which means they are not experts in the topic specific knowledge nor of *all* branches of science taught in years 7-10. This fact is reinforced by Kind's (2014) findings from tests of science pre-service teachers in UK for their understanding of chemistry concepts. She found that pre-service teachers who held a non-chemistry science degree did not have sufficient understanding of chemical bonding and combustion reactions to be able to effectively teach these concepts in a general middle school science course. Furthermore, Crisan and Hobbs (2019) noted that whilst there is a common knowledge held by 'in-field' teachers of general science, there are differences in the approaches to inquiry between the branches of physics and biology. This literature alerted me to the need to explore the knowledge of the teachers in my study and whether or how their content knowledge increased throughout their careers through teaching topics and through professional learning.

Teachers can and do add to their content knowledge *after* their initial tertiary education. Rennie, Goodrum and Hackling (2001, p. 470) argue that as professionals, teachers are life-long learners and should access professional learning opportunities to respond to 'the escalating knowledge in science, the ever-widening access to information through communication technologies, as well as the changing political and social influences on science'. Whilst a tertiary background in the sciences provides a solid grounding to expertise in content knowledge, excellent teachers continually add to their knowledge through collaboration with the science community, their colleagues and other sources of science knowledge as part of their professional learning (Faull, 2008). Teachers tend to increase their content knowledge in response to curriculum they are expected to teach. Arzi and White (2007) conducted a seventeen year longitudinal study of secondary science teachers in Australia to examine changes in their content knowledge. They found that the school science curriculum served as both a knowledge organizer and knowledge source for teachers. That is, when there is a change in emphasis in curriculum, some content knowledge is 'shelved' by teachers because it is not needed, whilst other content knowledge is refined and built upon. Arzi and White's study (2007) had two other outcomes of interest. Firstly, that teachers tended to learn this new content knowledge independently rather than through formal professional development offerings. This indicates that teacher personal initiative is important if content knowledge is going to improve during their career (personal attributes are discussed in section 2.3 below). Secondly, teachers who had pre-existing content knowledge were still more likely to identify and deal with alternative conceptions by their students. In addition, Hattie (2003) argued that it is not the amount of content knowledge held, rather it is the extent to which this knowledge is integrated and how new knowledge is incorporated that makes a difference to teaching practice. The research discussed thus far suggests that the source, quantity and quality of content knowledge of experienced middle school science teachers is variable. For my study of excellent science teachers, it was clear that the complexity of a teacher's content knowledge needed to be explored.

Besides content knowledge, teachers need to have knowledge of the purposes of the curriculum. Since the teachers in my study were in the state of Victoria, I reviewed *The Victorian Curriculum: Science* which they taught, and found that it reflected and incorporated the *Australian Curriculum: Science* (VCAA, 2017d). One of the aims of these science curricula is 'to provide students with a solid foundation in science knowledge, understanding, skills and values on which further learning and adult life can be built' (ACARA, 2009, p. 5; VCAA, 2017e). Thus, it is essential that excellent science teachers have a thorough knowledge of science. There are two strands for science in the *Victorian Curriculum: Science*: 'understanding science' and 'scientific inquiry skills' (VCAA, 2019). Scientific literacy is equally important to both strands as 'school science should prepare students to engage with science ideas in their work and their lives as citizens' (ACARA, 2012a; Finkel et al., 2009, p. 28). Rennie (2006) argues that to be scientifically literate involves having:

- An interest in and understanding of the world
- Making informed decisions
- Communicating about science
- Scepticism and questioning evidence about scientific matters
- Investigating and drawing evidence-based conclusions

(p. 10)

Thus, with an emphasis on scientific literacy in the curriculum, science teachers need knowledge of how science can be used to solve real-life problems. However, in reality, Capps and Crawford (2013, p. 498) state that although inquiry is recommended, a 'lack of knowledge and experience likely puts serious limitations on teachers' abilities to plan and implement lessons that will help their students develop an image of science that goes beyond the familiar body of knowledge'. This finding implies that knowledge and experience of the scientific inquiry process are essential attributes of excellent science teachers. In terms of my study, an excellent science teacher should know and understand the aims of the curriculum for all students to gain scientific understanding and inquiry skills by focusing on scientific literacy.

2.2.2 Pedagogical knowledge and pedagogical content knowledge

According to Loughran (2013), there are various definitions of pedagogy in the literature. In my study, pedagogy refers to the 'interactions between teachers, students, and the learning environment and the learning tasks' (Murphy, 2008, p. 35). Many researchers argue that knowledge of teaching and learning includes both general pedagogical knowledge and content specific pedagogical knowledge (pedagogical content knowledge, PCK) (Bransford, Brown, & Cocking, 2000; Shulman, 1987). Bransford et al. (2000) state that general pedagogical knowledge includes knowing the curriculum goals and being able to plan lessons, communicate effectively, use resources and manage the class so that students can achieve the desired outcomes. PCK requires an amalgamation of content knowledge, general pedagogical knowledge and knowledge of context, where the teacher can anticipate the kinds of difficulties students are likely to face in understanding a [science] concept and can use strategies to make new information meaningful (Shulman, 1987; Taber, 2014). The literature about general pedagogical knowledge and PCK provided important guides for identifying ‘excellent’ teachers for my study.

Since 1995, the OECD has conducted teacher and student surveys called the *Trends in International Mathematics and Science Study (TIMSS)* every four years with the aim of understanding the current state of learning and improving teaching and learning in mathematics and science (TIMSS & PIRLS International Study Center, 2012). Rather than listing specific class activities, the survey lists six types of instructional practices that they say ‘interest students and reinforce learning’ (TIMSS & PIRLS International Study Center, 2012, p. 371). These practices are thus deemed to be effective general pedagogical practices:

- Summarizing the lesson’s learning goals
- Questioning to elicit reasons and explanations
- Encouraging students to show improvement
- Praising students for good effort
- Bringing interesting materials to class
- Relating the lesson to students’ daily lives

(TIMSS & PIRLS International Study Center, 2012, p. 371)

The survey found that students who had teachers who used these strategies ‘every/almost every lesson’ also scored higher in the science achievement test, supporting the correlation between these teaching practices and student achievement (TIMSS & PIRLS International Study Center, 2012, p. 379). I expected these to be evident in the classrooms of the excellent teachers in my study.

Weimer (2013) states that student-centred pedagogy is when teachers teach students how to think, solve problems, evaluate evidence, analyse arguments, generate hypotheses; reflect on what they are learning and how they are learning it; motivate students by giving them some control over the learning processes and encourage collaboration. In a report commissioned by the Education Federation Australia, Black (2007, p. 6) stated that a student-centred pedagogy is essential to ‘cater successfully for students, including socio-economically disadvantaged students’.

Whilst teachers learn about pedagogy through their initial teacher education, it takes time and practice to develop, and experience does not necessarily equate to excellent pedagogy (Berliner, 2001). Marshall (2008) compared the development of teaching practices of experienced teachers (defined as those with more than ten years' experience) with those of Presidential Awardee science teachers in USA. He found that a teacher could have years of experience and still be 'just' good, or solid or they could even be ineffective. Marshall (2008) asserts that excellent teachers' classrooms are places of inspirational pedagogy, where there is a high level of achievement possible for all students in science process, inquiry and content. They use excellent questions to explore topics in depth and to challenge students' thinking. They can explain concepts clearly so students can learn. Schneider and Plasman (2011, p. 534) discuss the notion of a 'learning progression' for teachers' PCK development meaning that there is no set time frame and that a 'more sophisticated understanding does not mean that set goals for understanding (e.g., standards) will be achieved'. Students can also recognise and appreciate teachers with good PCK. A UK study by Wilson and Mant (Wilson & Mant, 2011a) analysed the views of over 5000 year 8 students (12 year olds) who had indicated that they were 'positive and enthusiastic' about their science lessons. These researchers found that the main characteristics shared by their teachers included: 'clear explainers, opportunities for thinking and problem solving and class discussions' (Wilson & Mant, 2011a, p. 124), all examples of well-developed teaching and learning strategies. Thus, excellent teachers consider pedagogical approaches which extend each students' thinking and understanding of science.

2.2.2.1 Inquiry pedagogy

Fitzgerald (2012) argued that inquiry-based pedagogical approaches to science teaching and learning promote student interest and engagement. Although inquiry is not the only student-centred instructional strategy, research suggests that it is a critical strategy that should be part of every science classroom (Bransford et al., 2000). The writers of the *Australian Curriculum: Science* argued that there needs to be an 'emphasis on a model of student engagement and inquiry' (ACARA, 2009, p. 13). Inquiry based pedagogies are supported by the Science Teachers Association of Victoria (STAV) (STAV, 2008, p. 2) who argue that these approaches promote 'deeper understandings … [and the] ability to draw evidence-based conclusions and to think critically'. Capps and Crawford (2013) summarized the pedagogies teachers need for planning inquiry-based lessons as:

> '…philosophical and socio-historical natures of scientific inquiry and the nature of science'; how 'to do inquiry including asking and identifying

> questions, planning and designing experiments, collecting data using data, and connecting data as evidence with explanations'; how to 'employ inquiry-based instruction in the classroom in order to address key science principles and concepts.' (p. 499)

Similarly, Hofstein and Lunetta (2004) found that inquiry-based practices improve students' science process skills, habits of mind, problem-solving skills, and understanding of the nature of science. Crawford (2007) proposed that teachers need to teach students *about* inquiry, *through* inquiry and *by doing* inquiry. Crawford (2007) also suggested that this requires teachers to use authentic problems, model scientific processes and assist students in making sense of data. Thus, in my study, it was important to examine if the teachers who are deemed to be excellent, and met the criteria I defined, did use inquiry pedagogies.

2.2.2.2 Practical work

Abraham (2011, p. 1) defines practical work as an 'activity in which the pupils are involved in manipulating and/or observing real (as opposed to virtual) objects and materials'. The inclusion of practical work or hands-on activities is common in secondary science, so it was important to review literature related to this pedagogy. There is a general belief amongst students, teachers and parent communities that practical work is an integral part of science education at school (Abrahams & Saglam, 2010; Toplis, 2012). In addition, Holeman (2017) found that practical work can increase student engagement with science. But is all practical work equally effective? Abrahams and Millar (2008) found that students (aged 11-16) liked practical work as a break from traditional methods of teaching, but whilst they could often recall what they observed, they did not necessarily recall the associated scientific ideas. Furthermore, such practical work tends to be chosen by teachers to reinforce factual scientific knowledge rather than for developing students' inquiry skills (Abrahams & Millar, 2008). Toplis (2012) also studied the role of practical work in science lessons for ages 13-16 in UK. The results indicated that these students thought practical work was social, allowed them some autonomy in learning and was an alternative to a 'pedagogy of transmission', but he also found that students thought that practical work also 'aid[ed] memory and revision' as they were memorable episodes (Toplis, 2012, pp. 531, 544). In contrast, Australian year 9 students were interviewed by Elliott and Paige (2010, p. 15) who concluded that 'students like to do experiments, but they want rigour …experiments should add to their understanding of concepts they are learning' and relate science to real life. New Zealand's *Education Review*

Office (2012) found students were more engaged when they had a chance to investigate their own ideas. Despite this, research indicates that open, student-led investigations are not the norm. In 2012, Universities Australia surveyed first-year university students enrolled in STEM and non-STEM courses. Thirty two percent said they never had that opportunity to investigate their own topic in school science and another thirty three percent chose their own topic for investigation once a term or less (Universities Australia, 2012).

Most secondary school science courses include practical work, however the learning that students gain from the activity is dependent on the learning goals and how the teacher plans and implements the practical work. For instance, research indicates that there should be a focus on activities that engage students cognitively and should not just be of situational interest if they are going to improve student outcomes (Hofstein & Lunetta, 2004; Rennie et al., 2001; Toplis, 2012). The National Research Council (1996) described this as “hands-on/minds-on” science. Holeman (2017) found practical work could be used to help students learn principles of scientific inquiry, improve their understanding of the concepts, learn specific practical skills (e.g. measurement). Other research suggests that the opportunity to experience and learn about inquiry thinking can be diminished if there is an over-emphasis on the ‘scientific method’ as a series of rigid steps (Tang et al., 2010). At the extremes, practical work could teach students about, ‘respecting evidence, open-mindedness, being open to new ideas, being creative & knowing that knowledge changes, being critical & sceptical of evidence & arguments’ (VCAA, 2014) or students could learn how to follow a recipe, manipulate equipment and ‘falsify’ results (Toplis, 2012, p. 535). Abraham and Millar (2008) found that practical work, whilst often the central feature of a topic, was likely to be considered successful by the teacher if the students had managed to produce the desired phenomena and make the desired observations. Pedretti, Bencze and Alsop (2007, p. 209) found that excellent science teachers’ choose practical work which ‘involves engaging in and developing expertise in scientific inquiry and problem solving in many contexts’ and where students can ‘engage in messy real-world problems, asking questions, seeking solutions, designing experiments, playing with the unknown’. In my study, the type of practical work the teachers used was observed and analysed in terms of how it facilitated student learning of science – understanding and inquiry skills, in engaging ways.

2.2.2.3 Class discussions

Class discussion is another strategy that is commonly used in science classrooms. Pimentel and McNeill (2013, p. 368) say that discussions can 'support students in developing a deeper understanding of science content, [and their capacity to] participate in scientific practices such as argumentation and changing their views of science'. Their observations and interviews of five teachers in the USA 'found that teachers rarely used probing questions or tossed back students' ideas' (Pimentel & McNeill, 2013, p. 367). This is contrary to the *Victorian Curriculum: Science* where one of the aims is for students to learn how 'to communicate scientific understanding and findings to a range of audiences, to justify ideas on the basis of evidence, and to evaluate and debate scientific arguments and claims' (VCAA, 2017e). This aim is fundamental to students doing scientific inquiry, as students use argumentation to evaluate evidence and to construct explanations. Teachers need to use instructional strategies to support students in developing their skills of argumentation such as teacher questioning that promotes problem solving and student-centred discussions. Giving students opportunities for scientific argumentation promotes scientific literacy skills such as critical thinking, using evidence to support claims and understanding scientific thinking (Driver et al., 2000). Smart and Marshall (2013) investigated the types of interactions that occurred in year 10 science classes in USA. They found science teachers with stronger content knowledge used open-ended, high-order questioning and facilitated more cognitively engaging discussions.

Besides enhancing students' deeper understandings of science content, classroom discussions serve to develop a community of learning. Dohrn and Dohn's findings (2018) suggest that an inclusive classroom can be created when the teacher balances the direct presentation of information with promoting exploration of ideas through students' own questions and answers whilst also sharing personal anecdotes and humour.

Since the literature showed that excellent science teachers should be able to facilitate discussions where students are required to consider their understanding and support and challenge ideas with evidence, this was another part of my study.

2.2.2.4 Assessment and feedback

Masters (2013, p. iv) states that, 'the fundamental purpose of assessment is to establish where learners are in their learning at the time of assessment'. Assessment can be diagnostic, to inform teaching, formative, for informing teaching and learning, summative, for informing parents or for accountability, and metacognitive, for helping students to monitor their own learning (Abell & Siegel, 2011). Assessment can be both formal, when the task is developed prior to the student performing it, and informal, when it is 'embedded' within and throughout each lesson (Oosterhof, 2009). Besides monitoring learning, assessment can be used to provide feedback for teachers to inform their teaching and for students to inform their learning and to provide information for parents on their child's progress (ACARA, 2019a). The curriculum defines what students should be learning by providing achievement standards, thus teachers of the *Victorian Curriculum: Science* are required to assess students' knowledge and skills of science concepts, scientific inquiry (VCAA, 2019).

A review of the literature revealed a lack of research specifically focused on excellent science teachers' assessment pedagogy, however, there are theoretical papers which describe best practice. Goodrum, Hackling and Rennie (2001) for example argue that excellent science teachers require a wide repertoire of assessment tasks to collect evidence so all students have the opportunity to demonstrate their understanding and skills. Some examples include: informal observation and questions, reports, practical work, written tests, contributions to discussions, oral or written explanations, diagrams and journals (Edwards, 2013). However, Edwards (2013) tempers this list by contending that teachers need to know and decide the type of assessment and when and how to use it to ensure the evidence collected is authentic and valid for the particular students and the topic.

Quality assessment tasks enable feedback that best supports students' on-going learning (Edwards, 2013). The ability to give timely and effective feedback to students about their learning is an important attribute of excellent teachers and is supported by a number of studies (Chism, 2006; Cotsen Foundation, 2004; Fitzgerald et al., 2013; Hattie, 2003). Advice from the Victorian Department of Education and Training (2016) is that formative feedback is an essential pedagogical strategy since it is used by both the teacher and the learner to determine where learners are in their learning and how to achieve learning goals. Potvin and Hasni (2014) note that research has found 'formative assessment and detailed feedback …favour interest, reduce anxiety and increase confidence and participation in learning' (p.107); thus making the learning environment a safe and engaging place. Further to this, Elliott and Paige (2010) report that Australian year 9 science students 'prefer instant feedback' (p. 16), possibly because they experience this in today's 'instant' society. Thus, in my study I explored the extent to which teachers integrated assessment into their lessons in ways that supported students' learning and demonstrated the extent of their excellence as science teachers.

2.2.3 Knowledge and engagement of students

For student-centred learning to occur, teachers need to know their students. The *Australian Curriculum: Science* expects that consideration [be] given to the unique characteristics of learners' (ACARA, 2009, p. 12). Research suggests that to make science education relevant and meaningful for young adolescents, it should occur within a social context and allow for students to connect to the world beyond the classroom (Jones et al., 2012). If teachers are aware of their students' prior knowledge, experiences and interests, they can teach 'concepts in context' which will engage students and make learning more meaningful (Blahey et al., 2002). Goodrum, Hackling and Rennie (2001) emphasise that learners are partners in the learning process and their learning preferences need to be considered when teachers are planning lessons. Goodrum et al. (2001, pp. 17–18) state that teachers need to consider students' 'prior knowledge and experience', allow students to 'reflect on their own thinking processes [and] interact and collaborate with others' and 'focus on promoting the culture of science'. This was relevant to my study since I explored how excellent teachers considered the engagement of students and connected the curriculum to their interests. Thus, capturing the students' voice and views on factors involved in their engagement in learning was important.

To cater for the diversity of students' needs, and in order to fully engage all students, teachers need to be flexible, responsive and creative in their lesson planning and delivery. Excellent science teachers are adaptable and flexible; they can quickly recognize significant events in their class and direct the activity to rectify alternative conceptions or take advantage of a 'teachable moment' (Berliner, 2001, p. 475). Robinson (2010) also suggests that to ensure engagement, teachers should personalise learning and shape the learning to individuals' requirements. There is an increasing focus on the importance of recognising that each student has different strengths, weaknesses, interests and ways of learning. To cater for all students, Matera, Traver and Powell (Matera et al., 2020) suggest teachers use five principles: know each student's cognitive and social needs, plan lessons for the students' levels, model good learning behaviours to encourage students to do the same, assess students' progress continually and provide regular interventions.

Knowledge of the individual students is critical. Berliner (2004b) reported on an experiment where expert teachers were asked to plan and deliver a science lesson to an unknown group of students. The teachers reported that both the planning and running of the lesson were difficult and stressful, as they didn't know the students' personalities or their cognitive abilities. He reported that expert teachers relied on identifying changes in their students' non-verbal cues to help infer their students' comprehension (Berliner, 2004a).

Amongst other factors, the student questionnaire in TIMSS asks students about classroom teaching and learning practices (TIMSS and PIRLS International Study Centre, 2013). Thompson and her colleagues (2012) analysed the data from the 2011 *TIMSS* and found that Australian year 8 students who reported they were engaged in science scored more highly on the achievement assessment than those who indicated they were not engaged with their science lessons. Unfortunately, at the same time, only 25% of the Australian year 8 students surveyed indicated that they enjoyed learning science. Contradicting this positive connection between achievement and enjoyment of science were the results from top achieving countries like Japan and Korea. The students from these countries recorded the lowest proportions of students who enjoy learning science, at 15% and 11% respectively (Thomson et al., 2012). These results suggest that further research may be needed to understand the relationship between classroom climate, student engagement and achievement.

2.2.4 Reflection and reasoning

An essential element of being an excellent teacher is the capacity to engage in critical self-reflection (Bransford et al., 2000; Faull, 2009). Shulman (1987, p. 1) identified 'reasoning, transformation and reflection' as important components of quality teaching and describes the thinking that teachers do behind their practice in the classroom. Furthermore, Ghaye (2010) contends that reflection is not just about self-improvement but also about understanding and questioning the evidence from teaching and learning. Teachers' reflection and reasoning can occur before the lesson, when the teacher is planning the unit, during the lesson, to respond to students' immediate learning needs and after the lesson when the teacher reflects on the lesson and makes adjustments for the next learning episode (Keast et al., 2016).

Schneider and Plasman (2011) examined nearly 30 years of research about science teachers' learning and their PCK. They found that reflection was crucial for teachers' PCK to develop to an advanced level; time in the classroom alone was not enough. Furthermore, Pedretti et al.

(2007) found that excellent science teachers relied on a good knowledge base of educational theory and trends in teaching practice on which to base their reflection upon. Keast et al. (2016) worked with expert teachers in exploring their metacognition by having teachers reflect on their lessons and by recording discussions of team planning meetings. Their data suggests that the expert teachers used complex reasoning and their thinking 'pinballs' between different foci, which reveals the huge amount of PCK they consider in their practice. Keast et al.'s (2016) findings indicate there is much more to be learnt about the reflection and reasoning of expert and indeed excellent teachers.

Schneider and Plasman (2011) reported a lack of research on what teachers do rather than what they think about their practice, especially beyond their time in initial teacher education. My study added to this field of knowledge about excellent teachers' reflection and reasoning.

2.2.5 Conclusions related to teacher knowledge

The review of the literature in this section has shown that teacher knowledge is a complex construct, as Shulman (1987) explained. Excellent science teachers need to have rigorous knowledge and understanding of science as a discipline and diverse field of learning (Hattie, 2003). But excellent teachers also need to have deep understanding of the curriculum and what pedagogical approaches will enable their students to achieve the required learning. Excellent science teachers have high levels of pedagogical knowledge and PCK and are able to use this to develop rigorous and engaging teaching and learning in science so that all students' learning is maximised. Exploring teachers' pedagogical knowledge was a further aspect of my study.

2.3 Excellent teachers' personal attributes

There is substantial literature related to the personal attributes of excellent teachers, so this section discusses these factors. Hattie (2004) argues for example that attributes that make a difference include authenticity, commitment and passion. Mortiboys (2005) says that in addition to content and PCK, excellent teachers also need to have high levels of emotional intelligence, since this has been shown to influence students' engagement and academic performance. Furthermore, the teacher's ability to form relationships with their students also adds to a positive classroom climate. The *Teaching and Learning International Survey* (TALIS) defines classroom climate as, 'the quality of social relations between students and teachers… which is known to have a direct influence on motivational factors, such as student commitment [and] learning motivation' (OECD, 2010, p. 91). A positive classroom climate creates a safe and challenging atmosphere for positive learning to occur. This section provides an examination of literature related to the role of excellent science teachers' authenticity, passion and commitment in creating positive classroom learning environments.

2.3.1 Positive and authentic relationships

The literature clearly shows that excellent teachers build positive relationships with students. Bolshakova, Johnson and Czerniak's (2011, p. 922) qualitative study of junior secondary science students in USA concluded that when 'students and teachers appeared to share a warm and caring relationship that built a sense of belonging within the classroom walls' both students' science self-efficacy and achievement in science improved. In another study, in the USA Brunkhorst (1992) surveyed year 7 and 8 students in exemplary science programs (as identified through the Search for Excellence in Science Education program) and compared them to responses from students of a general science group in USA. She found that,

> 'students of the exemplary program teachers perceive[d] their teachers as liking science, knowing a lot of science, yet willing to admit not knowing. Their students [were] encouraged to ask questions and share ideas. Their students enjoy[ed] the science learning environment the teachers ha[d] created for them, identifying science as their favourite subject at 29% frequency, compared with the national sample at 11% frequency'. (Brunkhorst, 1992, p. 574)

In an Australian study, Waldrip, Fisher and Dorman (2009) administered the, 'What is happening in this class' ('WIHITC') questionnaire to 150 middle school science students to identify teachers with positive affective qualities, who created a favourable classroom environment. These classrooms were places where students could safely ask questions and there was respect for all individuals and their rates of learning (Waldrip et al., 2009). The researchers then labelled the teachers who were given a high score from their students for having positive learning classrooms as being 'exemplary'. When this list of 'exemplary' teachers was presented to principals, they were not surprised at the list. The students' opinions were in alignment with the principal's professional opinion of the teacher quality (Waldrip et al., 2009). This demonstrates that students' views about their teachers should be considered when examining the quality of teaching. Student observations are based on high frequency of contact with their teacher, as opposed to evaluations by inspectors or administrators, who base their assessment only on one or a few observations (Coe et al., 2014; Goodrum et al., 2001;

Measures of Effective Teaching Project (MET), 2012). This is particularly valuable in Australian years 7-10 science education where there are no standardized tests to compare achievements of students and teachers. In my study, students' opinions about their science teacher and the classroom environment were sought.

Brookfield (2006, p. 68) defined authenticity as, 'the perception that the teacher is being open and honest in her attempts to help students learn' and emphasised this as an important attribute of excellent teachers. One aspect of authenticity is honest emotional engagement through humour and real-life stories. Olitsky (2007) investigated year 8 students' cognitive and social engagement with their science learning. She found engagement was best where teachers engaged emotionally with students, by sharing their sense of humour and acknowledging their own weaknesses. The students had a sense of belonging to the class where they were challenged and could take risks with their learning. Research has also shown that students are engaged with science when the human-side is incorporated. This includes inspirational stories of past students who have proceeded into science-related careers (Bolshakova et al., 2011) or short stories or anecdotes to help students understand the concept (Wilson & Mant, 2011a).

2.3.2 Passion for science

Ruiz-Alfonso, Vega, and Beltran (2018) argue that being passionate involves having a strong, positive, emotional attachment to something and is evident in practice through high levels of concentration and energy. Passionate teachers are 'enthusiastic, excitable, positive, and energetic' (Faull, 2009, p. 38). Through an online survey of practicing teachers in Queensland, Wyatt-Smith, Wang, Alexander, Plessis and Hand (2017) found that one of the five main reasons for choosing teaching as a career was people's passion for a specific subject. Furthermore, no matter if teaching was their first or later career choice, many of the teachers surveyed reported a passion for working with young people and sharing the love of their subject with them (Wyatt-Smith et al., 2017).

Hattie (2003) agrees that a teacher's passion impact student engagement and achievement in learning science. Hobbs (2012) reported that a teacher's passion is transferred to students through stories and anecdotes that humanizes the science. In his study of excellent teachers, Berliner (2004b) also identified passion for teaching and learning to be common attributes. Bolshakova, Johnson and Czerniak (2011) investigated the attributes of an exemplary teacher of year 7 science and found that past and current students recognised the teacher's passion. This was supported by the researchers' observations of a lesson where they also saw this reflected in the students' engagement in their learning. Science teachers' passion for science and learning can influence their students' attitudes to science beyond their school education. Hudson, Usak, Fančovičová, Erdoğan, and Prokop (2010) administered a questionnaire to Turkish and Slovakian pre-service science teachers to find out their lasting impressions of their secondary school science teachers. They found 87% of the pre-service teachers indicated their teachers' enthusiasm and positive attitude to science were important (Hudson et al., 2010).

The literature shows that passionate teachers show strong commitment to their work which increases the learning potential of their students (Mart, 2013). In my study I identified passion as an attribute of the excellent science teachers.

2.3.3 Commitment and drive

Altun (2017, p. 51) argues that, 'teacher commitment is an internal force that drives teachers to invest more time and energy in keeping up involvement in the school'. Excellent teachers show commitment to improving the learning experience for their students and improving their own professional growth (Faull, 2008). In addition, a teacher's commitment to their work varies during their personal and professional life-phases (Day et al., 2006). Day et al. (2006) found that a teacher's commitment to extra-curricular programs and professional learning was greater with factors such as positive and supportive school culture, manageable workloads, positive relationships with students, supportive personal relationships and good health. All these dimensions of commitment were relevant to my study and worthy of further research.

Other projects have focused on evidence of committed science teachers being involved in improving science experiences for students in areas beyond their own classrooms. In evaluating successful science programs in the UK, Ofsted (2011) reported that extra-curricular activities had a positive impact on students' attitudes to science and the students' achievement was good or outstanding in schools which offered such programs. Committed teachers build partnerships with stakeholders who can support their students' learning success. The ASPIRES project (Archer et al., 2013, p. 12), a 5 year study of 11-14 year olds' science aspirations in the UK found the most influential factors on students continuing with science in the post-compulsory years were their 'attitudes toward school science and parental attitudes to science, … [student]

self-concept in science and participation in science-related activities outside of school (in years 8 & 9)'. Archer et al. (2013, p. 5) proposed that teachers who '[support] families to feel comfortable and knowledgeable about science and to see its relevance to their everyday lives and futures might help more students… to develop and sustain science aspirations'. In my study, I explored the extent to which the case teachers employed partnerships to support their students' learning.

Committed teachers seek professional learning and collaborate with others to improve their knowledge and practice. Crosswell and Elliott (2004, p. 6) stress the importance of motivation as a driving force 'to engage in ongoing learning and to maintain professional knowledge'. A number of studies support the view that professional collaboration is essential for quality teachers as collaborative planning results in the implementation of a wide range of teaching strategies and a greater understanding of students' needs (Coe et al., 2014; DEECD, 2014; Jensen, 2010). Furthermore, this commitment shows a personal drive to achieve their best which Faull (2009) sees as setting high expectations not just for themselves, but also for their students. This is supported by Day et al.'s (2006) research that found students of committed teachers achieved at or above the expected levels.

Commitment to improving the students' learning experience requires a time commitment and continual drive or continual energy. This personal drive can sometimes be to the point of perfection which can lead to innovation and being an excellent teacher (Evans, 2000). Unfortunately, it can also lead to burn-out (Fensternmacher & Richardson, 2005). In my study, I explored the extent to which the excellent teachers were able to practice work-life balance so that their commitment was sustainable.

2.3.4 Conclusions on excellent teachers' personal attributes

Thus far, my literature review has established that excellent science teachers require academic, pedagogical and personal attributes. Excellent science teachers cater for their particular students' needs and interests and their classroom environment shows respect for and interest in learning science (Hudson & Kidman, 2008; Miranda, 2012). Therefore, excellence is not merely based on what teachers *know* about science (and education) but what they *do* with it (Hattie, 2003) and their capacity to build relationships with students and colleagues in honest and meaningful ways also matters. Professional teacher standards are now widely used to identify teacher attributes. The next section will investigate the relevance of standards for my study.

2.4 Professional standards for teachers

Ingvarson and Kleinhenz (2007) argue that teacher standards provide the teaching profession with a shared language about what is valued in quality teaching. Ingvarson and Kleinhenz (2006, p. 18) state that teacher standards are an '[articulation of] a vision of quality learning that will guide their more detailed work of describing what teachers should know, believe and be able to do'. Many countries have developed professional standards for teachers since the 1980s (Call, 2018). For example, in 1987 in the USA, the National Board of Professional Teacher Standards (NBPTS) was established in response to a concern that many teachers were 'mediocre' (NBPTS, 2014). The NBPTS used Shulman's (1987) conceptualization of teachers' knowledge as the foundation for the development of teacher standards for beginning teachers (e.g., Standards for Science Teacher Preparation, National Science Teachers Association, 1998).

Since standards are relevant in the identification of the skills and attributes of excellent teachers, in this section I discuss literature related to the development of the *Australian Professional Standards for Teachers* (APSTs) developed by the Australian Institute of Teaching and School Leadership (AITSL) (AITSL, 2011) and the Australian Science Teachers Association's (ASTA) *National Professional Standards for Highly Accomplished Science Teachers* (ASTA Standards) (ASTA, 2002, 2009) with the purpose of demonstrating the role of standards in identifying excellent teachers.

2.4.1 The Australian Professional Standards for Teachers (APSTs)

In 2008, the Australian federal and state governments signed two agreements to improve the quality of teaching in Australia (COAG 2008; MCEETYA, 2008). In 2009, AITSL was established and tasked to promote excellence in Australian Schools. The APSTs were developed to 'define the work of teachers and make explicit the elements of high-quality, effective teaching in 21st century schools that will improve educational outcomes for students' (AITSL, 2011, p.4). AITSL (2017) states that the development of the APSTs was 'informed by extensive research, expert knowledge, an analysis and review of standards in use by teacher registration authorities, employers and professional associations across Australia'. There was an extensive consultation process with feedback invited from teachers, principals and other stakeholders (AITSL, 2011). The validity of their implementation was supported by a three-year evaluation by researchers at Melbourne University involving feedback from teachers and school administrators around the proficiency descriptors. (AITSL, 2016). The current APSTs are mandated throughout Australia to ensure high quality teaching and high level expectations for teachers across all levels of the profession from graduate, to proficient, highly-accomplished and lead (AITSL, 2011).

The seven APSTs are organized into three domains: knowledge, practice and engagement (see Table 1). Each Standard is divided into focus areas which specifically describes what teachers should know and be able to do. For example, Standard one is that ‘teachers should know students and how they learn’ (AITSL, 2011). This standard has six focus areas describing the expected teachers’ knowledge of the diversity of students one might have in a classroom: their intellectual, physical and social stage; their linguistic, cultural, religious and socioeconomic backgrounds as well as how they learn (AITSL, 2011).

Table 1 Overview of the Australian Professional Standards for Teachers (AITSL, 2011)

Domains of teaching	**Standards**	**Focus areas (**that differentiate between teachers' career stages.)
Professional Knowledge	1. Know students and how they learn	1.1-1.6
	2. Know the content and how to teach it	2.1-2.6
Professional Practice	3. Plan for and implement effective teaching and learning	3.1-3.7
	4. Create and maintain supportive and safe learning environments	4.1-4.5
	5. Assess, provide feedback and report on student learning	5.1-5.5
Professional Engagement	6. Engage in professional learning	6.1-6.4
	7. Engage professionally with colleagues, parents/ carers and the community	7.1-7.4

In addition, the APSTs are intended to 'guide professional learning, practice and engagement, facilitate the improvement of teacher quality and contribute positively to the public standing of the profession' (AITSL, 2011). They are now required as the benchmark for teacher registration, to guide the identification of teacher proficiency across Australia and as a mandatory framework for Initial Teacher Education (ITE). Pre-service teachers (PSTs) have found the APSTs useful as they provide a 'shared language and acts as a 'learning scaffold', especially when on practicum (Loughland & Ellis, 2016, p. 56). In each state and territory, regulatory authorities monitor teachers' ongoing professional learning that should be focused on achieving these standards. The Victorian Institute of Teaching (VIT) is responsible for teacher registration in Victoria and requires teachers to show evidence of attending a range of professional development activities that address the seven APSTs. Ongoing registration requires teachers to have evidence of at least 20 days of teaching in a school in one year and 20 hours of professional development which is referenced to the APSTs (VIT, 2018). This indicates that both knowledge and experience are seen as being relevant to be a 'proficient teacher'. For the purpose of my study, the relevant 'career stage' of the APSTs was the 'highly accomplished' teacher. Teachers in all states and territories of Australia, except Victoria, can achieve certification to be acknowledged as a 'highly accomplished teacher' or 'lead teacher' (HALT) in accordance with the APSTs (AITSL, 2018b). HALT certified teachers 'demonstrate leadership and commitment to excellence in teaching' (AITSL, 2018b). Even so, the APSTs tend to describe 'highly accomplished' teachers as those who influence and work with colleagues (Bahr & Mellor, 2016).

However, there are criticisms of the APSTs. First, there is debate as to whether they are too generic to identify exemplary or lead practice, especially in secondary school teaching where the curriculum is often more subject-based and therefore requires more specific disciplinary and pedagogical knowledge (Doecke et al., 2013). Furthermore, Bahr and Mellor (2016) argue that although the APSTs describe teacher competencies, they do not acknowledge the personal attributes that enable an effective teacher to become excellent. Blackmore (2004, p. 441) suggests that the 'dimension of emotion' is not present in Standards that are used for accountability purposes because it is too subjective. There is also no mention of teacher reflective practice in the APSTs. Berliner (2004b, p. 22) suggests that unlike novice or beginner teachers, 'experts are not consciously choosing what to attend to and what to do' because much of their reflection and reasoning has become intuitive. While the literature does show that aspects of excellence do include the generic elements of the APSTs, it was important for the purposes of my study, to explore standards specifically related to science teaching.

2.4.2 The ASTA Standards

This section examines the *National Professional Standards For Highly Accomplished Science Teachers* (ASTA Standards) (ASTA, 2002, 2009). Similar to what was happening internationally in the late 1980s and 1990s, several subject-specific professional associations in Australia worked with educational experts to develop standards for teachers of their discipline (Doecke et al., 2013). For example, the Australian Association for the Teaching of English (AATE) and the Australian Literacy Educators' Association (ALEA) worked with researchers to produce the *Standards for Teachers of English Language and Literacy in Australia* (Doecke et al., 2013). The Australian Science Teachers Association (ASTA) developed the ASTA Standards for 'highly accomplished' science teachers prior to the APSTs, with the first draft in 2002 and the final in 2009 (ASTA, 2009). They were developed by a team of 15 experienced science educators, representing all states and territories and all school sectors, working with experts from Monash University. The ASTA Standards have never been officially used and have not been through any process of validation like the APSTs. This is because they were abandoned after the APSTs were created but the document did provide a useful framework that describes the knowledge and skills necessary specifically for ‘highly accomplished’ science teachers and was therefore a useful framework for my study (see Table 2).

Table 2 National Professional Standards for Highly Accomplished Science Teachers (ASTA, 2002, p. 1)

Domains of teaching	**Standards**
Professional Knowledge	1. Knowledge of science and science curricula 2. Knowledge of teaching, learning and assessment in science 3. Knowledge of students and how students learn in science
Professional Practice	4. Designing coherent learning programs 5. Creating and managing learning environments 6. Engaging students in scientific inquiry 7. Extending students’ understandings of major ideas in science 8. Developing students’ ability to use science in decision making 9. Assessing and monitoring student learning
Professional Attributes	10. Analysing, evaluation and refining teaching practice 11. Professional contributions to science education

The benefits of using the ASTA Standards in my study was that the descriptions corresponds with the literature about excellent science teachers’ knowledge discussed in section 2.2 above. They state that highly accomplished science teachers’ science content knowledge should be ‘broad and current’ and that teachers should ‘…extend students’ understandings of the major ideas of science’ (ASTA, 2002, p. 3). They also explicitly describe the work of teachers in science education, stating that teachers are able to ‘engage their students in scientific inquiry’ and that science teachers ‘model the habits of mind inherent in what it means to do science’ (ASTA, 2002, pp. 5, 6). Furthermore, the ASTA Standards ‘identify the essential features of highly accomplished science teaching without prescribing one way to meet those standards’ (ASTA, 2002, p. 6). Even though the ASTA Standards have explicit descriptions, they also provide enough breadth and depth in each criterion to be rigorous and allow for the impact of personal attributes. Lastly, the ASTA Standards highlight the importance of teacher critical reflection throughout; a factor that I have identified through the review as being a factor related to excellent science teachers (as stated section 2.2.4).

Whilst types of knowledge have been identified as separate entities in both the APSTs and ASTA Standards and by Shulman (2007), it is important to note that the Standards are interconnected. This is reinforced by AITSL (AITSL, 2011), who states that the standards are 'interconnected, interdependent and overlapping' (p. 3). Similarly when referring to teacher competencies, Coe et al. (2014, p. 10) suggest that the 'whole may be greater than the sum of the parts'. Thus, it is not just a matter of ticking the box for each knowledge area to ensure identification of excellence; an in-depth study was needed. The lack of reference to the personal attributes in both the APSTs and the ASTA Standards is surprising as they are obviously an important part of being an excellent teacher. It is interesting to note that two of the four standards in the *Standards for Chartered Teachers in Scotland* (a voluntary award for accomplished teachers) are 'professional values and personal commitments' and 'professional and personal attributes' (Ingvarson & Kleinhenz, 2007, p. 74) indicating that personal attributes are acknowledged as an important factor in excellent teachers.

2.5 Beliefs

Shulman (1987) argued that there are complex interactions that occur between a teacher's knowledge about content, learning and the specific context which influence a teacher's PCK. Borko and Putnam (2000) suggested that a teacher's beliefs are involved in these interactions by acting as filters of the knowledge cogitated. This section of my review examines the literature about teachers' beliefs. Firstly, I examine what comprises teachers' beliefs, where beliefs might originate and how they might influence their thinking. Secondly, the literature concerning the relationship between beliefs and teaching practice is examined.

There are conflicting definitions of beliefs, partially because it depends on whether it is viewed through a psychological or philosophical lens and partly because of the inconsistent language used by different researchers in describing beliefs. What is agreed is that all people have beliefs: a confident conviction that something is true (Oxford English Dictionary, 2015a). Pajares (1992) and Richardson (2003) both made the distinction between beliefs and knowledge by stating that knowledge can be justified and is based on known factual evidence whereas beliefs are more subjective; an individual can accept that other people may have different beliefs but still maintain their own. Richardson (2003, p. 3) argues that, 'Beliefs are propositions that are accepted as being true by the person holding the belief, but they do not require epistemic warrant. Knowledge, however, does.'

Thompson (1992, p. 140) suggested that, 'belief systems are dynamic, permeable mental structures, susceptible to change in light of experience'. Similarly, Mansour (2009) and Richardson (2003) agree that beliefs can change, however some beliefs can be held so strongly that they are unlikely to change, unless the individual is engaged in a significant event. Bryan's (2003) study supports Thompson, Richardson and Mansour's findings and goes further. She investigated the beliefs about teaching and learning held by a primary science teacher in USA. She found that not all beliefs are equal to each other: some are deeply entrenched and solid, whilst others are less central and are more likely to be open to change (Bryan, 2003). My study focused on the centrally held beliefs; beliefs that are strongly held and consistently expressed.

Abelson (1979) suggested that beliefs help individuals to define and understand the world and themselves, and they play a critical role in defining behaviour and organizing knowledge and information. Mansour (2009, p. 28) concurs, stating that beliefs 'act as an information organizer and priority categoriser, and in turn control the way it could be used'. Thus, beliefs can influence the development of teachers' knowledge, their priorities and their practice. Indeed, Wallace (2014) contends that it is well accepted by researchers that beliefs have a big impact on science teaching and learning. Hence, in my study, I was interested in the source of teachers' beliefs and the relationship between the teachers' beliefs, knowledge, personal attributes and practice. However, my study focused on teachers' beliefs about science and education.

2.5.1 Sources of teachers' beliefs

A well-known quote by John Dewey emphasizes a possible concern about teachers' beliefs and their choice of teaching approaches; 'If we teach today as we taught yesterday, then we rob our children of tomorrow' (Dewey, 1944, p. 167). Therefore, examining the origins of excellent science teachers' beliefs can help to determine whether those beliefs conflict with research-validated practices when making pedagogical decisions. Teachers' beliefs come from three main sources: their personal experiences as students, their own professional development, including their pre-service education, their own teaching experience and observation of other teachers (Levin et al., 2013). Nespor (1987) argues that these experiences form episodic memories which are very strong. All these sources have the potential to impact teacher's beliefs.

2.5.1.1 Beliefs from experiences as a student

Much of what teachers believe about school comes from their own experience as students, since they have all experienced thirteen years of being students in schools. Lortie (1975, p. 61) described this past school experience as an 'apprenticeship of observation', a unique experience for teachers compared to other professions. Earlier in my review (section 2.3), I discussed the findings of Hudson et al. (2010), who investigated pre-service science teachers' lasting perceptions of their science teachers; reinforcing the view that pre-service teachers already have a huge amount of experience about teaching and learning when they start their teacher education. Similarly, Schneider, Pakzad and Schlü (2011) found that pre-service biology teachers were greatly influenced by their beliefs formed from their own experiences as students and not just by the knowledge learnt in their initial teacher education. As science teachers' beliefs are influenced by their time as a student, section 2.6 provides an overview of past contexts and their potential influence.

Preservice teachers' (PSTs) beliefs about teaching and learning are challenged during their initial teacher education. Löfström and Poom-Valickis (2013) undertook a longitudinal study of PSTs' beliefs from their first year to their final undergraduate year in Estonia. They concluded that whilst some PSTs adopted new beliefs consistent with the theory of the course, they still held on to some of their former beliefs and so rather than their belief system changing, it became more complex. Consequently, they asserted that 'the nature of beliefs is highly influential on how prospective teachers respond to their teacher education curriculum' (Löfström & Poom-Valickis, 2013, p. 111). As a consequence, they recommended that teacher education should 'facilitat[e] the development of student beliefs about teaching by encouraging student reflection on their own learning' (Löfström & Poom-Valickis, 2013, p. 112).

2.5.1.2 Beliefs from professional learning

A teacher's pre-existing beliefs can affect what knowledge is learned and practiced, but can in turn be influenced by exposure to new knowledge. Nespor (1987) found that teachers are influenced by their beliefs more than by 'research-based knowledge or academic theory' (p.

324). This is because beliefs help to make sense of complex problem-solving encountered in the everyday life of a teacher (Jones & Carter, 2007). Anderson and Holt-Reynolds (1995) suggested that in-service teachers bring their beliefs into professional development experiences. Johnson (2006) examined the practices of middle school science teachers who participated in a particular professional development activity about inquiry-based learning. She found that only some of the teachers effectively changed their practice, since their individual beliefs about teaching and learning affected what knowledge they adopted, and consequently, whether they applied the new strategy in the reality of the classroom.

2.5.1.3 Beliefs from past teaching experience

Because there is an affective component to beliefs, they can be influenced by prior positive or negative experiences in the classroom. This is supported by Ozgun-Koca and Sen's (2006) research where they examined the beliefs about teaching and learning held by Turkish maths/physics PSTs before and after teaching. They commenced with a theoretical component, promoting student-centred approaches and was followed by PSTs attending school placement practicum. The researchers found that after the theory stage, most of the PSTs had a good understanding of a 'student-centred classroom'. However, after the school placement the PSTs 'resorted to a traditional view where they wanted to present their good subject area knowledge to their quiet and well-behaved students through a good quality of communication with different teaching methods' (Özgün-Koca & Şen, 2006, p. 957). This shows the impact of their teaching experience where their central belief of the 'traditional classroom' was reinforced. In my study, I examined whether the teachers' beliefs were affected by their initial teacher education program.

The experiences of teachers in the first five years of their teaching careers have been studied by many (Schaefer et al., 2012; Wong & Luft, 2015) who have found that their beliefs can be challenged and/or reinforced. Le Cornu (2013) found that teachers' beliefs during the early part of their career are influenced by their colleagues and the school context. Skott (2015) claims that a lot of research into teachers' beliefs has been around the implementation of a change such as a learning experience or learning intervention. Herrington, Bancroft, Edwards and Schairer (2016) provided thirteen in-service science teachers the opportunity to be involved in a six week research program in a science laboratory. They found nine of the teachers changed their beliefs about what constituted scientific inquiry and also enacted their beliefs by including more inquiry in their science lessons. The nine teachers who changed their beliefs included one of more than ten years teaching experience, which contradicts what is widely reported in the research literature that experienced teachers' beliefs are strongly held and difficult to change (Pajares, 1992; Wallace, 2014).

After reviewing more than six hundred research articles about teachers' beliefs, Fives and Buehl (2011) asserted that beliefs are also influenced by the goals of society, the nature of the curriculum and the relationships of teachers in the school community. These contextual factors are discussed further in section 2.6.

2.5.2 Types of teachers' beliefs

In 2011, Friedrichsen, van Driel and Abell (2011, p. 372) reviewed prior research and concluded that teachers' beliefs can be classified into three categories: 'the goals or purposes of science teaching, (the nature of) science, and science teaching and learning'. These categories are used in the following review of literature related to teachers' beliefs.

2.5.2.1 Beliefs about the goals and purposes of science teaching

The goals and purposes of science teaching are set out in curriculum documents, which in my study is the *Victorian Curriculum: Science*. Friedrichsen et al.'s contention (2011) suggests that a teacher's interpretation of the curriculum is framed by their beliefs. Earlier in my review I explained that the stated purpose of the *Victorian Curriculum: Science* is for all students to develop scientific literacy, with two main strands: science understanding and science inquiry skills (see section 2.2 of my review). Hildebrand (2007) describes this as being the intended curriculum. Whilst teachers have knowledge of science and pedagogical knowledge to assist in understanding the aims of the curriculum, they also bring their own beliefs which determine to some accept what they accept, reject or reconstruct of the curriculum. Thus, the intended curriculum becomes the enacted curriculum where teachers emphasise what they believe to be important. For example, teachers may believe that it is more important for students to understand scientific concepts, theories and models than it is for them to learn the skills of inquiry such as posing questions, investigating ideas and solving problems. In support of this, Tsai's (2002) study found a group of Taiwanese teachers had content-focused beliefs whilst Herrington, Bancroft, Edwards and Schairer (2016) found that the majority of science teachers in their study emphasised critically thinking after being exposed to professional learning about inquiry themselves. Furthermore, Friedrichsen and Dana's (2003) study of biology teachers found their beliefs about the general purpose of education to prepare students for life were also involved in how they enacted the curriculum.

2.5.2.2 Beliefs about science

Science teachers' beliefs about the nature of science also influences the enactment of the curriculum. Brickhouse's (1990) examination of three secondary science teachers showed that they all delivered the same curriculum with different emphases, based on what they believed about the nature of science. The first teacher believed that 'science was truth' and wanted his students to know about the major scientific theories. The second teacher believed that scientific theories were tools and wanted his students to learn how to use them to solve problems. The third teacher who viewed 'the scientific method' to be a linear and rational process 'that leads on unambiguously to scientific truth', also believed 'scientific procedures to be predetermined' and held that 'science activities require following directions to get correct answers' (Brickhouse, 1990, pp. 55, 56). In support of Brickhouse's findings about individuality, Gess-Newsome (2015) advocated that individual teachers have their own belief sets, so although a group of teachers may teach the same topic in the same school, each teacher will emphasize different aspects of the topic as their beliefs influence their practice.

2.5.2.3 Beliefs about teaching and learning science

Research has found that teachers have beliefs about how best to teach so that students can learn. Brown, Friedrichsen and Abell (2013) studied four pre-service biology teachers during their teacher education program. Whilst these PSTs increased their knowledge of how students learn science best and the role of teachers in the learning process, they still held beliefs about teaching and learning that were consistent with their own experiences as students of science. For example, they found these PSTs tended to inform students about new concepts and vocabulary through lectures rather than giving students the opportunity to form their own explanations, even though they had been taught the theory that a constructivist approach is a better way for students to learn (Brown et al., 2013). Furthermore, Wallace and Kang (2004) investigated experienced science teachers' planning of practical work. They found a difference in emphasis in the practical work based on the teachers' beliefs about which is more important for students: learning about the inquiry process or reinforcing conceptual knowledge.

Teachers have beliefs about the role of assessment in teaching and learning. Barnes, Fives and Dacey (2015) proposed that teachers' beliefs about the purpose of assessment ranged from assessment for improving student learning, to assessment for student feedback and motivation, through to assessment for external accountability. Teachers' beliefs about assessment may not align with the goals and purposes of the curriculum. Matese, Griesdorn and Edelson (2002) investigated two teachers' beliefs about assessment in an inquiry-based science program. One teacher decided not to assess students' inquiry and metacognition early in the unit as she believed assessing the students' content knowledge was more important. The assessments this teacher used were written and marked by her, with students receiving a grade and written feedback which explained the 'right conclusions' (Matese et al., 2002, p. 10). This indicates that this teacher believed that assessment was initially between the teacher and student and stayed in the class environment, but ultimately resulted in a grade for accountability.

This section has shown that how, why and what a teacher teaches and how they assess can be influenced by their beliefs. As Fives and Buehl (2011) state, these beliefs act as filters to knowledge and experience and therefore influence teachers' practice. Tsai's (2002, p. 778) study of teacher beliefs found that there is 'interplay' between teachers' beliefs about science and beliefs of teaching and learning science. In addition, he found that more experienced science teachers had even more complex connections between these beliefs than early career teachers. As the teachers in my study had at least five years of teaching experience, it is expected that interviews and observing teachers' practice would identify which beliefs may be more important than others through observing 'beliefs-in-action' (Bryan, 2012, p. 480). Therefore, my study aimed to examine the beliefs of excellent teachers and consider how these beliefs influence exemplary practice.

2.6 Contexts – past and present

This section of the review discusses literature pertinent to secondary science education from the late 1970s to the 2000s, when the teachers in my study would have been students. This is relevant because, as sociologist Lortie (1975) suggested, we often teach the way we were taught. I explore why and how the content and approach to teaching science has changed during this time to provide contextual understanding of science education.

2.6.1 Past science education contexts

Secondary school science in the twentieth century was reflective of the 'industrial age' where the purpose was to prepare those students who wanted science-related careers (Fensham, 2006; Rennie et al., 2001). Its delivery tended to be didactic; teacher-centred with the transmission of a known body of knowledge of and about the world, but more importantly focused on *training* of students in science processes and skills (Rennie et al., 2001). This was evident in the Australian Science Education Project (ASEP), which was widely embraced in Australia during the 1970s and 1980s (Kidman, 2012). Kidman explains that ASEP was an activity-based science curriculum for years 7-10 with a strong emphasis on inductive practical work. Although ASEP allowed for the curriculum to be self-paced and semi-personalised, it was mostly taught as a step-wise, non-varying approach to 'doing science' (Rennie et al., 2001). Practical work tended to be recipe-style, with the results predetermined in a fixed knowledge-base (R. Gunstone, personal communication, November 23, 2018).

In 1985, the Australian Science Teachers Association (ASTA), the professional body of science teachers in Australia contended that the then curriculum had 'an undue emphasis on the teaching of content, leaving little time for the development of scientific processes, manipulative skills, scientific attitudes, or an understanding of human aspects, environmental issues, and the application of science' (ASTA, 1985, p. 10). This prompted another change in science curriculum in Australia. Each state developed their own science curriculum, but they all considered the interests of students and acknowledged students' prior knowledge. The human components of knowledge such as open-mindedness, scepticism, creativity and inquiry were also included in the curriculum design (Kidman, 2012).

Despite the new direction, Goodrum, Hackling and Rennie (2001, p. 152) reported that there was a 'sizable gap' between the intended science curriculum and what was actually being enacted in the classroom and that secondary science classrooms were still 'traditional, disciplined based and dominated by content'. In the 1990s and 2000s, many teachers still tended to use a lot of chalk-and-talk teaching with students copying notes off the board and, although there was more practical work, they continued to be closed exercises where students followed recipes (Lyons, 2006). He reported that narratives from students in Australia, Sweden and England were all similar in describing their secondary science classes as consisting of difficult, boring and irrelevant content that was transferred from the teacher or a textbook to the class (Lyons, 2006). In addition, in their Australian study, Rennie, Goodrum and Hackling, (2001) showed the same results; science was neither relevant nor engaging and was not connected with students' interests and experiences.

The above describes the context of secondary school science that may have been experienced by the excellent teachers in my study as students. My study ascertained the influence of these teachers' experiences on the beliefs held about their own practices as science teachers.

2.6.2 Current context of science education

The *Australian Curriculum: Science* was initially released for schools in 2010. Since then, each state and territory in Australia has adapted the Australian Curriculum to the local context, whilst maintaining the rationale and aims of the national curriculum (VCAA, 2017d). The Victorian government's initial response to the Australian Curriculum was the *AusVELs* curriculum in 2013 (VCAA, 2017d). *AusVELs* became the *Victorian Curriculum* in 2016 (VCAA, 2017d). The science learning area of *AusVELs* had similar priorities as the *Victorian Curriculum: Science*, so the teachers in my study were familiar with scientific literacy being a priority during the data collection phase of my study, 2017-2018.

Whilst scientific literacy is the main goal of the *Victorian Curriculum: Science*, the curriculum also aims to cater for all levels of ability and to inspire a life-long interest in questioning and appreciating the science that students will encounter in real life. The rationale for the *Victorian Curriculum: Science* states that,

> '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'. (VCAA, 2017e)

The Curriculum states that it is schools and teachers who decide the best 'pedagogical approaches that account for students' needs, interests [as well as] the school and community context' (ACARA, 2012b, p. 13). Therefore, the success of students studying the *Victorian Curriculum: Science* is dependent, to a large extent, upon the science teacher who interprets the curriculum and develops teaching and learning to achieve the learning required. Thus, teaching science in years 7-10 in the context of the *Victorian Curriculum*: *Science* requires teachers to have knowledge of contemporary scientific content and issues, knowledge of how best to teach the content and how to create a learning environment where their students' cognitive needs are catered for and their interest in science is encouraged. Put more simply, teaching in this context is complex, so an excellent teacher of science needs a diverse range of personal and professional skills and knowledge to be successful in maximizing students' learning. In my study, I investigated how the teachers' knowledge, personal attributes and beliefs influence their enactment of the *Victorian Curriculum: Science*.

In October 2018, the first national standardised assessment of scientific literacy in years 7-10 (NAP-SL) was conducted in sample schools in three Australian states, including Victoria (ACARA, 2019b) . The report from this assessment only became available four weeks before the submission of this thesis, so is not discussed here. Instead, a snapshot of Australian students' achievement in science occurs through a sample of our year 9 students who take part in the Program for International Student Assessment (PISA) (Thomson et al., 2016). This means that for my study, excellent science teachers could not be identified through the comparison of students' achievement. It is also important to note that the TIMSS achievement test assesses knowledge rather than problem-solving skills and in terms of the *Australian Curriculum: Science*'s aims, high achievement in TIMSS may not be a good measure of the learning that is promoted in Australia (Ey, 2013). In terms of my research, teachers did not need to consider any mandatory or standardised assessment for their middle school science students. Instead, I relied on other means of identifying the teacher participants (see methodology).

2.6.3 Local school contexts

Whilst there is consistency of intended curriculum in Victoria, there is a range of secondary schools providing families with a choice of context: government, independent, co-educational, single-sex, religious association, select-entry (Victorian Department of Education and Training, 2019) and curriculum is always mediated by how it is implemented in schools. Jones and Carter (2007) suggested that a school's environment such as policies, facilities and interactions with parents and colleagues can affect teachers' instructional decisions. For example, a study of science in primary schools in Western Australia found that teachers in high and medium socioeconomic schools conducted more open-ended practical activities than in low socioeconomic schools (Tao et al., 2013). The Alliance for Girls' Schools' Australasia (2016) state that girls' only schools have pastoral care and academic programs specifically designed to motivate and give girls' more belief and resilience in pursuing STEM subjects. Furthermore, the school's climate and structure can affect a teacher's practice. Bahr and Mellor (2016) state that for quality teaching to occur, the school needs to ensure there is collegial respect, collaboration and professional learning and where teachers have freedom to implement initiatives with the purpose of improving student learning.

I included an examination of the teachers' school contexts in my study to better understand how these factors were involved in their teaching practice.

2.7 Conclusion

The aim of this chapter was to review the literature related to the key concepts and current thinking about excellent teachers, their knowledge, personal attributes, beliefs and contexts in which they teach. Two main aspects need reiteration. First, based on the work of past researchers, I decided that the following aspects of being an excellent teacher would be explored in my study.

- Excellent science teachers have professional knowledge as described by the ASTA *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002). This means they will have knowledge of science, pedagogy for developing engaging science teaching and learning, curriculum, students as learners and the school context.
- Excellent science teachers have personal attributes as described by Keeley, Smith, Buskist (2006). This means they will be passionate, creative, committed, life-long learners, effective communicators, have a positive attitude and be approachable.

Second, the analysis of the literature demonstrated that research has examined teachers' knowledge, personal attributes, beliefs and contexts of science teachers either separately or as a combination of these factors. Indeed, all these factors are represented in an early model of influences on teachers' PCK developed by Magnusson, Krajcik, and Borko (1999). Whilst, many research studies since have used their structure, there has been growing concern about its inability to describe the complexity of teachers' work (Friedrichsen, 2015; Gess-Newsome, 2015). Most past research has focused on pre-service, primary or senior secondary teachers. There is a lack of research on excellent science teachers in years 7-10. To try to better understand the complexity of excellent science teachers, my study examined the interactions and influences of these teachers' knowledge, personal attributes and beliefs on their practice.

Chapter 3 Methodology

3.1 Introduction

The purpose of my research was to conduct case studies to explore the various factors influencing the development of excellent middle school science teachers (years 7-10) and the relationship between the teachers' prior experiences and education, their beliefs and their professional practice.

The research questions for this study were:

1. How do personal and contextual factors influence the development of excellent teachers' knowledge, personal attributes, beliefs and practices?
2. What do excellent science teachers believe about teaching and learning in science in years 7-10?
3. How are the beliefs of excellent science teachers demonstrated in their professional practices and classroom teaching?

Since my questions require deep understanding and explanations of teachers' backgrounds, beliefs and practices, this study used qualitative interpretive research methods. Qualitative researchers 'study things in their natural settings' and 'in terms of the meanings people bring to them' (Denzin and Lincoln, 2011, p. 3)**.** Likewise, an interpretive research paradigm allows the researcher to study 'the meaning of actions that occur' (Erickson, 1985, p. 119).

In this chapter, I explain the research methods used in my study in more detail. I provide a rationale for the use of case study methodology and explain the methods of data collection. I justify the methods used to analyse and interpret the data and discuss how the validity of the data and the resulting conclusions has been addressed. The final section discusses the limitations of my study.

3.2 Choice of case study methodology

According to Creswell (2013), four assumptions should be considered in choosing a qualitative paradigm: ontological, epistemological, axiological and methodological concerns. As the research questions require the development of deep understanding, case studies are appropriate for the following reasons:

- Ontology requires the capturing of evidence of how things develop in reality, or how they come to be, so it is important to collect participants' own words to explain their perspectives on what is happening and their beliefs and practices in real life classrooms. This is particularly important since my questions were about *why* excellent science teachers hold certain beliefs and *how* these beliefs are translated into their own pedagogies in classrooms. Case studies are therefore appropriate as they allow the researcher to explore the complexity of the 'real world context' by collecting multiple sources of evidence and then to converge this data to form an explanation of the phenomenon (Yin, 2014, p. 13). In particular, Yin (2014) asserts that interviews are central to case study research, as they allow the researcher to explore participants' personal perceptions and own sense of reality.

- Epistemology is the branch of philosophy concerned with the theory and nature of knowledge, the rationality of belief, and justification. In my study, I used a multiple case study design based on three teachers in three different schools so that excellence can be examined in different contexts. Furthermore, the case study method allows for detailed and in depth understanding of each particular context. Yin (2014) explains that in comparison to just a single case, conclusions formed from multiple cases are often more robust, allowing for similarities and differences to not only be identified but to be analysed within and between cases to give more opportunity for a more enriched understanding.

- Axiology refers to the values that I, as the researcher, bring to the study (Creswell, 2013). When collecting data, it was important that I showed openness, sensitivity and respect for the participants and the views they expressed. In considering the data, it was important to acknowledge my interpretation of the data was value-laden because of my own past experiences. My 25 years of experience as a middle school science teacher gave me both insights and biases, which were important in understanding the case studies under investigation.

- Finally, the qualitative interpretive methodology paradigm allowed me to study the teachers' beliefs in practice and for me to use inductive rather than deductive analysis (Denzin & Lincoln, 2011). Identifying patterns through the analysis of the case studies allowed me to identify themes based on the participants' realities rather than on a predetermined theory (Creswell, 2013). Inductive data analysis was ongoing, and knowledge emerged and became more detailed.

3.3 Pilot study

A pilot study was conducted to provide an opportunity to test and refine the data gathering techniques and to uncover potential problems (Creswell, 2013). It allowed me to assess the suitability of the questions and observations for the main study and to gain experience in using them. Yin (2014) advises that although the protocol for data collection is set, it is not always predictable what information will be gained and making adjustments before the main study can save time and energy for the researcher and for the participants. This is particularly true in a qualitative interpretive study where the analysis is progressive and insights are gained during the data collection phase (van Teijingen & Hundley, 2001).

In selecting a participant for the pilot case, I chose a past colleague I knew, which allowed me to ask questions that required a degree of trust, and to readily follow up when required (Yin, 2014). She was currently teaching year 8 science at a local school and was willing to be part of the pilot study. Ethics and data collection processes were administered in the same way as intended for the main study, but only the initial interview was conducted in the pilot study. The approach included:

1. Erin (pseudonym) was given the explanatory letter and consent form (see Appendices A and B).
2. The teacher demographic questionnaire was emailed to Erin for her to complete and bring to the first interview (see Appendix C).
3. The interview occurred at a time and place convenient to Erin.
4. Data were analysed to check that it provided answers for the three research questions.

Based on the findings of the pilot study, the following modifications to the data collection procedures were:

- The teacher demographic questionnaire: some questions were restructured to ensure the interviewee could understand. For example, a table was constructed to allow all undergraduate and postgraduate studies to be completed accurately. The questionnaire was also set up on an online survey tool, SurveyMonkey™ so it could be easily accessed and completed. The teachers were sent a link to the SurveyMonkey™ and a Word document format of the questionnaire so they could choose how they preferred to complete it.

- The semi structured interview questions for teacher participants were refined to allow for more useful responses to be given and streamlined to eliminate replication.

3.4 Selection of participants

Case study research requires purposeful selection of participants. My objective was to collect deep and insightful information about excellent secondary school science teachers, in order to gain a deep understanding of their beliefs and practices. Denzin and Lincoln (2011) advise that paradigmatic or exemplar cases be chosen in this situation as they 'highlight the general characteristics of this group' (p. 308).

3.4.1 Selection of teacher participants

To identify possible teacher participants, I emailed three expert science teacher educators within the Faculty of Education to ask them to recommend potential teachers who they deemed be excellent practitioners. These teacher educators have worked with many practising science teachers through professional development and partnerships and were therefore in a position to have discussed the teachers' pedagogy and observed them in the classroom. In the email to the teacher educators, I outlined the purpose of my study and the criteria I had developed through my literature review to identify excellence and to set boundaries for my study. The criteria were that the participants would:

- currently teach year 7-10 science
- have more than 5 years teaching experience
- be highly respected by school leadership, parents and/or students in teaching middle school science
- be enthusiastic about teaching science and students learning science
- knows science content and can communicate it clearly
- know their students and cater for their diverse learner needs

While it was clear to me that the teachers who then volunteered after being recommended by the science teacher education colleagues, may not meet all criteria, I intended to make a judgement about their suitability during the study. Subsequently, I did not continue the research with one participant as she did not meet the parameters of excellence. From the five recommendations made, one teacher did not meet the criteria, one was not available, and the three other teachers participated in my study. The profiles of the three case study teachers in my study, Lindy, William and Hannah [pseudonyms] are in Table 3 which shows that they are representative of excellent science teachers for my study.

Table 3 Profiles of each excellent science teacher studied

	Lindy	**William**	**Hannah**
> 5 years teaching	• 7 years • Years 7-12 + tertiary	• 33 years • Years 3-12 + tertiary	• 25 years • Years K-12
Currently teaching years 7-10	Year 8 – Change of state	Year 10 Genetics	Year 9 – Chemical reactions
Formal qualifications & other experiences of science and teaching	• B.Sc. (Hons in immunology) • Dip.Ed. (biology, chemistry) • M.Ed. • 2 years of laboratory research • Head of science faculty	• B.Ed. (chemistry & maths) • Head of science faculty	• B.Sc. (Hons in neuroimmunology) • Dip.Ed. (general science, biology) • Certificate in Educational Neuroscience • 2 years of laboratory research • Head of science faculty
Reputation as a science teacher	• Teaching colleagues • School newsletter • Principal	• Local paper • Past students • Commendation in Prime Minister Awards	• Past students • Past parents • Commendation in Prime Minister Science Awards

My initial contact with the teacher participants was via an email in which I introduced myself and requested a brief, initial informal visit for the purpose of building rapport and trust between the teacher participant and myself. Since I was asking the participants to share their beliefs and personal experiences, establishing a rapport was essential (Rubin & Rubin, 2012). The explanatory statement for my research (Appendix A) was also attached to this initial email so the participants had time to read it before we met. This first meeting was framed as a social ‘meet and greet’; no data was collected, and no audio recording was required. It was hoped that any perceived unequal power dynamic would be removed and that the participant would be clear about their anonymity in the study, feel comfortable and recognise my genuine interest in their beliefs and practices. We discussed the scope of my study and ensured the participants understood what would be involved. All three participants subsequently signed the consent form agreeing to participate, to be interviewed and to have their classes observed. They were also informed that they could withdraw from the study at any time and were reassured that the data they provided would be confidential. After the initial interview, I sent the participants another email with the explanatory statement for their school principal and the permission document to be completed by the principal (Appendices J and K).

3.4.2 Selection of student participants

Students can be an important source of information on the quality of teaching and the learning environment in individual classrooms. Studies have found that student ratings are more highly correlated with student achievement than principal ratings and teacher self-ratings (Lyons & Quinn, 2010; Measures of Effective Teaching Project (MET), 2012). Questioning students about their perceptions is useful as it is based on many experiential observations rather than a ‘one off’ visit’ or hearsay. Data about the three teacher participants was obtained from two cohorts of students: firstly, the whole class was given a student reflection task and secondly a focus group was interviewed. Each of the three teachers allowed me to distribute explanatory letters to all students in the class under investigation. Students gave these letters to their parents/guardians who then returned a signed consent form, allowing their child to participate. All students were asked to sign an assent form to be involved in the study. Before conducting the student reflection task with the class, I explained my research to the students verbally and gave them an opportunity to ask questions. This occurred after the third time of me observing the class, when students had become familiar with having me in their classroom.

Four students from each class were chosen for the focus group through discussion between the teacher and researcher about what information I needed to collect. I wanted a wide cross-section of students, mixed ability, engagement level and gender, to get their perceptions of their science teacher. All four students were asked to sign an assent form (Appendix H) to be involved in the focus interview. They were informed that they could withdraw at any time and were reassured that the data they provided would be confidential. None of the students refused to participate. In fact, they were keen to take part – perhaps because their opinions were being respected.

3.5 Methods of Data Collection

I collected data in the participant teachers' schools and classrooms by talking directly with the participants in semi-structured interviews and by directly observing them within this environment. In addition, I collected relevant lesson plans, worksheets, assessments and curriculum documents and took photos of the physical environment (without students or teachers) which added insights into teachers' beliefs and practices. From this varied data, I was able to identify themes and patterns that emerged to develop a deep understanding of the teachers' beliefs and practices and the students' views. The findings from each case were used in comparison with the findings in the others, to enrich the discussion.

The data collection included questionnaires, interviews, focus group discussions and classroom observations. The sequence of data collection for each case study followed this order:

1. pre-interview questionnaire for teacher participants
2. in depth, extended interview with each teacher participant
3. pre-class interview with teacher participants
4. classroom observation
5. post-class interview with teacher participants
6. repeat of methods 3-5 for at least 3 separate lessons
7. student reflection task administered to whole class
8. focus group discussions with four students
9. collection of relevant documentation

Each of these methods is explained in detail in the following section.

3.5.1 Evidence from teacher participants

3.5.1.1 Teacher Questionnaire

Some of the information required for my study consisted of factual demographic data. In order to utilize interview time for more in-depth exploration of topics, teacher participants were asked to complete a survey before the first formal interview. Teachers were sent a link to

Surveymonkey™ and a Word document of the questionnaire so they had a choice of format to use to complete the questionnaire at a time convenient to them (see Appendix C). Although the questionnaire was simplified by having drop-down choices in the online version, the data collected was descriptive for each participant and contributed to the qualitative evidence. The questionnaire provided some background information about the participant's experiences which served as a basis to direct some of the interview questions.

3.5.1.2 Interviews with teacher

I conducted three different interviews with teachers; an initial in-depth interview, a pre-lesson interview and a post-lesson interview for each class observed. The initial interview was a semi-structured, one-on-one interview. The purpose was to obtain information about the teacher's beliefs and practices about teaching and learning science and the origins of these beliefs. Each interview took about 60 minutes and was audio recorded. All teachers were asked a common set of questions, however sometimes the participants' answers led me to ask further questions to build on my understanding. There was also variation to some questions based on the teachers' responses in the previous questionnaire. I took some brief notes during the course of the interview, but I focused on active listening techniques with the goal of accurately hearing and interpreting the teacher's verbal and nonverbal communication (Given, 2008). The questions (see Appendix D) focused on capturing data related to the main research questions to find out their beliefs about the purpose of science education in the middle years (years 7-10), how their beliefs correspond with the 'broad assumptions' of the *Shape of the Australian Curriculum: Science* (ACARA, 2009, p. 13).

The pre and post lesson interviews were also semi-structured (see Appendix E). The purpose of the pre-lesson questions was to find out the teachers' learning intentions and how they planned to achieve them. The post-lesson interview allowed the teacher to give their perspectives on the pedagogy and effectiveness of the lesson. It also allowed me to ask questions in response to the observations I made during the lesson. Both the pre-lesson and post-lesson interviews were audio recorded to allow for accurate transcription of the discussions.

3.5.1.3 Observations

Observation provides an opportunity to collect primary data of the teachers' practice, rather than a second-hand account obtained through interviews (Merriam, 2009). There were two main purposes for observing each teacher participant in their classroom. Firstly, to identify the context of their practice and secondly, to see if the beliefs they conveyed in their interview could be demonstrated in their classroom practices.

After the initial interview, each teacher identified four lessons in the following two weeks that would be good examples of the varied ways that they teach so I could observe their pedagogical approaches. Rather than just relying on 'noticing' events that occurred, it was important to focus on the factors related to my definition of excellence and the beliefs purported by the teacher participants including in relation to:

- the learning intentions for the lessons
- how the teacher tuned the students into the learning, developed the lesson, assessed students' understanding in formative and summative ways, and concluded the lesson
- the resources teachers used
- class management and organization
- the teacher's interpersonal skills
- communication - interactions between teachers and students
- affective attributes – passion, interest, enthusiasm, challenge
- content knowledge – clarity of explanations

To ensure that I focused my observations on the above, I constructed an observation table to monitor classroom interactions in such a way that the observations could be related to specific elements (see Appendix F) which served firstly, as a quick way to record my field notes (by highlighting the criterion as it occurred) and secondly as a reminder to pay attention to the behaviours related to the above points related to excellence. The field notes consisted of factual observations and reflective components as they arose. At times of individual and group work, I took on the role of 'observer as participant' (Merriam, 2009, p. 124) as I moved around the room with the permission of the teacher and students, and talked with students about their learning I observed as the teacher also interacted with the students. As soon as possible after the observation, I recorded more detailed descriptions and reflections, so that this data became a comprehensive account of the lesson observed.

3.5.1.4 Artefacts

Artefacts provide material evidence which can provide information that augments evidence obtained from interviews or observations and are essential in case study research (Matera et al., 2020; Yin, 2014). Once each case study teacher's participation was confirmed, information about their current school contexts was obtained through a search on the internet in particular, their schools' websites. With the permission of the participating teacher, other artefacts were collected during school visits when they became relevant to the study. They included: photos of science facilities and classroom displays, lesson plans, student work with teacher feedback, and worksheets or instructions for activities used during the lessons observed.

3.5.2 Evidence from students

3.5.2.1 Student reflection task

After I had observed the teacher in three science classes, the students were asked to complete a short task which was designed to find out what they thought about the learning environment in their science class under the teacher participant's instruction. The teacher agreed to leave the room and each student was given a piece of A5 paper. On one side, I asked them to complete the sentence, "Science is ...", by writing or drawing (or both) what they thought. I emphasized that there were no right or wrong answers and that I was interested in their own opinion, so it was an individual task. After a few minutes, I asked students to turn over the page and respond to the sentence stem, "This science class is….". The students' responses were collected. They did not have to write their name on the paper if they did not want to. The purpose of this task was to see if and how the teachers' beliefs about science and science learning had influenced their students' views and to build a picture of the extent to which the students were engaged, since it would be expected that an excellent teacher motivated students' interest and curiosity.

3.5.3.2 Interview with students

After observing the four lessons, a semi-structured interview was held with four students who were members of the class observed. The purpose was to seek the students' opinions about their learning experiences. The questions (see Appendix I) probed students' interest in science, understanding of the learning intentions in the lessons, and their thoughts about the learning activities they were engaged in that either helped or hindered their learning. Because of the complexity required in examining the concept of being an excellent science teacher, I prepared the questions by adapting and combining three survey instruments used in classroom research. These instruments are:

- the *What Is Happening In This Classroom? (WIHIC)* questionnaire (Fraser et al., 1996). This was included because the questions provided information on teachers' pedagogical practices.

- the *Test of Science Related Attitudes (TOSRA*) (Fraser, 1978) This was included as it provides information about which of the teachers' beliefs about science and science education are articulated in their classroom.
- the *Tripod Survey* (Ferguson, 2012; Measures of Effective Teaching Project (MET), 2012). This was included because the questions were helpful in finding out students' perceptions about their teachers' content knowledge, pedagogic skills, and the personal attributes that help them build relationships with students.

Table 4 shows the main areas of the classroom environment for which each survey is designed to collect data upon.

Table 4 Instruments informing data collection and analysis

WIHIC (Fraser et al., 1996)	**TOSRA** (Fraser, 1978)	**Tripod** (Ferguson, 2012)
Items grouped under seven constructs: • student cohesiveness • teacher support • investigation • involvement • task orientation • cooperation • equity	Items grouped under seven constructs: • social implications of science • normality of scientists • attitude toward scientific inquiry • adoption of scientific attitudes • enjoyment of science lessons • leisure interest in science • career interest in science	Items grouped under seven constructs, called the "7 Cs": • care • control • clarify • challenge • captivate • confer • consolidate

Whilst some of the constructs in these three surveys are essentially the same, they provided a foundation on which I was able to construct my interview questions for the students. The interviews provided valuable data, especially for research question three that focused on how the beliefs of excellent science teachers were demonstrated in their professional practices and classroom teaching.

3.6 Timeline of data collection

Term 4, 2016: Pilot study

Note: No initial meeting was required for the pilot study due to pre-existing collegial relationship between researcher and pilot teacher

- Demographic questionnaire
- Initial interview with pilot teacher
- Transcript of interview emailed to the pilot teacher for verification

Term 4, 2016: Case Studies 1-3

- Initial meeting between researcher and teacher participant to establish an equal relationship and rapport

School holidays, January 2017: Case Studies 1 & 2

- Emailed teacher participant the link to the demographic questionnaire
- Interviewed teacher participant
- Transcript of interview emailed to the teacher for clarification and amendment

Term 1, February - March 2017: Case Studies 1 & 2

- Visited the teacher's school during term time
- Interviewed the teacher before teaching three middle school science classes
- Observed the teacher during each class
- Interviewed the teacher after each class
- Administered the student reflection task
- Focus interviews with 4 students from the observed classes
- Collected relevant documents

Term 2, April - May 2017: Case Study 3

- Visited the teacher's school during term time
- Interviewed the teacher before teaching three, year 9 science classes
- Observed the teacher during each class
- Administered the student reflective task
- Interviewed the teacher after each class
- Focus interview with 4 students from the observed classes
- Collected relevant documents

3.7 Data Analysis

The pilot study interview assisted me in early development of my data analysis strategy. The pilot interview was transcribed and themes arising from the research questions were identified and coded for using NVivo™, a computer software tool. This initial coding later assisted me in analysing the actual case studies. Informal analysis also had its beginnings early in the research as I developed initial impressions that were captured in field notes of the teacher participants during the initial interview. The transcription of the interviews also revealed patterns and themes. The frameworks I used for analysis included the key research questions, the ASTA *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and the *Framework for examining beliefs* (Fives & Buehl, 2008). These frames include factors of professional knowledge, practice, personal attributes and beliefs which I will now discuss.

The *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002) were developed by the Australian Science Teachers Association (ASTA) in 2002. I used these descriptors as one of the analytic frames my study, as they were specifically developed for science educators and describe the professional knowledge of highly accomplished science teachers. These include knowledge of:

- Science and the science curricula
- Teaching, learning and assessment
- Students and how students learned.

(ASTA, 2002, p. 1)

In addition, the ASTA Standards also describe professional practice such as:

- Managing learning environments
- Engaging students in scientific inquiry
- Attending to students' understanding of major ideas in science
- Developing students' ability to use science in decision making
- Assessing and monitoring student learning
- Evaluating and refining teaching practice

(ASTA, 2002, p. 1)

The standards clearly allow for the complexities involved in excellent science teachers' practice. The other strength of using the ASTA Standards in my analysis is that they describe how science teachers manage the learning environment and thus they give scope and flexibility for individuals to enact each standard within their own school contexts.

Keeley, Smith and Buskist's (2006) *Teacher Behaviour Checklist* identifies excellent teachers' personal attributes with their associated behaviours. I used this as a basis of examining the teachers' personal attributes in my study, particularly with the evidence obtained from observing the teachers' lessons. This includes:

- enthusiasm about teaching and about the topic
- respect for students
- being approachable
- high expectations of students
- positive attitude and commitment
- effective communication

The *Framework for examining beliefs* (Fives & Buehl, 2008) was also used to support the analysis of data because rather than theoretical underpinnings, the foundation of its development is in the work of practicing teachings. This Framework organizes beliefs into the following categories:

- beliefs of the importance of teaching knowledge
- beliefs of the ability to acquire teaching knowledge
- beliefs of the need for cognitive skills
- beliefs of the need for affective qualities

(Fives & Buehl, 2008, p. 159)

I used NVivo™ software as it assisted in managing the large amount of data which consisted of text, audio and scanned documents. This software enabled me to identify evidence of teachers' knowledge, personal attributes, beliefs and contexts and thus to readily assign codes to it. NVivo™ also allowed for some segments of data to be coded to more than one category. Coded data could be easily retrieved and analysed for their significance to the study based on similarities, differences and possible connections. For example, one case study teacher may have discussed his/her beliefs about the purpose of science in years 7-10 during the semi-structured interview. Using the 'query' tool in NVivo™ allowed me to find corroborating evidence of this belief from the lesson observations, the pre- and post-lesson interviews and collected artefacts. It also meant I could easily compare the existence of this belief between the three case study teachers. As Merriam (2009) states, computer assistance in this coding and retrieval gives the researcher more time to look closely at the data and think about the meaning.

A descriptive narrative was constructed for each case study, starting with the school context and the teacher's background education and experience. This information was relevant to my study since it highlights the similarities and differences in contexts between each case study. As the narrative developed, the process of explanation-building occurred. As Yin (2014) explains, this strategy involves starting with an initial statement then revising after examining the evidence from each case.

3.8 Validity of the study

There are many perspectives and terms used by researchers regarding validation of qualitative research (Creswell, 2013). For example, terms such as 'trustworthiness' and 'rigor' have replaced by some for the more traditional terms of 'validity' and 'reliability' (Merriam, 2009). But in the end, the central concern is whether the qualitative research is conducted in a manner so that the results can be understood and creditable. Creswell (2013) argued that validation in qualitative research is 'an attempt to assess the accuracy of the findings, as best described by the researcher and the participants' (p. 249). To this end, I focused on six strategies to validate my research: Prolonged engagement, detailed descriptions, triangulation, member checking, researcher bias, chain of evidence.

3.8.1 Prolonged engagement and detailed descriptions

The data collection phase of my research occurred over four to five months (December 2016 – May 2017) and included several visits to the schools and classrooms so that teachers and students became familiar with my presence. Informal, friendly conversations with teachers and students on general subjects of interest helped in establishing trust and rapport. This was necessary as participants had to be willing to share the details of personal thoughts and opinions about their teaching and learning (Rubin & Rubin, 2012). This prolonged engagement also reduced the impact of having an observer in the classroom and led to minimal effect on normal classroom interactions and behaviours.

The emergent design of my study meant that the time and techniques required to collect rich data could be adjusted for each case. I followed the advice given by Merriam (2009), who suggests that when the researcher starts to hear or see the same things over and over again and that no new information is evident, then data collection can be considered complete. This meant that the duration of some interviews was longer, as the participant's answers led to further questions that unearthed deeper understanding of the case.

This prolonged and flexible approach to data collection allowed me to collect an appropriate amount of data to form a rich, detailed description of the beliefs and practices of these three excellent teachers. Additionally, the rich data from three different contexts not only showed how unique each teacher's reality is, but also the complexity of each case. I did not aim to generalize the findings from my study to other teachers, but my aim was to develop rich description and analysis to help the research community understand the development and practices of excellent science teachers.

3.8.2 Triangulation

Denzin and Lincoln (2011) explain that triangulation involves using multiple ways to confirm the findings that emerge. In my study: multiple methods, multiple data sources and multiple theories were used. Triangulation was achieved within each case study as the data was cross-checked between the survey, interviews, class observations and the documentation. Triangulation was also achieved by comparing data between the three case studies. When there was convergence of corroborating evidence both within and between cases, I could give more weight to the findings about factors influencing excellence (Yin, 2014).

3.8.3 Member checking

The findings from the data were given back to the teacher participants for them to check that my interpretations provided a true representation. This was done as soon after the interviews as practical and then again after identification of themes. Merriam (2009) explains that the participant should be able to recognize their experience or suggest 'fine-tuning to better capture their perspectives' (p. 217).

3.8.4 Researcher bias

As a qualitative researcher, I needed to be aware of the influence of my own values and expectations and the way I collected and analysed the data (Denzin & Lincoln, 2011). As Merriam (2009) points out, 'an observer cannot help but affect and be affected by the setting and their interaction may lead to a distortion of the real situation' (p.137). But I tried to avoid bias by consciously having an open mind about the significance of data collected and by cross-checking information between sources. Informal field notes included my emerging ideas of interpretation as they occurred during the interviews and observations. Additionally, debriefing with my supervisors occurred throughout the data collection phase. In the role of critical colleagues, they highlighted alternative considerations of the meaning of the data.

3.8.5 Chain of evidence

To increase the reliability of my research, I maintained a chain of evidence which is a detailed account of the procedures used so that the external reader can trace where conclusions were made (Yin, 2014). The NVivo software allowed me to organize the transcripts, observations and documents for each case study and to highlight and make annotations to show the direct links between the evidence, research questions and the conclusions. This database of information also ensured that all the original evidence was stored, securely and password protected, in one place and was considered in the findings of each case study.

3.9 Ethical considerations

Case study research using human participants has specific ethical considerations and it is the researcher's responsibility to conduct the research in a moral and professional manner (Denzin & Lincoln, 2011). It was important to take the utmost care to protect the teachers, students and schools in the case studies. Ethical approval to conduct the research was granted from the Victorian Department of Education and Training (project ID: 2016_003254) and the Melbourne Catholic Education Office (research number: 0569) and Monash University (research number: CF14/3873 – 2014002). Permission was sought from the individual principals of all three schools via an emailed explanatory statement and consent form (see Appendices J and K). Participants were invited to volunteer to be involved in this research after the purpose, processes and use of their data were explained both verbally and in written form. Student permission to participate in the study was obtained from parents or guardians and students were also asked for their consent to participate (See Appendices G and K). As a registered teacher with the Victorian Institute of Teaching (VIT), I was able to work with students within the school settings without the participating teacher being present. All participants were given the option of withdrawing from the study at any time. There was no coercion or incentives offered for their participation. Teacher participants were given the opportunity to check the transcripts of their interviews for accuracy and clarification. To protect the privacy and confidentiality, participating schools, teachers, and students were given pseudonyms. Participants were invited to read the research once it was completed and all tape recordings were destroyed when the study was completed.

3.10 Note to reader

In chapters 4 – 10 evidence in the form of teacher and student comments have been written in italics, to make it clear when the quotes are directly their words rather than my interpretation.

For ease of navigating the thesis, some data in chapters 4 - 10 is bookmarked and hyperlinked to where it is later discussed in the text. Hyperlinks are shown in blue font. For example, on page 88, by clicking on the link in '(see Ch4_1)' the reader will be taken back to page 76 where there is a quote from Lindy. To return to the original position, the reader should click on the link 'Ch4_1'.

Sometimes, a piece of evidence will be referred to multiple times in the analysis. In these cases, all discussions will have a link back to the quote, however, the reader will not be returned to their original position if the link has a 'nr' subscript. For example, on page 82, the link in 'Ch4_14$_{nr}$'.

Chapter 4

Background context, knowledge, personal attributes and beliefs of an excellent science teacher - Lindy

4.1 Introduction

In the next two chapters I provide a deep discussion of the background, attributes, beliefs and practices of the first teacher, Lindy (pseudonym), to deepen my analysis of the complex range of personal and professional factors involved in the development of excellence in science teaching.

Chapter four focuses on analysis of the data in terms of Lindy's personal and contextual background and the first two research questions:

1. How do personal and contextual factors influence the development of excellent teachers' knowledge, personal attributes, beliefs and practices?
2. What do excellent science teachers believe about teaching and learning science in secondary school?

Lindy is a science teacher at Meridale College (pseudonym). She was identified for my study by a science teacher educator who had worked with her on an extended professional development program, who deemed her to be 'excellent'. At the time of my case study Lindy was in her sixth year of teaching and it was her second year at Meridale College; an all-girls Catholic secondary college in suburban Melbourne. In this chapter, Lindy's story is constructed from data drawn from semi-structured interviews, classroom observations and documentation collected from Lindy and her students. My analysis was conducted through consideration of the theoretical frameworks discussed in the literature review including the *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006), and *Framework for examining beliefs* (Fives & Buehl, 2008). I have drawn on these sources to identify, analyse and discuss key themes related to the contexts, personal attributes and beliefs that emerged from the data in relation to the research questions.

I begin this chapter by discussing Lindy's experiences as a student at secondary school and then at university. Next, I discuss her past work experience and experience as a teacher in the two schools where she has taught, Firlake College (pseudonym) and Meridale College. Finally, I discuss Lindy's beliefs about science and how it should be taught to students at year 8. This discussion is then used in the next chapter to assist my analysis of the extent to which her personal background, attributes and beliefs have influenced her teaching practice in a year 8 science class.

4.2 Past contexts

4.2.1 Experiences as a student

Schneider and Plasman (2011) and Schneider et al. (2013) found that science teachers' knowledge is greatly influenced by their own experiences as a student. Thus, I begin with an analysis of Lindy's experiences as a student at secondary school and at university.

4.2.1.1 Secondary school

As a student, Lindy attended an all-girls Catholic secondary school in suburban Melbourne, similar to Meridale College where she now teaches. When I asked her about her memories of learning science, she clearly remembered the first time she used a Bunsen burner in year 7. She also recalled that her year 8 science teacher was,

> *really mean, very grumpy and stern ... never cracking a smile ... very little personal connection to [her] students* (Ch4_1).

But beyond that, she did not remember what her science classes were like and commented that, they *didn't stand out as being exciting or different…it was traditional* (Ch4_2). Lindy told me that at some stage in years 7-10 she developed the perception that she was not good at science, so she started her year 11 VCE[1] studies without any science subjects in her course. She recalled,

> *I didn't pick science because I didn't think I was good enough at it in years 7-10 and it didn't fit with my direction. ...I was tracking to be a lawyer …I was so passionate about becoming a lawyer at age 16, the sciences just didn't appeal to me*. (Ch4_3).

In her initial interview, Lindy provided two motivations for her aspirations of becoming a lawyer. Firstly, she commented that she was *really good at arguing as a kid and my mum said I'd make a great lawyer* (Ch4_4). Secondly, she recalled that,

[1] VCE is the Victorian Certificate of Education which the majority of students study during years 11 and 12, their final years of secondary school.

> *Ally McBeal*[2] *was a factor for law – how crazy she was, that was me. At a really young age I knew I was a bit odd. I'd see her do crazy things and think, that's something I'd do too, and she's an adult* (Ch4_5).

Initially, Lindy's year 11 VCE studies included legal studies and economics, but at the end of her first semester, she confided in her home-room teacher about her lack of enjoyment in her studies. He was a chemistry teacher and suggested that she might consider changing to science, since he believed she could successfully learn science. Secondly, a casual discussion about Lindy's dilemma that her mother had with a colleague at work put Lindy in contact with a research scientist, Daniel [pseudonym]. This led to Lindy completing a week of work experience with Daniel in his virology research laboratory during the school holidays. This was clearly a positive experience for her. Lindy told me,

> *I got an idea of what it was like to be a scientist. I LOVED it. I was working alongside a PhD student who talked to me about her research. She included me in it, and I helped her with little things. She actually took the time to explain the research to me. Daniel was the same – he'd sit down with me over lunch and tell me about his research. I went back* [to school] *in semester 2 and signed up for biology and chemistry* (Ch4_6).

As a result of her chemistry teacher's faith in her abilities and her work experience, Lindy changed her VCE subjects to biology and chemistry, and her career direction to becoming a scientist.

Lindy's recounting of her journey through secondary school demonstrates that she viewed her schooling as a means to an end; the decisions she made were in accordance with her possible future career. Tytler et al. (2008) list major factors in adolescents' career decisions including personal interest, self-concept, personal attributes and identifying with a role model. Lindy's secondary education occurred in the 1990s and early 2000s. As Hackling et al. (2001) state, most science classes at this time were traditional and did not cater for students' interests. Lindy did not find science particularly interesting in years 7-10 (see Ch4_2) and further, she did not feel confident in her science abilities (see Ch4_3). But she had a positive self-concept of her ability to make an argument and she personally identified with the character in Ally McBeal. These factors all promoted the idea of a career in law. Lindy's homeroom teacher and her work

2 Ally McBeal was a television series in the late 1990s about a young female lawyer.

experience provided the opportunity to interact with passionate scientists, providing positive role models. Considering these factors, her career aspirations changed (see Ch4_6).

In contrast to her time in years 7-10 science, Lindy has distinct and positive memories of her VCE biology and chemistry classes. Lindy recalled one chemistry class,

> *We were filtering out the solid with the pump and our teacher completely shattered the glass and it went everywhere. When you're a student you don't want that to happen, but she [the teacher] knew that accidents happen* (Ch4_7).

Lindy also explained that she needed to work hard to learn science in VCE. *I had a tutor for chemistry …I found it really hard but found it really interesting* (Ch4_8).

Lindy's memories of the incidents described so far have all involved the personal attributes of key people involved: her year 8 teacher was *mean*, her chemistry teacher was *cool,* the researchers were passionate and inclusive. This is indicative of her belief in the importance of positive relationships in teaching and learning and will be discussed further in section 4.4.1.3. Furthermore, Lindy's overall attitude to learning science was more positive during her VCE classes than in earlier years. Ainley and Ainley (2011) found that students who could see the personal value in learning science, such as a future career as in Lindy's case, showed more enjoyment of their science classes. Hulleman and Harachkiewicz (2009, p. 1411) also found that when they implemented a 'motivational intervention', high school students' interest and achievement in science increased. As Lindy's future was dependent on success in VCE science, she was willing to work hard, (see Ch4_8) and felt supported by the classroom environment, (see Ch4_7) where mistakes could happen without retribution. This view is supported by Waldrip et al. (2009), who found that students appreciate a safe working environment.

4.2.1.2 Tertiary education

After VCE, Lindy enrolled in a Bachelor of Science at Lamb University [pseudonym]. In first year, she studied biology, chemistry, psychology and statistics. She laments not having studied earth science in her degree as nowadays she does not feel completely confident when teaching this topic. During her summer holidays, Lindy continued to work at the research laboratory where she had completed work experience in year 11. She described her first-year biology lecturer as *an old lady, standing on the podium, writing notes on the board* (Ch4_9). About halfway through her degree, Lindy started to consider a career as a science communicator to *bridge the gap between science and what the public saw of it* (Ch4_10). At the same time, she experienced increased success and enjoyment in learning science, commenting that, *as my subjects became more specific, I started to get better grades and started to enjoy it more* (Ch4_11). Due to her increased success at university and continued interest in her part-time work in the virology laboratory, Lindy persisted with her planned career path of becoming a research scientist. Lindy completed her Honours year, majoring in immunology.

Lindy's impression of her biology lecturer in the first year of her undergraduate degree was underwhelming (see Ch4_9). Similar to her experiences of learning science in years 7-10, she did not enjoy the 'transmission of content' method of teaching. Anderson and Holt-Reynolds (1995) reported that for pre-service teachers to understand the expanse of pedagogical knowledge, they need to start by examining themselves as 'self-as-student' before understanding themselves as 'self-as-teacher'. Lindy's evaluation of learning science at both secondary and tertiary levels shows that she is cognisant that science could be more interesting than what she had experienced. She also thought that she could communicate it in a more interesting way (see Ch4_10). Furthermore, Lindy's self-concept from her work in the research laboratory had a positive effect on her academic achievement and vice versa, reinforcing the concept of success breeds success (see Ch4_11). Marsh and Craven (2006) report on the positive reciprocal effects of academic self-concept on academic success. Additionally, Lindy's concern about her content knowledge of earth science is legitimate. She did not study either earth science or physics in VCE or at university. Teachers of general middle school science are expected to teach a breadth of topics and research has raised concerns about the poor content knowledge on teachers' PCK (Childs & McNicholl, 2007; Tobin & Fraser, 1990).

After her Honours year, Lindy worked as a research scientist in another virology laboratory for two years before returning to complete her Diploma of Education (reasons for which will be discussed in section 4.2.2). Lindy's teaching methods in her Diploma of Education were biology and chemistry. She said that she enjoyed her Diploma of Education course and gained respect for the work of teaching.

> *I loved the Lamb University…teaching model. It made everything an experiment to me. It meant that this very subjective thing could be looked at objectively and that appealed to the scientist in me… it was highly reflective. You had to collect evidence (audio, video, student assessment) unpack it and think about it. It's basically an experiment. That heightened my respect for what I was learning. If it didn't have this approach*

> *(let's use evidence, let's be explicit about what we're doing and let's make it an experiment) then I don't think I would have responded to it as well* (Ch4_12).

Lindy's respect for the teaching profession changed as a result of her Diploma course. Her comments (see Ch4_12) demonstrate that at the start of her course she undervalued teachers' work; a view commonly held in western cultures (Boote, 2006; Goodrum et al., 2001). Once she realised that quality teaching was based on evidence-based research, her respect for teaching as a profession increased. From a professional growth perspective, Lindy's comments (see Ch4_12nr) are consistent with Kroll's (2004) assertion that teaching is reflective, and an inquiry approach is essential for a teacher to learn and improve their ability to teach. Lindy valued the intellectual task of reflection.

After her Diploma of Education, Lindy taught science for three years at Firlake College before completing her Master of Education whilst still teaching full-time. Her Masters research project was about her students' science identity as a result of participating in a "real-world" biotechnology experience. This was based on a special program she established at Firlake College which will be discussed further in section 4.2.3.1. When my study was conducted in 2017, Lindy was planning to start her PhD in Science Education to examine the factors that promote females to achieve highly in the VCE sciences. *I'm always trying to find more innovations to make it better for them* (Ch4_73).

Lindy's topic for her Masters project echoes the development of her own self-concept during her undergraduate science studies, whilst experiencing 'real science' working as a research assistant in the laboratory. It is again evidence of her reflection upon herself as a student (Anderson & Holt-Reynolds, 1995). There is evidence that Lindy incorporates real life experiences into science education for her students, lamenting her own experiences as a secondary school student, but reflecting her time as a tertiary student. The topics she pursued for her Masters and PhD are both based on her teaching practice, showing a commitment to ASTA Standard 10 by analysing, evaluating and refining her practice (ASTA, 2002). It is interesting to note Lindy's choice to participate in sustained professional learning through two higher degrees which require sustained, long-term commitment to extra study, rather than relying on shorter professional development opportunities alone. According to the Australian Qualifications Framework (Australian Government - Department of Education and Training, 2013) Masters and PhD degrees are at a high level because they are higher in complexity and develop depth of understanding, expert and specialised knowledge and skills. These degrees require many hours of work over an extended period. To complete a Master's degree whilst working full-time requires both passion and commitment and shows Lindy's commitment to life-long learning.

In summary, Lindy's undergraduate degree gave her a good understanding of chemistry and biology, with her Honours year providing an even deeper and contemporary understanding of biology and of how scientists work. Her Diploma of Education and Masters of Education provided opportunities for her to develop a deep and rich pedagogical content knowledge that allows her to teach and engage students with scientific concepts, consistent with ASTA Standard 1 (ASTA, 2002, p. 12). Her Masters project and plans for her PhD indicate that she is committed to developing her expert knowledge of teaching and learning in science to increase her skills as a teachers and her students' academic achievement in science (see Ch4_12nr, Ch4_73).

4.2.2 Experiences as a research scientist

After her Honours year, Lindy applied for five positions as a research assistant before attaining a role in a laboratory examining HIV. Lindy described working in the laboratory to be completely different from school and university science.

> *[As] a student (at school and Uni) you don't get to see the real-world operation of what a lab is. All the messages your teachers and your assessments send you about what it is to be a good scientist, actually don't make you a good scientist* (Ch4_13).

She really loved her work but admits that she started to be concerned about the long-term professional opportunities.

> *There's a lot of competition in science; funding is limited, people get cranky with each other. I know I could have kept going but I thought I'd always be pushing for something I couldn't achieve; not beyond my capabilities, reaching with high energy at that top end and I'd just fall short. So, I thought it just wasn't right for me* (Ch4_14).

In her second year of working as a research scientist, Lindy became involved with an outreach program at her work. She represented the laboratory at many events where she explained science research to students and the general public. During National Science Week[3], Lindy was involved with a program organized by the Australian Society for Medical Research (ASMR). This involved talking about science to rural and remote area schools and on the radio. She also delivered some presentations to visiting secondary school groups at the Gene Technology Access Centre (GTAC). Enjoying this experience, combined with her concerns as expressed in Ch4_14, Lindy again started thinking about a career in science communication. After investigation, she learned that she would have to go interstate to study science communication. At the same time, Lindy's personal circumstances changed, as she had reasons to stay in Melbourne. It was then that she found she could get a scholarship to study a Diploma of Education for science teaching at Lamb University that would give her the skills to pursue a career in science communication, sharing scientific understandings with the public. Thus, she left her research position and started her Diploma of Education, with the intention of using it to be a science communicator/educator at GTAC or at a similar outreach science centre.

Lindy's return to study after only two years as a research scientist illustrates the importance of job security for Lindy. She enjoyed the laboratory work, but the indefinite nature of research funding made her feel insecure (see Ch4_14nr). The secure monetary aspect of the scholarship was also an important factor in her decision, as was her knowledge that she already knew of positions available in science communication, rather than in schools. That Lindy had not considered teaching when she was growing up and was still reticent to consider teaching even when she started her Diploma of Education, shows that teaching was not a natural inclination or 'calling' for her. Lindy only saw merit in teaching when she learnt it could be objectively critiqued (see Ch4_12nr). As a child, Lindy was praised for her ability to argue a point and her work in science research also required critical thinking (see Ch4_4). When she discovered that good teaching required critical reflection of her practice and was intellectually demanding, her respect for the work of teachers was heightened. Glasner (2003, p. 13) states, 'excellent teachers

[3] 'National Science Week is an annual festival of science that takes place in August each year across Australia. This celebration aims to increase the public understanding and appreciation of science, innovation, engineering and technology, and their role in maintaining and improving our society, economy and environment' (ASTA, 2018).

are not born, they develop and grow in a supportive environment'. Thus, Lindy's growth as an excellent teacher began during her initial teacher training.

4.2.3 Experiences as a teacher

This section provides an overview of Lindy's teaching experience at the two schools where she has taught – Firlake College and her current location, Meridale College.

4.2.3.1 The early years

After completing her Diploma of Education, Lindy's first teaching position was at Firlake College (a pseudonym) where the environment supported her continued growth as a teacher. Firstly, Lindy explained that Firlake College was a very professionally engaged school.

> *We were expected to read and discuss contemporary ideas and the staff really embraced a very pedagogical and theoretical understanding of why and what we did. … we did a lot on 'visible thinking' routines*[4]. *…As a first year out teacher, I thought this was what happened – people observe your classes, you join a breakfast group and talk about your practice* (Ch4_15).

Alongside the professional discussions and readings, Firlake College became a 'hub' school for Lamb University's teacher education program. This included having a large group of pre-service teachers complete their placement at the school each semester. Lindy thought this was a good connection in her early career. She recalled that,

> *what I did at university was constantly being 'brought back to my face' and it meant I got so much better* (Ch4_16).

The second reason Lindy felt professionally supported was the encouraging school leadership team and close relationships between the staff. She particularly had strong admiration for her Head of science who,

[4] Visible thinking is a research-based projects from the Project Zero team at Harvard University. It explicitly creates a focus on thinking, learning, understanding and collaboration within the classroom (Harvard Graduate School of Education, 2016a).

> *did some amazing stuff. She brought in the 5Es*[5] *to the school including a lot of professional development which got embedded in all science. We are still really good friends* (Ch4_17).

Lindy's Head of science and the school's leadership team trusted and supported her in setting up a biochemistry program at the school. Mid-way through her first year of teaching, by chance, Lindy found a brochure for school kits of biotechnology laboratory equipment. She was excited as the equipment was similar to what would be found in a modern research laboratory. It reminded her of her passion for research. Lindy could see that if her students could use this equipment, they too could experience the same positive emotions about science that she did (as discussed in section 4.2.1.1). Lindy went to great lengths to set up the program, recalling that she,

> *put together a proposal, did the pricing. …The principal and business manager took it to the Friends Committee who gave me $30,000. Then the principal gave me some time relief to set up the program which ended up being called the Budding Biochemists program* (Ch4_18).

This program was very popular with the students at Firlake College. It became a highlight of the school's science program and was featured in the school's marketing to attract potential students. For Lindy, the thrill was in the impact it had on her students, since

> *their eyes lit up and they told me, 'I feel like a real scientist''… For me, I really love real-world science learning; I like kids to work as scientists and to have those sorts of projects. So, where I can find opportunities in the curriculum to leverage that, I will do my very best* (Ch4_19).

After 3 years in the science faculty, Lindy applied to be part of the school's year 9 cross-curriculum program where students considered authentic problems and were taught 'thinking routines' (Harvard Graduate School of Education, 2016a) to understand and solve them. Lindy recalled that this experience, *had a massive influence* on her. The program coordinator, Doug (a pseudonym) shared his understanding and passion for teaching and learning with Lindy. His

[5] 5Es is an instructional model which supports the constructivist view of learning science. It consists of 5 phases: engage, explore, explain, elaborate and evaluate (Bybee et al., 2006).

philosophy was based on what he had learned through professional learning experiences with the Harvard Project Zero[6] team. The whole year 9 program involved team teaching and was constantly reshaped in response to student feedback. Lindy told me that she found it to be,

> *quite different* and *not the sort of teaching if you want to ...keep control ...or focus inward* (Ch4_20).

Doug also introduced Lindy to the idea of what he called, 'wilding the tame'. This idea is again based on research by the Project Zero team where students are encouraged to be open-minded, curious and sceptical (Perkins, 2000). The approach involves students applying their knowledge to learning experiences in the view that learning is not about the accumulation of knowledge, instead it is being able to employ it when the need arises (Perkins, 2000). Lindy explained that Doug had the idea of a '*wild barometer'* and the year 9 teachers,

> *really focused on keeping the learning and the topic in the middle of the barometer, where students felt it was a creative space and a safe place, so they could take risks with their learning ...for students to just get involved* (Ch4_21).

ASTA Standard 11 (ASTA, 2002, p. 24) highlights the importance of 'learn[ing] from colleagues through collaboration on professional tasks'. Schaefer et al. (2012) reported on the importance of quality professional development, mentoring from experienced teachers a supportive administration and genuine collaboration for early career teachers. The staff at Firlake College provided this strong professional and personal mentorship for Lindy in her early career which gave her the opportunity to continue to learn and gave her a strong pedagogical understanding (see Ch4_15, Ch4_17 and Ch4_21). The partnership between Firlake College and Lamb University provided a continuing opportunity for Lindy to reflect on the relationship between theory and practice which Freedman and Appleman (2008) found to be important for early career teachers' early identity (see Ch4_16). The opportunities to reflect on her teaching and practice, combined with her experiences in the year 9 program, challenged her ideas about what effective teaching looked like and she gained confidence to experiment with her teaching approaches (see Ch4_20). Setting up the Budding Biochemists program would have taken Lindy a lot of time and effort, showing how committed she was to teaching

[6] Project Zero is a research group based at Harvard University. It aims to investigate and improve 'the nature of intelligence, understanding, thinking, creativity, cross-disciplinary and cross-cultural thinking, and ethics' (Harvard Graduate School of Education, 2016b).

science from the start of her teaching career. Lindy's actions, (see Ch4_19) are consistent with ASTA Standard 4 (ASTA, 2002) which states the importance of real life contexts to make learning meaningful for students. It connects with Lindy's own experience, (see Ch4_5) and Ch4_13) where her passion for doing science was ignited.

In summary, Lindy's teaching experience and professional learning has exposed her to innovative and contemporary ideas about teaching. For example, the year 9 program was based on the ideas in the Project Zero research, particularly in regard to problem-based learning and the thinking dispositions. Her early career development involved collaborations with colleagues who were supportive and enthusiastic about teaching and learning and Lindy has taken opportunities to improve her skills and knowledge. Her Head of science, for instance, gave her freedom to instigate the Budding Biochemists program and the positive feedback from students was a great motivator for her to continue to be enthused by new ideas. In general, the whole school professional development program at Firlake College stimulated Lindy's growth as an early career teacher.

4.2.3.2 Head of science

After five years at Firlake College, Lindy felt that she wanted to *use what she had learnt*, so she applied to be the Head of science at her current school, Meridale College. She had been in this role for two years at the time of this study. In the first six months, Lindy struggled with leading her new science teaching team, and in particular,

> *was really struggling to understand my staff. I felt so disconnected from them …I didn't think they had the same values as I did. We were having meetings that were quite adversarial* (Ch4_22).

She found resistance amongst her new colleagues to having conversations about teaching practice and the effects on student progress.

> *People were just getting ideas from reading the textbook, [the curriculum was] all structured around the textbook chapters, like cut and paste. …assessment was just test, test, test, prac report* (Ch4_23).

These approaches were contrary to her past experiences during her teacher education and at Firlake College, where the emphasis was on teachers reflecting on their practice, constantly assessing the evidence to improve their teaching and their students' learning. A breakthrough came when she set a time in a faculty meeting for each teacher to write a letter to a student, describing what they hoped the student would achieve from their class. The outcomes of this task highlighted to Lindy that the other science teachers' beliefs were more similar to her own beliefs than she had originally thought. The aspirations expressed in the letters resulted in the science faculty's Science Manifesto which is discussed in detail in section 4.4.2. My first visit with Lindy was at the start of her third year of leading the faculty. She confidently told me that she had led the development of more cohesiveness and openness to new ideas in the science faculty team.

Although Meridale College is a similar school to Firlake College in terms of the socio-economic status of students and Christian philosophy, when Lindy started there, it lacked a reflective, collaborative professional learning community. Coe et al. (2014) assert that great teaching requires a school culture that promotes critical reflection, innovation, encouragement of debate and the sharing of ideas. In this regard, Hackling et al. (2001, p. 12) would say that the Firlake College situation is commonly found amongst secondary schools and that Meridale College is an exception, mainly because, 'teachers have inadequate time for preparation, reflection and collaboration'. Furthermore, relying solely on a textbook for teaching science has been shown to promote the transmissive method of teaching without regard for students' interests, or abilities (Hackling et al., 2001; Lyons, 2006; Tytler, 2007). Johnson and Donaldson (2007) found that teacher leaders with four to ten years of teaching experience often met with resistance from their more experienced colleagues. Rather than blaming her colleagues, Lindy's approach to her concerns was consistent with ASTA Standard 3.3 (ASTA, 2009, p. 15) and shows she is a, 'problem-solver and team builder; [who applies her] leadership qualities and expertise creatively and productively to achieve solutions even in difficult conditions'. This account also shows how Lindy resolves issues, as she has an ability to reflect on the situation, her own role and how she could achieve a better outcome. Lindy recalled her frustration about the reluctance or inability of her new science faculty members to examine their practice and to discuss other possibilities. Where many leaders may have tried to force their peers towards their way of thinking, Lindy examined her own leadership skills, sought advice from others and 'experimented' with ways to start the conversation. Her actions are also consistent with ASTA Standard 3.4 (ASTA, 2009, p. 16) as she, 'inspire[d] and mobilise[d] others to engage with and respond to challenges …by developing a sense of shared purpose and strategic direction for action'.

4.3 Lindy's personal attributes

Personal attributes have been found to be important qualities of excellent science teachers (Tobin & Fraser, 1990; Waldrip et al., 2009; Walker, 2008). This section focuses on the personal attributes of influential people in Lindy's past and her personal attributes in the past. Firstly, the attributes that are directly relevant to her classroom practice are examined, followed by those that are relevant to her professional work beyond the classroom.

4.3.1 Authenticity

Research has shown that the authenticity of the teacher has a positive impact on learning and on the enjoyment of the teaching and learning process (Brookfield, 2006; Frego, 2006). During our interviews, Lindy gave several examples of relationships with her secondary school teachers which were positive and grounded in mutual respect. Lindy's favourite teacher at school was her dance teacher who taught her for 5 years. Lindy described her as,

> *just really beautiful … I have made contact with her again through a mutual friend and Facebook. Great woman. She was just really gentle. Encouraging. Animated. Funny. Personable. Fabulous* (Ch4_24).

Even though dance was her favourite subject and she was very good at it, Lindy did not choose to study dance in VCE because she knew a career in dance was not feasible. She recalled that her dance teacher,

> *helped [her] to accept that and said, 'what you get out of it is not for your career; it's for balance and for your soul'* (Ch4_25).

In addition, Lindy told me she enjoyed sharing a joke with her VCE maths teacher and respected her VCE English teacher's passion for her subject and appreciated how she managed the disruptive students (Ch4_27). Even so, Lindy recalled that she was, *crushed* (Ch4_28) when this teacher told her mother not to expect Lindy to achieve good results in her exam. Lindy took this as a challenge because she *wanted to make her [teacher] proud* (Ch4_29). She worked hard and ended up exceeding expectations.

Lindy also recalls that she was never the kind of student who disliked teachers or disrupted classes, even though some were difficult to like (see Ch4_1). She described herself as the student who,

> *would always do the right thing by the teachers and they could rely on [her] to answer questions and be on task* (Ch4_30).

However, she does recall (to her embarrassment) being rude to a replacement English teacher in year 10 because,

> *it was like she was explaining everything to a 6-year-old. I felt like she treated us as if we knew nothing* (Ch4_31).

Upon reflection, Lindy thinks this teacher probably was not so bad, but was just *very different to [her] normal English teacher who was on sick leave and who [she] loved* (Ch4_32).

The above account shows that Lindy's teachers showed genuine care and concern for her personal and academic development (see Ch4_1nr, Ch4_24 and Ch4_25). Their honesty and ability to listen allowed her to enjoy learning, motivated her to work hard and empowered her to make decisions (see Ch4_25nr and Ch4_29). Humour, rigor, passion for their subject and discipline are also common attributes that earned Lindy's teachers her respect (see Ch4_27). This is consistent with the behaviours identified by Keeley et al.(2006) as being qualities of excellent teachers. Lindy's teachers made her feel valued and respected as both a learner and as a person. This was reciprocated by Lindy in her attitude to learning and her loyalty to them (see Ch4_30, Ch4_31 and Ch4_32)). Bolshakova et al. (2011) found that an authentic relationship between student and teacher built a sense of belonging and students' self-efficacy and achievement improved.

4.3.2 Reflective capacities

Lindy is critically reflective of herself in both her personal and professional lives. As a secondary school and undergraduate student, Lindy resisted becoming a teacher and only enrolled in the Diploma of teaching to become a science communicator. However, Lindy gained a heightened respect for teachers' work during initial teacher education because it involved evidence-based reflective practice (see Ch4_12nr) Lindy also experienced a very reflective culture in the first five years of teaching at Firlake College (see Ch4_15nr). This is consistent with Shulman's (1987) suggestion that reflection and challenge are crucial for people's transition from expert learner to novice teacher and reflective practice is seen to be very important for expert teachers (Keast et al., 2016). As an illustration of this, when Lindy first started teaching, she modelled herself on her VCE English teacher. She described this as,

> *a delicate balance of strict rules (we got 'discipline points' which accumulated to detentions if we didn't do homework or bring our dictionary) and academic rigour* (Ch4_33).

On reflection, Lindy found that this style did not suit her, and she commented that,

> *When I started teaching, I don't think I had that sense of the importance of relationships. I valued relationships when I built them with students who valued science, but I couldn't understand why I wasn't having those relationships with kids who weren't successful in my classes. It took me a lot of trial and error to work this through and also modelling from more experienced teachers ...other types of teachers and how they integrated that social and emotional stuff into their classrooms* (Ch4_34).

As a novice teacher, Lindy's pedagogical knowledge had not fully developed, so she replicated what she had experienced as a student (see Ch4_33). This is not uncommon in early career teachers as the cognitive load is enormous (Borko & Livingston, 1989). True to what she had learnt in her initial teacher education, (see Ch4_12nr) Lindy reflected on the situation, made observations of herself and others to identify the problems and to solve them. Once Lindy was better able to adapt her practice and attend to her students' needs, her relationship with them changed for the better (see Ch4_34).

Lindy was critically reflective about her teaching practice and her role as a team member.

> *I think I'm innovative, responsive, creative, but frustrating to work with; all over the place. ...I think working with me could be hard for those teachers who just needed curriculum documents, worksheets and order and structure* (Ch4_35).

During her first six months as Head of science at Meridale College, Lindy reflected on her own practice as a leader and tried different ways to connect and understand her peers. For example, she reflected that in working with her team,

> *Seventy-five minutes would go by and we wouldn't achieve anything. ...We were arguing over ridiculous things. After some thought, I decided to flip it – we started with the developmental, big picture stuff and I set my watch, so we had 30 minutes at the end to deal with the administration stuff* (Ch4_36).

Most importantly, Lindy has gained a better understanding of herself as a teacher by critical reflection.

> *I'm a perfectionist. I don't think when you're a teacher that you can be a perfectionist because if you did everything to the best of your ability, you'd just be working constantly. It's good to aspire to perfection but it's not possible because self-preservation would go out the window. ...I embrace the unexpected now (Ch4_37).*

Lindy is a reflective practitioner who analyses challenges in her practice and looks at her own skills to find solutions. ASTA Standard 10 (ASTA, 2002) highlights the importance of a teacher's ability to identify their own strengths and weaknesses if they are going to continue to be effective. Being able to articulate the effect of her strengths and weaknesses in working with her colleagues and students, shows humility which is a characteristic of effective teachers identified by Keeley et al. (2006).

4.3.3 Passion

Lindy often uses strong adjectives such as 'love', 'amazing' and 'passion' to express her feelings when recounting events. Her own passions and that of her teachers were important factors in her motivation to learn and enjoy her learning when she was a student (see ch4_3nr, ch4_6nr, ch4_9nr and ch4_12nr). Passion has continued to be an important attribute in her teaching as she is elated when her students enjoy learning about science (see ch4_19nr). Throughout the case study, I observed Lindy to be an energetic and passionate person. No matter what was being discussed, Lindy was engaged and interested.

Ruiz-Alfonso et al. (2018) affirm the importance of a passionate teacher in creating students who are engaged with and curious about their learning. The 'Vision for Teaching Science in Australian Schools', at the beginning of the ASTA Standards (ASTA, 2002, p. 8) states that, 'highly accomplished teachers have a passion for science, for learning and for growth in the knowledge and capabilities of their students'. This notion is definitely one of Lindy's ingrained personal attributes.

4.3.4 Commitment and drive

Lindy's account of herself, as a student, shows that she has always been dedicated to achieving her goals (see Ch4_8nr and Ch4_30nr). This was encouraged by her parents, who saw the purpose of education as a necessity to securing a well-paid career. She recalled that,

> *My mum's thing was always 'what are you going to do with it?' Hence, she never encouraged dance. ...Once the lawyer thing went out the window, mum said what are you going to do. I thought science degree. 'what are you going to do with it?'* (Ch4_38).

As discussed in section 4.2.1.2, Lindy made decisions as a means to an end: she pursued Honours in immunology as a way to become a research scientist; she pursued a Diploma of

Education to become a science communicator. In her second year working as a research scientist, she began to feel that this was not a long-term career for her. With no direction, Lindy became unsettled and discontented (see Ch4_14nr). Even though dance was her first love at school, she knew that it was not a viable career path and she struggled with this. It was her dance teacher who suggested that she could do activities just for enjoyment and relaxation (see Ch4_25).

Lindy's account of her career in teaching showed that she is committed to giving her students every opportunity to pursue their goals as well. Once she fell in love with science (see Ch4_6nr), she wanted to share it with everyone. This is evident in her involvement with communicating science to students and the general public when she was a research scientist and setting up the Budding Biochemists program in her first year of teaching. These opportunities had not been part of her experience as a secondary student – perhaps if they had been, she would have chosen a science path earlier.

Lindy's commitment to continued professional learning needs to be acknowledged. As discussed at the end of section 4.2.1.2, Lindy completed a Master of Education and plans to embark on a PhD. In addition, she has sought opportunities to challenge and improve her PCK. For example, when she heard about the Maker Movement[7] she took the opportunity to experience it personally to find out how this approach might encourage disengaged students in STEM education. This complements her inclination to reflect on areas that need improvement and to research solutions (as expressed in section 4.3.2). Lindy proactively looks for learning opportunities. Evidence of this is her application to teach in the innovative year 9 program in her third year at Firlake College and her recent choice of summer reading, Hattie's book, *Visible Learning*.

Lindy's commitment to becoming a better teacher is consistent with attributes of excellent teachers (Keeley et al., 2006). Her rise to Head of science after just 5 years of teaching involved a steep learning curve. Lindy invested a lot of personal time and energy into increasing her

[7] The Maker Movement is interested in combining technology such as electronics and robotics with arts and crafts to create new devices and to tinker with existing ones. It emphasizes learning-by-doing (Sharples et al., 2013).

professional knowledge base. Crosswell and Elliott (2004) stated that this high commitment is required for teachers to be effective. Finally, Lindy's commitment to improve as a teacher is consistent with ASTA Standard 10 (ASTA, 2002, p. 24) as she analyses her practice, seeks advice from colleagues and/or professional workshops and 'model[s] the development and improvement implicit in life-long learning'.

4.4 Beliefs

This section will refer to some experiences discussed previously in this chapter since beliefs are influenced by past events as a student and as a teacher (Levin et al., 2013).

4.4.1 Beliefs about teaching, learning and students

4.4.1.1 Excellence and purpose

Lindy's current school, Meridale College is a Catholic independent girls' school. As this is similar to her own secondary school and to the only other school where she has taught, Firlake College, Lindy reported that she felt comfortable with the values of the school including excellence, hospitality, compassion, justice. During my visits to the school, I observed posters around the school and in the school reception area, highlighting these values. Lindy explained that the school's four core values underpinned everything they do. In the year of my study, the school's focus was on excellence. The poster for excellence included a quote from a catholic nun that stated,

Excellence - challenging each person to achieve their best.
"There is nothing of greater importance than the perfect discharge of
our ordinary duties."
Catherine McAuley

We discussed the coincidence of this being the core focus of my research. Lindy used this definition when describing herself when I asked why she thought she had been identified as an excellent teacher for my study; *...using our definition, I'm excellent [as] I'm trying my best* (Ch4_39). She continued her explanation by saying,

> *I'm willing to try new things. I really desire engaging all students, regardless of who they are. I want them to experience success and I want them to find something that they love about science. ...it depends on your definition of what an excellent teacher is. If the definition is one who listens to and keeps learning with their students, then that's me* (Ch4_40).

In addition, Lindy believes that a good teacher teaches a student how to learn, not just what to learn. She refers to the *Good Learning Behaviours List*, in the Project for Enhancing Effective Learning [PEEL][8] material (Baird & Northfield, 1992). She told me,

> *There is a language of learning that we need to talk to our students about …the good learning behaviours are excellent …so a student can articulate where they're at as a learner* (Ch4_41).

The above précis of what Lindy believes excellence to be is compatible with research findings. The master teachers in Keeley et al.'s (2016) study also characterised excellent teachers as always striving to improve and as good listeners (see Ch4_40). Johnson (2009) established that effective teachers share their love of science with their students, value the process of learning and teach students the language to collaborate and to learn from each other (see Ch4_40nr and Ch4_41). Furthermore, Lindy's beliefs are consistent with ASTA Standard 5 (ASTA, 2002) as she encourages her students to take responsibility for their own learning, by explicitly promoting behaviours that help with learner success.

4.4.1.2 Preparation and developing engaging practice

Lindy's initial teacher education embraced the constructivist model of teaching and learning. She welcomed the idea of learning as a social process and learning through hands on experiments and activities. Section 4.2.1.2 established that this is not what Lindy experienced in her learning of science at secondary school. In contrast, she had these opportunities during her time as research scientist, which worked well for her. She stated,

> *The constructivist model worked well for me. ...I liked the idea that learning as a social process. ... to me, learning is collaborative, and if you can't collaborate in a way that's effective, you can't show what you've learned* (Ch4_42).

Her initial teacher education allowed Lindy to reflect upon herself as a learner and to connect this to what is important for all learners – such as enjoyment, collaboration, creativity and problem solving. One particular activity she remembers during her initial teacher education course was an experiment to make a parachute to drop an egg from height and not allow it to break. Lindy described her thoughts at the time saying,

[8] PEEL is a long-term collaboration between academics and classroom teachers who research classroom practice with the aim of identifying ideas and practice that stimulate and support students to become independent, active and reflective learners.

> *it was fun. Why don't we do more of this with our kids? It was really frustrating to know that I never got to do that type of thing when I was at school. It was the type of thing I wanted to do* (Ch4_43).

Lindy's reflections on her time as a PST at Lamb University shows that she believes good science teaching should use an inquiry-based approach, where students can develop their curiosity and enjoyment of science whilst learning from objective and varied evidence. This is consistent with the vision for the ASTA Standards which states that teachers should 'develop attitudes and values such as …a will to be imaginative, combined with …a respect for evidence' (ASTA, 2002, p. 8). It is also consistent with the aims of *Victorian Curriculum: Science* (VCAA, 2017e) which states, students should develop, 'an understanding of the nature of scientific inquiry and the ability to use a range of scientific inquiry methods'.

In planning to teach, Lindy uses *the Backward design model*[9] *and the philosophy of visible thinking* (Ch4_45). She always has *the big picture in mind. ...I tend to think about the destination for our students. I also look at the function of science education* (Ch4_46). Lindy believes one such function is to teach students learning skills to succeed in the future. Lindy is aware of her students' low literacy levels and how important this is for their future learning. Thus, Lindy emphasizes literacy skills in her teaching such as *unpacking questions* and *constructing answers*.

> *It's about helping students with the language and tools. ...If we can help them how to construct an 'explanation' answer it's a catalyst for them to do the other stuff as well* (Ch4_47).

Lindy believes that she should be responsive to her students' learning needs and their interests. In terms of addressing their interests, Lindy said she will,

> *always continue to listen to what my students say and what they're interested in ... using these learning opportunities in my classroom* (Ch4_48).

[9] Backward design model is a framework for curriculum planning. It starts with identifying desired learning outcomes and how this will be assessed then planning the learning activities (McTighe & Wiggins, 2012).

She is aware that this approach can cause problems when she is working to a timeframe, with external deadlines, but her belief persists. She told me,

> *It can be frustrating working with me when there is an amazing tangent that a kid has brought up and I'm 2 lessons behind everyone and they're trying to give the students the test* (Ch4_49).

The beliefs discussed here have their origins in Lindy's adolescent learning experiences. Section 4.2.1.1 verifies that she believes education is a 'means to an end', that students should enjoy science and have confidence in their abilities. This influences Lindy's planning as she incorporates general literacy skills and activities to make science interesting (see Ch4_46 and Ch4_48). Lindy's belief in responding to her students' learning means that her lessons need to be flexible to allow for unexpected learning events to be pursued. Brookfield (2006) states that students appreciate a teacher who is responsive to making their learning meaningful. Lindy's belief is also supported by ASTA Standard 5 (ASTA, 2002, p. 17) which states the, 'learning opportunities …are relevant, vital, exciting and varied, reflecting the nature of science itself'.

4.4.1.3 Relationships

Lindy believes that positive relationships between students and teachers are very important. This is evident in her recollections of her own schooling and her relationship with her teachers as discussed in sections 4.2.1.1 and 4.3.1. Those who showed that they were human by making mistakes, sharing humour and being good listeners were those who she classed as the better teachers. The centrality of her belief in positive relationships is also evident in her memories of her time in the research laboratory. Recollections of her first visit to the laboratory were accompanied by a strong, positive emotional response (see Ch4_6). Lindy emphasized the collegiality she felt as the scientists who worked there took the time to explain their research to her. In contrast, Lindy was negatively impacted by poor relationships. For example, at the beginning of her second year as a research assistant her enjoyment of work decreased. *I felt the dynamic between me and my supervisor really soured ...I didn't like the feel* (Ch4_50). Additionally, when she started at Meridale College and she struggled to connect with the other science teachers (see Ch4_22). Lindy knew that the science faculty could not move forward until they respected each other and could work together. It was not until the science teachers shared and understood each other's beliefs about science education that they were able to work collaboratively. *I realized we weren't that different* (Ch4_51).

These examples show that Lindy believes that the sharing of ideas and open and positive collaboration are important amongst scientists, teachers and learners. It also shows the importance she places on interpersonal relationships and the sense of belonging and working in a team. In particular, as Head of science, Lindy needed her team to discuss strengths and weaknesses in their program. Husu and Tirri (2007) assert that a supportive, collegial atmosphere is required for this to occur. Lindy's beliefs align to ASTA Standard 5 (ASTA, 2002, p. 17) which states, 'relationships are warm and supportive and characterised by mutual respect, cooperative behaviour and a sense of community.

Lindy's beliefs about adolescents have changed from when she was a student at school and university, when she had little respect for them. If anyone suggested teaching as a career for her before she had started her Diploma of Education, her response was, *I don't want to teach those obnoxious, little mugs* (Ch4_52). Her attitude started to change when she presented to school groups at GTAC, but even then, she did not want to have a long-term relationship with them.

> *Even when I was studying teaching, I wasn't going to go into schools. I was going to go to GTAC – because it would be as a science educator, science communicator not as a science teacher* (Ch4_53).

It was when she started teaching that Lindy's beliefs about the importance of relationships with her students started (see Ch4_34nr). This belief was reinforced with the positive relationships created through the Budding Biochemists program (see Ch4_19nr). Then, the integrated year 9 program at Firlake College opened up the opportunity to see the positive outcomes from respecting students' voice in their learning (see Ch4_21nr). In regard to years 7-12, Lindy finds year 8 is the most difficult year to teach, but she believes that if the teacher is *open, positive* and *authoritative* (Ch4_54) they can help the student learn.

> *Year 8s are going through all the hormonal changes …and if you don't shape your classroom so that it allows them to go through all that in a safe space …I think you are going to have a really hard time with them* (Ch4_55).

That Lindy's belief in the importance of the relationship with her students came so late is surprising, based on the positive relationships she had experienced as a student with her teachers (see Ch4_24nr). Miranda's (2012) findings reinforce Lindy's belief, as all teachers interviewed believed that teachers should respect students as learners, share humour and create positive, learning environments. Likewise, Berliner (2004b) found in his study, one aspect that is important to excellent teachers' success, is knowing students' personalities and cognitive abilities. Learning is a team effort involving a relationship between teacher and learner. ASTA Standard 2 (ASTA, 2002, p. 13) states, 'establish constructive interpersonal relationships and use this knowledge to build positive environments for science learning'.

4.4.1.4 Assessment

Lindy believes that all students can learn science if they have confidence and that how assessment is approached can affect this confidence. She says that what makes a student successful is *the confidence to take a risk* (Ch4_56). She believes that part of this is a mind-set, but confidence can also be taught through role modelling, by setting up the classroom so it is a safe place and by articulating opportunities where it is safe to take a risk. One thing she tells her students is,

> *Any assessment task you do is a snapshot of where you are right now. It's not a product of who you are. It doesn't define you. It doesn't define your intelligence for the rest of your life. So what? You bombed out. What did you learn?* (Ch4_57).

Lindy believes that a school's assessment policy affects students' understanding of learning. Whilst at Firlake College, the school changed to continuous reporting which is task focussed. Lindy felt that this,

> *changed the way my students cared and engaged with their learning. They started to see everything as formative, rather than summative* (Ch4_58).

Furthermore, Lindy expressed concern about assessment via summative topic tests alone (see Ch4_23) as she does not believe that they show if a student's learning is long-term and permanent and whether there is *continuity in [their] knowledge development* (Ch4_59). She incorporates *diverse strategies of assessment*, which are,

> *not necessarily all reported on. ...It gives kids an idea of where they're at. ...So, for year 8 in term 1 there's two mini tests, a self-designed experiment and a project poster. An example of a project is applications of cellular respiration and the respiration via the lungs. It involves information literacy and we've worked with the library staff on this* (Ch4_60).

The project poster gives Lindy's students scope to choose an area of respiration that is of personal interest and to demonstrate their understanding across topics at a microscopic and macroscopic level. The range and frequency of assessment tasks provides many opportunities for formative feedback. Her view is that,

> *We'll always have time in the lesson after I've given feedback where I explain what I've given marks for, where they've missed out on marks (in general). They have an opportunity to contribute to that discussion* (Ch4_61).

Lindy takes deliberate care in constructing assessment rubrics to ensure the expectations are not ambiguous by using explicit language.

> *Descriptors like 'to a limited extent' or 'to a greater extent' ... what do they mean? When you ask students to do assessment you need to tell them what you want them to do: describe it? explain it? There's a difference* (Ch4_62).

Lindy is conscious of preparing her students in years 7-10 science for success and this is reflected in her choice of assessment tasks. She is determined to give students confidence in learning science so that choosing to study science at VCE level is a feasible option for them. One possible task for school assessed coursework (SAC[10]) in VCE in all sciences is a poster presentation (VCAA, 2013a, 2013b, 2013c). Lindy believes that motivating and giving students experience of what to expect in science education in the VCE and beyond means they are more likely to choose to study science in the future. This is consistent with recommendation five by Lyons and Quinn (2010, p. 112) for increasing enrolments in post-compulsory science subjects, states that girls in particular, need to be more confident in their science learning and ability to achieve.

4.4.2 Beliefs about science education and its purpose

Lindy's beliefs about science education are reflected in the faculty's 'Science Manifesto' which Lindy led her faculty to create. This is a set of statements for both students and teachers expressing the purpose of learning science at the school and to what they believe students should aspire including:

1. Develop a sense of awe and wonder for the world around you. Let your scientific learnings help you see the beauty in the hidden detail of things both great and small.

[10] SAC – School assessed coursework is the internal assessment component of every VCE subject. SACs are written and assessed by the school's teachers.

2. Have the courage to make mistakes and make them often. The greatest scientific discoveries have emerged out of trial and error.
3. Endeavour to see how science connects to your everyday life. It will be a powerful ally in making informed, evidence-based decisions in an increasingly scientific world.
4. Don't just be an asker of questions. Be a finder of answers. But use caution in your search, as not all sources of information are equally reliable.
5. Be informed and engage in local and global scientific issues. Collaborative innovation by all citizens, including you, will be essential in making the world a better place.
6. Be conscious that science is ever evolving. As new technologies emerge, we should pause to consider the ethical and moral implications of their advances.
7. And above all, be positive about your learning in science. For you will acquire knowledge and skills that are invaluably transferable in this ever-changing world.

Although these were developed collaboratively with others, Lindy said that she referred to these statements often when explaining her beliefs and practices in teaching and learning science. Lindy's belief in these principles had their origins in past experiences, particularly from her time working at the research laboratory.

Lindy's recollections of learning science as a student in years 7-10 are quite vague. There is evidence of two factors as to why this might be the case. Firstly, the emphasis of her science classes was on recall of factual knowledge, with teachers mainly using lecture style teaching, with very few opportunities for hands-on learning. Secondly, Lindy had already decided on her career path into law, so she felt science was irrelevant and served no purpose for her. Lindy now believes science should be enjoyed by all students and this is clearly evident in the 'Science Manifesto'. It also correlates strongly with the aims of the *Victorian Curriculum: Science* (VCAA, 2017e).

Many of Lindy's beliefs about science developed during her association with the research laboratory which started with work-experience when she was a student in year 11 and continued through to full time work as a research assistant after her undergraduate studies. Her experiences in research influenced what she believes that her students should experience when learning science; that is, that science education should be hands on, contemporary and inquiry based. This is supported by a statement Lindy made in her initial interview.

> *I really love real-world science learning; I like kids to work as scientists and to have those sorts of projects. So, where I can find opportunities in the curriculum to leverage that, I will do my very best* (Ch4_63).

Lindy's belief in basing science on real life was evident early in her career at Firlake College when she was inspired to create the Budding Biochemists program which gave her students the opportunity to experience 'real science' (see Ch4_19nr). Her belief in the benefits of students experiencing 'real science' also formed the focus for her research in her Master of Education. Her research supported her beliefs as her findings showed that students felt positive about learning science and could envisage further studies or a possible future career involving science.

Lindy believes that her laboratory research experience helps her to implement the science curriculum in the classroom. Lindy remarked on a recent government briefing she attended about the *Victorian Curriculum: Science* where it was reinforced that the curriculum was not prescriptive and that teachers should '*interpret*' and '*be creative*' with the Curriculum. However, Lindy thinks that even though teachers might want to do this,

> *the limitation is not knowing how, where or why to do this because they aren't familiar with the real world of science* (Ch4_65).

Based on her laboratory experience, Lindy knows that scientists develop their specialised knowledge only when needed and that,

> *what you learn at Uni ...is probably less than 1% of the area you become an expert in ... you have to be good at consuming, using and even creating knowledge rather remembering learned knowledge* (Ch4_66).

Similarly, in secondary school science, Lindy believes in teaching life-long learning skills rather than expecting students to be *encyclopaedias of all the fundamentals of science* (Ch4_67). Furthermore, working at the laboratory made Lindy aware of other aspects of science, such as the commitment required to be a good scientist (see Ch4_14nr). She therefore understands that a career in scientific research is not for all students and but believes that understanding science is useful in everyday life.

Lindy has clearly developed the view that connections to real life science is a vital element of being an excellent science teacher. Lindy believes that the process of scientific investigation is important for students to experience to gain an interest in science, to maximise their learning and to develop high level, authentic knowledge and skills (see Ch4_66). This is comparable to her own experiences since it was the work experience in the laboratory that sparked her interest in science, which contrasted with the boredom she experienced as a student of science where remembering the content was the focus (see Ch4_63). Her approach is also consistent with the ASTA Standards 7 and 8 in that she uses contemporary and hands-on science to extend her students' understanding of the big ideas and to 'develop their confidence and abilities to use scientific knowledge and processes' (ASTA, 2002, pp. 19–20).

Meridale College uses the Victorian Curriculum in years 7-10. It has two main strands: understanding science and inquiry skills (VCAA, 2017e). Lindy views this formal curriculum as giving her *stability*, in that it provides her with a framework to guide the depth and breadth of learning at each year level. After attending a professional learning session about the Victorian Curriculum, Lindy believes teachers should be, *…encouraged to interpret it, be creative, make it exciting* (Ch4_69). She does however, express a belief that some teachers may interpret the curriculum differently, depending on their school's priorities and their own knowledge. Lindy stated,

> *I think a teacher who lacks confidence or just wants to get it done, might not be able to see what can be done or put the effort in. They might want to make it more interesting, but the limitation is not knowing how, where or why to do this because they aren't familiar with the real world of science* (Ch4_70).

This statement indicates that Lindy is confident that she has the knowledge and skills to interpret the *Victorian Curriculum: Science* to her students' benefit and that rather than being prescriptive, it gives her the scope to be creative in her lessons.

However, Lindy believes that the *Victorian Curriculum: Science* does not explicitly identify the, *sense of global collaboration or innovation in science research* (Ch4_71). It is up to the teacher to know where and how this can be highlighted in the curriculum. Lindy believes this would be difficult for teachers who have not experienced working as a scientist themselves. Despite these concerns about whether all teachers have the knowledge to do implement it, Lindy agrees with the Curriculum statement that,

> 'The work of scientists reflects the nature and development of science, is built around scientific inquiry and seeks to respond to and influence society's needs.

> Students' experiences of school science should mirror and connect to this multifaceted view of science'. (VCAA, 2017e)

Whilst Lindy personally enjoys the topics in the year 8 Victorian Curriculum: Science, she finds it challenging to provide opportunities for her students to understand how they are relevant to their current and future everyday lives.

> *Most of the concepts are so abstract that it's very hard for the students to get their heads around what's going on* (Ch4_72).

Lindy believes that the purpose of teaching science is not just to transfer knowledge to students, but also to give them skills that will facilitate their life-long learning. Her emphasis on scientific literacy and on 'helping [students] to be interested in and understand the world around them' (Rennie et al., 2001, p. 466) is consistent with the *Victorian Curriculum: Science* (VCAA, 2017e).

4.5 Conclusion

This chapter has discussed Lindy's professional knowledge, personal attributes and beliefs about teaching and learning science. She clearly has excellent knowledge in the areas of scientific content, pedagogy and of how students learn, which align to the knowledge areas identified by Shulman (1987). Lindy is a reflective practitioner who continuously questions her practice and seeks opportunities to improve. Lindy's affective attributes are consistent with those identified by Keeley et al. (2006) as corresponding to teachers of high quality, particularly her passion for teaching and learning science. Finally, Lindy articulated beliefs about the purpose of teaching and learning science and about how students learn best, which, as Fives and Buehl (2011) suggest, filter, frame and guide her teaching practice.

The conclusions established about factors related to Lindy's excellence as a science teacher in this chapter are that she has a passion for sharing her love of science with her students through real life scenarios involving scientific inquiry. She believes that learning occurs in an emotionally safe environment where students are given the language and tools to communicate their learning. Finally, Lindy believes that one needs a purpose to engage in and be passionate about learning; an end product to strive towards. For her middle school science students, the end-product is very engaging approaches to learning, and motivation to engage in future studies in science and science-orientated careers.

Chapter 5

Factors involved in an excellent science teacher's professional practice - Lindy

5.1 Introduction

In this chapter, I identify and analyse Lindy's current professional practice, particularly in the teaching of her year 8 science class. This chapter focuses on the analysis of the data in terms of the first and third research questions.

1. How do personal and contextual factors influence teachers' beliefs and practices?
3. How are the beliefs of excellent science teachers demonstrated in their professional practices and classroom teaching?

The data analysed is again drawn from semi-structured interviews, classroom observations and documentation collected from Lindy and her students. The *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and *Framework for examining beliefs* (Fives & Buehl, 2008) continue to inform my analysis of excellence. I begin by discussing the relationship between the curriculum and Lindy's practice in teaching a year 8 science class. I then discuss Lindy's practice in terms of her teaching and learning, reflective practice and her relationship with students in the classroom. Finally, Lindy's collaboration with her colleagues within the school and with other professional communities are discussed in terms of how this relates to her professional knowledge, beliefs and practice in the science classroom.

5.2 Analysis of Lindy's teaching and learning practice

5.2.1 Current context

5.2.1.1 The school

In 2017, when my study was conducted, Lindy was working at Meridale College four days per week as the Head of science, teaching general science to a year 8 class and teaching VCE chemistry to years 11 and 12.

Meridale College is an all-girls Catholic secondary school in suburban Melbourne. The school's vision statement is that the school aims to, 'empower students to engage in authentic learning ... focus on the literacies required for collaborative learning in a knowledge-based society. ... within a faith based, nurturing and educationally challenging environment.'

(Meridale College website). The school has approximately 500 students in years 7-12, with 56% of students in the middle bands of the ICSEA scale[11] and 30% in the bottom scale, which is slightly lower than average for Australian schools (ACARA, 2017). More than 40% of students come from a family where English is not the first language spoken (ACARA, 2017). The median VCE study score in 2016 was 28[12], which is just below the state median of 30. Students at Meridale College are offered two pathways in the senior years: VCE and VCAL[13], which include five VET[14] options, with the majority of students choosing to study VCE. Victorian schools that offer VCAL and VET pathways often do so to cater for a student population who prefer to be hands-on with their learning and do not plan to continue to university education. Students can also combine VCAL and VET courses with VCE subjects to keep their options open for further study. In 2017, sixty-five percent of graduates from Meridale College students went on to university. (Meridale College Annual Report, 2017). In years 7-10, the school uses the *Victorian Curriculum: Science* as the core planning framework.

The high proportion of students with English as their second language at Meridale College is a good reason for Lindy's emphasis on literacy skills in her classes (see section 4.4.1.2 and quote Ch4_47). Billman and Pearson (2013) found that combining the learning of science with learning literacy skills resulted in students having positive gains in both knowledge areas. Furthermore, this is consistent with one of the aims of the *Victorian Curriculum: Science* (VCAA, 2017e) which is, 'an ability to communicate scientific understanding and findings to

11 ICSEA is the *index of community socio-educational advantage*. It gives an indication of the students' family backgrounds and the school's geographical location, factors which influence students' educational outcomes at school (ACARA, 2017).

12 VCE study score indicates the relative position compared with all students in the state for that year. It is assessed on a scale of 0 to 50, with the mean study score across the state is 30 with a standard deviation of 7.

13 VCAL is the Victorian Certificate of Applied Learning which is a hands-on alternative to the VCE.

14 VET is Vocational Education Training which provides workplace-specific skills and knowledge for a range of careers and industries, including trade and office work, retail, hospitality and technology (Australian Government, 2017).

a range of audiences, to justify ideas on the basis of evidence, and to evaluate and debate scientific arguments and claims'.

5.2.1.2 The science laboratories

Meridale College has four well equipped, recently refurbished science laboratories. The layout is fairly typical for a science facility in a Victorian school. There is a central preparation area and a full-time laboratory technician which means hands-on activities can be easily organized. All the laboratories have a similar layout of practical benches around the sides of the room with class seating in the middle of the room. The area around the practical benches is reasonable, but the central seating area is quite crowded with desks and chairs. The laboratories are used by all students in years 7-12, so there are examples of students' work from all year levels on the walls. Lindy makes sure students' scientific posters are displayed in and around the science classrooms. Lindy explained that the purpose of displays is,

> *so, it looks like the corridor of a research lab which has all the posters from the labs. When I went to research conferences, there were always posters and you would learn so much instantly. I think that's part of the collaboration when you're in a scientific community. I communicate this to my students* (Ch5_1).

Above the whiteboard, each laboratory has a common series of posters made by the teachers in the faculty. These posters constantly promote the 'Science Manifesto' (see section 4.4.2) to students and teachers.

The visual reminders of the 'Science Manifesto' and the students' posters are evidence of Lindy's belief in the importance of students understanding the work of real scientists, for them to consider how their learning relates to the wonders of real life and to give them confidence that they are able to learn science. There is surprisingly little research on the impact of displays and posters in the secondary classroom have on learning. However, Adoniou (2017) contends that visual displays can promote the school's values and celebrate and reinforce student learning. In Lindy's case, the Manifesto posters promote the values of science and of learning science, the students' posters celebrate students' achievement, and both displays remind students of what they can aspire to as their learning progresses.

5.2.2 Planning and teaching

The sequence of lessons I observed were part of a unit on chemistry. This aligns with the *Victorian Curriculum: Science* descriptions:

- Science for understanding: The properties of the different states of matter can be explained in terms of the motion and arrangement of particles (VCSSU096)
- Inquiry skills: Questioning and predicting (VCSIS107); planning and conducting (VCSIS108); recording and processing (VCSIS110); analysing and evaluating (VCSIS111); communicating (VCSIS113)

(VCAA, 2017e)

Lindy had finished teaching the topic and students had already completed a written test to assess their understanding of the theory. The main task was for students to choose an everyday material and design and conduct an experiment on it to investigate features when it 'changes state'. After performing their experiment, students were asked to present their design, observations and the interpretation of their results in a poster. The class consisted of twenty-five year 8 girls. Lindy told me they were a diverse group including students who are diligent, distracted, and others with conditions including special needs such as autism, English as an Additional Language (EAL) learners and some with personal or family issues.

5.2.1.1 Before the lesson

Before observing each lesson, I conducted a pre-lesson interview with Lindy to find out what she had planned for the lesson. She was embarrassed to admit that her planning was often last-minute saying, *everyone thinks that teachers have to be perfectly planned* (Ch5_2). Although she did not have a written plan for any of the lessons I observed, she did have a mental plan and could distinctly describe her intentions for each lesson, commenting that,

> *I tend to have a big picture of the lesson, but then the little details click into place when it happens* (Ch5_3).

Lindy explained that her process of planning involved reflecting upon what happened the previous lesson; considering what concepts might need clarification and what the next steps in the learning process might be.

> *I don't think my really well-planned lessons always go the way I think they'll go …whereas I think the spontaneous ones tend to address the immediate needs. If you plan too far in advance, you miss those immediate needs. …if you had an infinite amount of time you could have an infinite number of ideas* (Ch5_4).

Lindy's flexible planning of lessons is only possible because of the detailed pre-planning of the unit completed by the year 8 science teaching team staff. They meet to create the unit guide at the start of the year and then again at the start of term where they use the Backward design model (see Ch4_45 and Ch4_46nr). As the unit planning is such a detailed process, Lindy finds her 'rough' individual lesson planning allows her to be flexible and able to respond to her students' learning needs as they arise during the lesson.

Whilst Lindy enjoys planning to teach, she stresses that there is a lot to take into consideration. She finds the science concepts at year 8 to be extra challenging to teach as,

> *all the fundamental concepts of science have been put into one year. ...I don't enjoy watching students struggle with the abstract concepts. I find the challenge is in trying to make these concepts relevant to the students. So, every year I try to find innovations to make it better for them* (Ch5_5).

In planning the chemistry unit, Lindy and the year 8 teachers included the poster as part of the task, giving students an experience of what future studies in Science might be like, particularly VCE science. A poster presentation is one requirement of the assessment in the VCE sciences (VCAA, 2013a, 2013b, 2013c). When I interviewed Lindy's year 8 students, four of the five told me they plan to study science in VCE and see science as being important for their planned careers as doctors, radiologists, or working in an old people's home. One student commented that,

> *It's an important subject because there are so many career paths that need science, so it helps you know what you want to do* (Ch5_6).

Lindy's loose mental planning is an attribute Hattie (2003) sees as common in expert teachers as they anticipate student performance and are able to respond so that teaching and learning stays on track (see Ch5_4). Lindy is able to be flexible within each lesson only because of the detailed preparation of the overall unit and the large repertoire of strategies and activities upon which she can draw to meet the needs of her students. This shows not only the importance of her professional knowledge, but also her ability to decide what knowledge to access to deal with situations as they arise. Lindy's knowledge of students' difficulties in understanding particle theory combined with her beliefs that her students should experience success and see the relevance of science to their lives, are factors that influence her PCK for this topic (see Ch5_5, Ch5_6). Loughran (2013, p. 118) calls this the 'complexity of pedagogy' as she continually makes professional judgements in her pre-planning and during the lesson based on her knowledge and framed by her beliefs. This complexity is also consistent with what Borko and Livingston (1989) found in their comparison of novice and experienced teachers; novice teachers prepared detailed lesson plans but found it difficult to adapt to students' needs as they arose. As Sawyer (2011) suggests, being able to balance between structure and improvisation of a lesson makes a good teacher great.

5.2.1.2 During the lesson

In all the classes observed, Lindy started with a whole group discussion, recapping the last lesson and discussing the learning goals for the day. This was achieved through a series of questions and answers between teacher and students. According to Lindy's students, whole group discussions are a frequent activity in their science classes. In interviewing her students, they identified the most common activities in science were whole class discussions, individual work - where Lindy would help them one-to-one, experiments with practical reports and watching videos. One student also said,

> *Sometimes we brainstorm on the board and we all chip in and talk about what we know* (Ch5_7).

In one lesson I observed, students were improving their own experimental designs. In the previous lesson, each group of two to three students had been given the task to 'design an experiment that demonstrates the effect of change in temperature on an everyday substance'. The students' first task was to swap their written method with a person from a different group who gave feedback on their method and vice versa based on the task's assessment rubric. After this, students were instructed to get into their small groups to make modifications based on the feedback. Students had submitted a list of the equipment that they needed for their experiment in the prior lesson and Lindy had asked the laboratory assistant to fulfil their list, according to the student instructions. The equipment was provided, with some students expressing surprise when the equipment was not quite what they requested. Lindy gave students time to modify their equipment requests and their method, based on this experience. Lindy attended to each group, ensuring they understood what they were doing. There was definitely a focus on inquiry. Students realized how precise they needed to be with their written communication so that others could understand it. Another advantage of this step was students being able to see and touch the equipment. Lindy said this helped students visualize their experiment, which in turn prompted them to plan a more accurate and practical method. Students were excited to touch the equipment and it helped them to focus on the task, so they would be ready for the next lesson. Amending their equipment list and method was not an onerous task for the students as they all had a laptop and were very comfortable with collaborating on Google Docs© via Google Classroom©. It was easy for them to edit their work and for all of them to be involved. Lindy emphasized clear communication and collaboration, allowing students to learn from errors and 'try again'. As Lindy says,

> *Often students have this perception that a scientist works on their own, works at their bench, but no, it's very collaborative and the sharing of information and getting feedback from people is very important in allowing people (scientists and learners) to move forward* (Ch5_8).

Lindy uses Google Classroom as a teaching and learning tool, since it allows her to check on students' progress and provide feedback between lessons.

The next couple of lessons involved students performing their experiments. There was diversity in the students' experimental designs and in the substances they chose to test, so different outcomes and evidence were considered. For example, some experimented on freezing and heating chocolate, whilst others tested jelly-babies or different types of candle wax. Some used thermometers for quantitative data and others used their smart phone to take photos and made qualitative observations. To apply heat, some groups used a Bunsen burner to heat, others a hot plate, whilst others used a beaker of boiling water. From an observer's perspective, it could have seemed like chaos, because the students had control of the activity, rather than the teacher. Even so, Lindy was calm and allowed her students to follow their own methods. She only stepped in when there was a risk to safety. Lindy monitored the activity by stopping at each desk and giving students a chance to ask her questions and seek support. If part of their experiment did not work, I heard students discuss it within the group and at times they sought advice from Lindy. The students had the opportunity and the time to modify their method and to try a different approach. When students had a query, Lindy tended to ask a question in return, handing them the role of being the problem-solver. To reach all groups during the lesson meant that Lindy could not have any in-depth discussion with students about what their results meant in terms of the particle theory they had been studying. Without this discussion, there would have been a low cognitive demand on students, however, as an excellent teacher, focused on improving students' scientific inquiry skills, Lindy knew that students' understanding of the content knowledge also improved through the processes of the overall task. This was Lindy's intention, and she commented that,

> *I like to do inquiry where they've got plenty of time to observe, then I do some teaching to find out why they have predicted or observed and get them to start forming explanations* (Ch5_8).

Clearly, she was constantly encouraging the students to reflect and develop high order thinking. Lindy was confident that her lesson helped students to experience how real scientists work, as the structure of this inquiry task was an opportunity for students to inquire, collaborate, persist and enjoy science. Lindy's students also perceive inquiry to be an important approach in science education. One student noted that compared to other subjects, *science is more experimenting and finding out about stuff on your own* (Ch5_9). However, Lindy was humble about her successes, and reflected that the lesson was *chaos. Controlled chaos* (Ch5_10).

The task discussed above highlights a number of the aims of the 'Science Manifesto', which reflect Lindy's beliefs. Students were 'endeavouring to see how science connects to everyday life'. They were animated and engaged with their tasks showing a 'sense of awe and wonder'. They were encouraged to be 'risk takers', have 'the courage to make mistakes' and 'learn from trial and error' (see 'Science Manifesto' and Ch4_41nr, Ch4_56 and Ch4_71). Finally, scientific inquiry was occurring as students made decisions about the experiment when the unexpected happened, showing that they were 'askers of questions' and 'finders of answers' (see 'Science Manifesto'). In setting this task, Lindy demonstrated ASTA Standard 8 (ASTA, 2002, p. 20), since students were able to explore, 'appropriate topics and issues [as selected by students], …weighed up evidence and asked, 'what's fair?' and, 'what's reasonable'? This is consistent with Potvin and Hasni's (2014, p. 98) findings which indicate that students' interest, motivation and attitude towards science are enhanced by hands-on, inquiry-based tasks where 'independent thinking' is encouraged. Toplis (2012, p. 539) also found that hands-on experiments increased students' 'sense of ownership and autonomy' of their learning (see Ch5_9). Developing student autonomy and ability to solve problems collaboratively are both beliefs that Lindy hold about excellent teachers (see Ch4_41nr).

In the next lesson, students were set the task of preparing their poster about their experiment. Once again, the lesson started with a whole group discussion, which focused on students interpreting their observations by considering what was happening at the particle level. Lindy reminded students that they needed to explain their observations. She used language that students had been introduced to before - 'big level' and 'small level' - to make connections between what they could see with what they could not. During the discussion, students were comfortable with giving explanations based on this language, linking their observations to the particle theory. Students then worked in their pairs to construct their poster. Lindy told me that this task allowed students to,

> *apply the concepts they'd learnt before to something (their experiments) they'd done themselves instead of using those standard examples you find in a textbook* (Ch5_11).

Lindy is aware of the difficulty for lower secondary students to understand abstract ideas in the curriculum (see Ch4_72), so she organises activities so that students are not overloaded and provides scaffolding to support them in their learning. Researchers (Šorgo & Špernjak, 2012; Varma, 2012) found that students can experience cognitive overload when asked to perform practical work whilst also considering the content. By leaving the discussion about connecting observation to theory to the lesson after the experiment, Lindy showed that she is aware of how much information her students can deal with at one time. She used explicit language to help students develop scientific literacy so they can describe their observations, ask questions, construct explanations using their scientific knowledge, and communicate their ideas to others. This is consistent with one of the main aims of the *Victorian Curriculum: Science*; for students to develop 'an ability to communicate scientific understanding and findings to a range of audiences, to justify ideas on the basis of evidence' (VCAA, 2017e). Loughran (2013) would say that her attention to her professional knowledge and considering learning priorities in her planning is an indicator of Lindy's strong PCK of teaching the topic of particle theory to her students.

Comments from the interviews with Lindy's students showed that they see science as relevant to their lives and to society. For example, students said that science,

> *teaches us about our body and also teaches us about other stuff that other subjects don't teach you. That's important because it's about the stuff that other people have found out and about the world you're living in* (Ch5_12). *Science is everything we know. I think science is how we find out things. But science doesn't have all the answers, but it tries to find the answers* (Ch5_13).
>
> *To be a scientist you can find out how to make a cure and help other people* (Ch5_14).

These comments are consistent with Lindy's aims in teaching science. Her students see the relevance of science in their own everyday lives and to society (see Ch5_12, Ch5_14) and understand the key role of scientific inquiry (see Ch5_13). This is consistent with recommendation two in Lyon and Quinn's (2010, p. 111) report which suggests that, 'school science learning experiences be more interesting, practical and personally relevant'. In addition, Lindy's practice is consistent with the ASTA Standards, in particular, ASTA Standard 1.3 (ASTA, 2009, p. 6) since she, 'nurture[s her] students' curiosity, imagination and creativity and make[s] meaningful connections between science, other areas of learning and real-life experiences'. Her teaching also reflects ASTA Standard 2.3 (ASTA, 2009, p. 10) as she gives students opportunities to, 'make connections …with prior knowledge …and their interests and aptitudes'.

5.2.1.3 Implementing wider curriculum aims

Lindy believes that the purpose of teaching is not just subject specific, but also involves teaching students to become literate, numerate, critical thinkers and successful, life-long learners, as specified in the Victorian Curriculum (VCAA, 2017d). She is conscious that more than 40% of her students come from a family where English is not the first language spoken and,

> *particularly in science, if there is a literacy issue it's really hard [for students] to get any validation of what they understand from any work they do* (Ch5_15).

Lindy's practice demonstrates her belief that she should explicitly teach her students English literacy skills. In one lesson, I observed Lindy reviewing the passive present tense of common words and phrases that her students might use in writing their scientific report. This reflects what Lindy reported having read in an article recently.

> *It was about challenges with chemistry and the literacy of words like 'increase' or 'decrease'. You think, 'what do I do? Where do I start with these kids?'* (Ch5_16).

Another strategy she has introduced to address low literacy is the use of Education Perfect[15] across years 7 to 10 science. Lindy adopted this tool because she thinks,

> *that textbooks are so full of text. Students are not used to reading heavy texts; especially our kids who struggle with literacy* (Ch5_17).

The Education Perfect platform allows teachers to customize the content so that students can successfully access and understand scientific concepts.

[15] Education Perfect is an online learning platform which provides online interactive lessons suitable for both the classroom and individual learning. Teachers can individualise the curriculum content for students and students can receive immediate feedback (Education Perfect, 2017).

Besides addressing her students' literacy skills, Lindy also focuses on supporting them when they have weak numeracy skills. The Victorian Curriculum for chemical science at year 8 requires students to learn that, 'states of matter can be explained in terms of the motion and arrangement of particles' (VCSSU096) (VCAA, 2017e). One way of describing the arrangement of particles is in terms of their density. Lindy and the year 8 team decided not to use the term density as this is a quantitative concept which would *interfere with students getting any descriptive understanding of it* (Ch5_18). Lindy explained that,

> *as soon as you give them numbers and do maths, their brains just shut down. It's more important to maintain this qualitative engagement with understanding* (Ch5_19).

Lindy feels comfortable making this decision as she is also the year 11 chemistry teacher and is aware that she will need to introduce the maths of density when students reach that level.

The Victorian Curriculum states that English as an Additional language students, 'require additional time and support, along with informed teaching that explicitly addresses their language needs and assessments that take into account their developing language proficiency' (VCAA, 2017b). ASTA Standard 1.1 (ASTA, 2009, p. 4) refers to the science teacher recognizing students' levels of competence in literacy and numeracy. Furthermore, the APSTs (AITSL, 2011) state that lead teachers should cater for students from 'diverse linguistic backgrounds' and (Standard 1.3), 'improve students' literacy and numeracy achievements' (Standard 2.5).

Lindy embraces use of Information and Communication Technologies (ICT) in the science classroom, for instance she uses Google classroom, which allows her to monitor students' progress and give formative feedback on extended tasks. She said that,

> *They can't remember everything we talk about in class to include in their report. ...over the weekend, I like to go in (to students' work on Google Docs) and give more specific feedback so they remember* (Ch5_20).

Furthermore, she uses a program which helps her to personalise learning.

> *It's all online and interactive lessons that they can go home and review. It's got formative feedback at each step. We can set students tasks to do and students get immediate feedback* (Ch5_21).

Lindy's decision to use ICT is consistent with the APST's (AITSL, 2011) which states that leading teachers are expected to use ICT effectively to 'make content relevant and meaningful' (Standard 2.6) and ASTA Standard 1.4 (ASTA, 2009, p. 7) refers to teachers 'understand[ing] how digital technologies affect the way students think, interact with and process multiple streams of information'.

Another element that Lindy believes helps students to be successful in learning science is the *confidence to take risks*. Lindy explained that particularly in her year 8 class, she supports her students' confidence by being,

> *clear with instructions [and giving them] a little bit of autonomy, but not for long lengths of time* (Ch5_22).

Taking risks is also evident in Lindy's class when students were performing the experiments they had designed. Unless the process was potentially physically unsafe, Lindy allowed the students to try their own procedures and if they made mistakes, to learn from them (see section 5.2.1.2). When this happened, rather than directly telling students how to fix it, I observed that Lindy used guided questioning to discuss what happened and helped students to explore how their experiment could be improved.

Lindy is cognisant that interpersonal skills are essential in group work which she believes is also central to the way scientists work in real life (see Ch4_42 and 'Science Manifesto'). Lindy is pro-active in teaching students team skills, so they do not need to rely on her intervention. Lindy explained that whilst doing a group project earlier in the year, she explicitly taught her year 8 students how to work together and *what to do when things went wrong*. She had students create a list of sentence starters that went on the classroom wall as reminders. They included statements like, 'I feel...', 'Is it OK if we...?', 'That's a great idea...' and 'I'm wondering if...'.

This evidence shows that Lindy scaffolds learning and guides her students through the scientific process, so they can recognise problems and justify their decisions. This is consistent with ASTA Standard 2.2 (ASTA, 2009, p. 9) as she 'model[s] and teach[es] the habits of mind of scientific inquiry and students, 'feel confident in posing questions, expressing ideas … [and] intellectual risk-taking'. Lindy also scaffolds learning so students learn to be collaborative. ASTA Standard 1.3 (ASTA, 2009, p. 6) states that highly accomplished teachers of science 'provide strong links to …interpersonal and communication skills'. These skills are part of the

Victorian Curriculum: Personal and Social Capability that all teachers should address in their teaching (VCAA, 2017d).

5.2.1.4 Reflection

Reflection is a significant feature of Lindy's teaching and planning. In all our pre and post lesson interviews, Lindy shared critical reflections on her teaching and her students' learning. She explained how different this year 8 class was to one she taught in the previous year.

> *They are like chalk and cheese. ...I could give last year's group a challenge and they were responsible with their learning and self-directed ...they would stay on task. When I first started working with this year's class, I felt I had to modify my very open approach to inquiry. ...I needed to give them discrete little chunks of time. I am very conscious of the way they work.* (Ch5_23).

Lindy also reflected on the 'big picture' of being a teacher in general.

> *I listened to them. ...I think you come into teaching as a science graduate thinking you'll change the world because of your passion for science. Then you actually realise that the way you change the world for these kids is by listening to them. It may not be that science is their passion, but just by being a good person to them. ... Stuff happens that you can't control, and it compromises how effective you can be. It's very difficult. But that's teaching. I think teaching is full of unexpected things and you just have to do your best* (Ch5_25).

These examples show how Lindy's reflective practice leads her to find solutions to improve her teaching and the students' learning. The importance of context is also demonstrated here. By embracing the unexpected and understanding the influence of context, she is able to make adaptations to make the best of a situation. Thus, critical reflection plays a big part in Lindy's attributes as an excellent teacher. Bransford, Brown and Cocking (2000) agree that the teacher's ability to be metacognitive and flexible is an important attribute for improving practice. Interestingly, although Lindy's passion for science is still very apparent, her passion for facilitating her students' learning has heightened since she began teaching (see Ch5_25). Fives and Buehl (2011) assert that reflexivity is a critical component in teachers questioning, enacting and changing their beliefs.

5.2.1.5 Conclusion

I found Lindy to be both organised and prepared for teaching; consistent with the qualities of excellent teachers (Keeley et al., 2006). Lindy's planning and practice demonstrates her thorough knowledge of the *Victorian Curriculum: Science* as well as standards in numeracy, literacy and critical and creative thinking and other learning areas. She creatively interprets the curriculum to emphasise what she believes provides meaningful science learning experiences for all her students; confidence in their ability to learn, enjoyment of learning and an appreciation of the relevance of science in their everyday lives and in their futures. She emphasises the learning of scientific literacy skills and inquiry skills within a context that students find relevant and engaging. Lindy's planning involves frequent reflection on her own practice and on her students' previous learning. She uses this reflection as the basis for planning, however her plans are kept flexible, so she can respond to immediate learning concerns and opportunities as they occur in the classroom. Lindy provides her students with opportunities to explore science mainly through discussions and practical activities. This exploration gives her students autonomy over their learning whilst developing their own metacognitive skills. Her students reflect on their own learning and receive feedback from peers and Lindy allows them to learn and improve their understanding and skills.

5.2.3 Assessment of, for and as learning

During the practical/poster task described above, Lindy used multiple assessment strategies to improve her students' learning including self-assessment, formative feedback from the teacher, peer assessment and students' experiencing trial and error. This was shown in the opportunities students had to modify their experimental design, as well as in the carefully structured and sequenced steps Lindy planned that are listed here:

- the design task occurred at the end of the unit when students had been exposed to the theoretical concepts.
- the students' initial design was done collaboratively so that students could help each other.
- the students wrote the design using Google Docs© so that Lindy could give written feedback to each student between lessons.
- as mentioned previously, students could revise their design with the equipment as a prompt.
- peer feedback from other student groups was given before performing the experiment.
- during and after performing the experiment, students could modify the design before the final presentation of their work on the poster.

- discussions between Lindy and each pair of students occurred during the practical task and poster preparation.

Reflecting on the lesson where students conducted the experiments they had designed, Lindy made some preliminary inferences about what the students had learned from the task. She said,

> *I'm hoping that their methods have improved from last time ...I think their understanding of the scientific process might have improved. ...I won't know until I get their posters ...I'm waiting to see the evidence* (Ch5_27).

In my classroom observations, I saw Lindy giving both verbal and written feedback to her students as part of formative assessment. For example, when discussing the explanation of their experimental results, Lindy encouraged students to refer to their recent topic test and past work (answers and feedback) to check how to link their observations with the theory of the physical and chemical properties of their substance. She said,

> *I work with them quite explicitly to write those explanations. I can see on the test that some of them have it and some don't. So hopefully the feedback will impact their ability to do their explanations on this task* (Ch5_28).

Besides the formative assessment I observed, Lindy's students also completed a mini-test half-way through the unit to give the students an indication of how they were progressing. Summative assessment for this unit consisted of a topic test and the poster. The topic test was 45 minutes long and consisted of four questions, each with three to four parts. The first part of each question required low-level cognition, but the subsequent parts required students to show high levels of understanding with answers requiring detailed explanations. Lindy is cognizant of the limitations of the data provided by a topic test and commented that,

> *I think teachers can sometimes say, 'yes, she knew it, she showed that in the test' and then move on. I think it falls out of their head. So how do you get continuity of knowledge and continuous access and permanency?* (Ch5_29).

Lindy uses multiple strategies of assessment *as* learning, *for* learning and *of* learning consistent with Black and Wiliam's (2009) work on the importance of emphasizing these varied dimensions in teaching. Lindy showed that assessment of her students' learning is important in providing her with feedback on the efficacy of her teaching and possible directions for her future planning to meet diverse learner needs. Lindy provides her students multiple chances to learn from feedback, which is evidence of her belief that learning is a journey. She knows that continuous, formative assessment allows her students to develop their understanding as necessary and are then to apply their understanding in different contexts. This is in line with Binkley, Erstad, Herman, Raizen and Ripleys (2012) contention that besides being evidence to inform future teaching and learning, formative feedback directly supports the learning process, if there is the opportunity for the student to act upon it. Furthermore, Shute (2008) states that frequent, formative feedback is particularly supportive of beginner and/or struggling students. As already described, many of Lindy's year 8 students have low literacy levels, so she is responsive to the context in which she teaches.

Finally, Lindy's practice is consistent with ASTA Standard 2 (ASTA, 2002, p. 13) which states that teachers should, 'know that all learning builds on previous experiences and mental constructs and that they [teachers] must find a way of relating and meshing these…'. The structure of the topic test is consistent with Marshall's (2013) findings, which state that highly effective science teachers challenge students with questions at various levels, including the higher levels. It is also consistent with ASTA Standard 7 (ASTA, 2002, p. 19) which indicates that teachers, should '[develop] a deep understanding of concepts with the major ideas of science'. By providing many types of assessments, Lindy gives her students a range of ways to demonstrate their understanding. This is consistent with ASTA Standard 9 which identifies the importance of giving students opportunities to use 'the most effective means of allowing their students to demonstrate learning' (ASTA, 2002, p. 22).

Lindy keeps detailed records of each student's learning progress. In discussing the results of the topic test, she was able to tell me each student's strengths and weaknesses and explain how she planned to address these during the poster activity and in her future teaching. She said that,

> *In the test, Bella [pseudonym] was able to describe the physical properties, but the question required her to give the chemical properties. She also has her energy levels around the wrong way. So, for the poster activity, I need to think how I can help her to understand* (Ch5_30).

In returning her students' marked topic tests I observed that some students were upset with their results. Lindy encourages her students to view assessment as a positive part of learning (see Ch4_57).

ASTA Standard 9 (ASTA, 2002) states that keeping meaningful records of students' progress is important not just for reporting, but also to inform future teaching. Lindy's message to her students is also consistent with ASTA Standard 9 (ASTA, 2002), as she guides her students in reflection and self-assessment to improve their understanding of themselves as learners.

As this section shows, Lindy's understanding and use of assessment is a key aspect of her excellence as a teacher, reflected in references to multiple frameworks for excellence. Lindy uses assessment to inform her planning of lessons, improve her students' understanding and to provide evidence for her students' progress. It is also evidence of the alignment of her beliefs with her practice. Formative feedback and assessment play a major role in her teaching practice as she believes that learning is life-long and that all students can learn.

5.2.4 Relationship with students

Lindy's year 8 science class is a positive place for students to be. In interviews, the most common response from students was that, *science is fun*. Other comments included:

> *[Lindy] is always organised and explains everything very well; exciting, amazing; respectful, responsible, safe; we help each other; [Lindy] controls the class very well; the teacher is nice so you're not afraid to ask a question when you don't understand; I have learnt so much in this class and its only term one; we are all able to show our full potential; [Lindy] thinks of many ways to help you learn about science.* (Ch5_32)

Lindy's students' comments support many aspects of the positive teaching and learning that Lindy tries to promote in her classrooms. Many of the points the students identified are about relationships: respect for each other, collaboration and teamwork, emotionally safe environment, clear communication. These points are discussed in more detail below.

Lindy considers contextual factors that can affect student learning. For example, she showed awareness of how her students' mental alertness and attention can vary depending on the time and day of the week. At the start of one lesson, I observed that some students entering the classroom were visibly upset. Lindy knows her students well and is aware of the class dynamics. She said that,

> *They are an interesting class socially. [Relationships are not good] between friendship groups because there's not many similarities. They don't respect each other just yet* (Ch5_33).

So, Lindy modified her teaching plan for that lesson because she felt she needed *to deal with that personal stuff first before any learning could occur* (Ch5_34). She allowed students to explain the problem, giving them specific guidelines and warning them to,

> *Be careful about what you say and how you say it. It's about the future, not about the past* (Ch5_35).

In our post-lesson interview, Lindy said this incident was the highlight of the lesson since,

> *someone listened to them. I think I addressed the thing that was bugging a lot of them. I think when something like this happens, they need to feel that an adult cares enough about them to do something about it* (Ch5_36).

Lindy's focus on her students' emotional well-being is valued by her students.

> *[Lindy]is so positive all the time. She's always smiling which makes us really happy. She cares about us. Some teachers are 'yeah, yeah', but she'll take time out of her lesson to help us. She really cares about each and every one of us and how we want the class to be* (Ch5_37).

This incident shows Lindy is aware of the developmental stage of year 8 students (see Ch4_55). It also demonstrates her belief in the importance of relationships *with* her students and *between* her students (see Ch4_40nr) and her authenticity (see section 4.3.1). Lindy's practice is consistent with ASTA Standard 5 (ASTA, 2002, p. 17) as 'when problems arise, [she] defuses confrontations and deals with them fairly and respectfully. Students are involved in establishing and maintaining behavioural expectations and boundaries'.

Besides helping students with their personal growth, Lindy actively promotes personal, interpersonal and problem-solving skills when students are working on a group task. For example, during one lesson I observed, the students finished the experimental part of their group work and were expected to work with their partners on presenting their findings in the poster. Lindy used different strategies to keep students on task and working together. Firstly, she set clear goals for the whole class, so they knew what was expected of them by the end of the lesson. Secondly, she supported them one-to-one by redirecting students whose attention was not on the task. Lindy purposefully gave students the opportunity to take responsibility for their actions and she made sure she did not come across as being confrontational. I observed Lindy remind a pair of students to use their time wisely when they were off task. She did so in a very fair, level-headed way, showing no anger or frustration saying, *I'm getting the feeling that you're avoiding work today. Would that be right?* In another situation where one student was looking frustrated with her partner who was just socializing, Lindy said, *Sophie, what are you up to? How do you think Katie feels about that?* In the post-lesson interview, Lindy told me she was conscious of how she dealt with behaviour by posing a question to the student.

> *I think if I just say, 'you're avoiding work' it's really confrontational, but this way I'm giving them the opportunity to explain themselves* (Ch5_38).

Lindy shares her optimism about life with her students and what she has learnt from experience saying that *learning is about moving forward. Each year I teach …I get better at it. Think of it as a journey* (Ch5_39).

Her genuine care and interest in her students' wellbeing also motivate her students to want to learn. In the words of one of her students,

> *She's fun. She smiles a lot. When you walk into the classroom you feel happy about coming to science. You feel welcome. When teaches she puts a few jokes in here and there so it gives you a better attitude to coming. We concentrate better I guess because it's more fun* (Ch5_40).

Lindy's approach demonstrates ASTA Standard 2.1 which emphasizes that teachers should, use collaborative and problem-solving approaches to strengthen relationships and resolve issues' (ASTA, 2009, p. 8). In addition, one of the aims of the Victorian Curriculum (VCAA, 2017c) is for students to, 'work effectively in teams and develop strategies to manage challenging situations constructively'. Hofstein and Lunetta (2004, p. 36) emphasized the importance of promoting cooperative learning in the science classroom as, 'a large number of studies demonstrate distinct benefits in students' achievements and productivity' and to 'develop a classroom community of scientists'. This supports Lindy's belief that she wants students to experience what it is like to be a *real scientist*. This is reflected in the 'Science Manifesto' which states, 'be positive about your learning in Science, for you will acquire knowledge and skills that are invaluably transferable in this ever-changing world'. Her actions are also similar to how she approaches her own challenges (see section 4.2.3.2). As mentioned earlier, Lindy guides her students through problem-solving strategies and self-reflection so there is better collaboration and teamwork which promotes better learning. That she practices what she preaches shows that Lindy holds this belief strongly.

Similar to Kroll (2004, p. 202), Lindy models the Christian philosophy of her school in that she is a role model for teaching being, 'moral work that must be guided by an ethic of care'.

Lindy's caring classroom environment reinforces the findings of Waldrip, Fisher and Dorman's (2009) study of excellent teachers who found that teachers identified by students for having positive classrooms were the same teachers that the principals identified as quality teachers. Keeley et al. (2006) also assert that this rapport, of making the class laugh through funny stories and class discussions is an attribute of excellent teachers. Furthermore, Ruiz-Alfonzo et al. (2018) concluded that teachers who are supportive, encouraging, and caring create students who are passionate for learning (see Ch5_40).

This section has shown that Lindy gives as much attention to maintaining positive relationships in the class as to preparing what and how science needs to be taught. The attributes she displays in her relationships with her students is consistent with Faul's (2008) list, as Lindy is,

- communicative – engaging, humorous, listener and knowledgeable
- authentic – caring, empathic, open and reflective
- passionate – positive, energetic, enthusiastic

In addition to these attributes being visible in her teaching practice, they are also attributes that Lindy believes in, showing the importance of positive relationships in Lindy's profile.

5.3 Collegiality, collaboration and personal practice

A teacher's work is influenced by work with colleagues within the school and both professional and personal interactions with people and organisations beyond the school. This section examines the evidence of Lindy's life beyond the classroom in terms of its effects on her science teaching practice.

From the first email communication with Lindy and throughout the case study data collection, I found Lindy to be enthusiastic, friendly and accommodating. Lindy showed great interest in my research, was keen to be of assistance and to learn more about what my study would reveal about her own practice and beliefs. She was obviously very busy with work and home commitments, but always gave her time freely. I observed her greet other staff and students in the school with the same courtesy. Lindy was professionally dressed, which corresponds to the Meridale College uniform standard expected of the students. She is clearly a competent and professional woman.

5.3.1 In the school context

When asked how her colleagues would describe her, Lindy used the words, *innovative, responsive, creative, but frustrating to work with* (Ch5_41). She explained that the frustration would be because,

> *when there is an amazing tangent that a kid has brought up ...I'm two lessons behind everyone and they're trying to give the students the test* (Ch5_42).

Lindy's comments indicate that she feels some conflict here between her obligations as a team member with her teaching colleagues and her commitment to allowing her students to embrace science. Her belief in giving her students opportunities to explore their ideas in science and give time to students' interests over-rides the time constraints that might be preferred by either her colleagues or imposed by course guides and the curriculum (also see Ch4_48nr). According to research, being flexible and opportunistic in teaching is indicative of expert teachers (Berliner, 2004b; Borko & Livingston, 1989). It is characteristic of ASTA Standard 2.3 (ASTA, 2009, p. 10) which promotes teachers to use, 'unexpected and unintended outcomes as opportunities for generating and exploring new questions'. Lindy's insight into how her behaviour affects others shows she is empathetic, a quality of individuals within a healthy professional learning community (Hord, 1997).

Lindy constantly challenges her ability to be a better science teacher. She believes that it takes an excellent teacher with specialist knowledge to be able to achieve this in practice. Lindy is critical of her own content knowledge, particularly in the sub-strand of 'Earth and Space Science'(VCAA, 2017e). She did not study this content at university and she feels that this constrains her ability to creatively interpret the Curriculum in this area to the maximum benefit of students (see Ch4_65 and Ch4_66nr). Another example is when she thought her practical skills and knowledge were *getting a bit old.* To remediate this, Lindy organized for a 'scientist in residence[16]' to work on a research project with the Meridale College year 8 cohort. Lindy felt this arrangement not only benefitted her students, but also gave the other year 8 teachers and herself some updated, more contemporary skills. Lindy also learns from working with

16 Scientist in residence program facilitates partnerships between schools and industry to bring real scientists into the classroom.

colleagues on small projects. In the year before my case study, Lindy had been a mentor for a graduate teacher who needed to complete an action-research project to fulfil the requirements for full teacher registration. The project was about improving scientific literacy by teaching students to be better able to construct evidence-based conclusions. Lindy worked with the graduate teacher to make a student-friendly guide on how to understand questions and construct answers by using the 'claim, evidence, reasoning' framework (CER) (McNeill & Krajcik, 2012). She noted that,

> *If we can help students with how to construct an explanation answer it's a catalyst for them to do the other stuff as well* (Ch5_43).

Instead of ending this project when the graduate teacher left, Lindy's hope is for the whole science faculty to use this CER guide with their students. She is also planning to bring in the 'Cornell method'[17] this year to teach students how to make effective notes.

> *When you're working with really experienced teachers, there's stuff that they feel is really important for students to know, even if it's not in the achievement standard* (Ch5_44).

The above examples are indicators of Lindy's belief in life-long learning for herself and her colleagues. Lindy uses various means to improve her own knowledge about science content, practical skills and scientific literacy skills. It also shows how she wants to share her new knowledge with her colleagues, to the benefit of her students. Lindy's practice is consistent with ASTA Standard 10 in that she is, 'committed to continuing [her] own professional learning', 'model(s) the development and improvement implicit in lifelong learning' and, 'learn[s] from colleagues through collaboration on professional tasks.

5.3.2 In contexts beyond the school

Lindy's life phase allows her to be committed to her work. She told me that she made an intentional decision to work hard and to move forward in her teaching career. Lindy has been married five years but had no children at that point. She said her husband is a committed and successful police officer, so work consumes both their lives. They both use their time outside of work hours for professional reading and learning.

[17] The Cornell method provides a systematic format for condensing and organizing notes. Research has shown that it is useful where students are required to synthesize and apply learned knowledge (Wikipedia Contributors, 2017).

Devine, Fahie and McGillicuddy's research (2013) supports the contention that teachers whose personal lives allow time and energy for the emotional and intellectual commitment that Lindy displays, are more effective in practice. Day et al. (2006) also found that the extent to which a teacher can maintain this commitment is dependent upon their capacity to manage interactions between their personal, work and professional lives.

At the time of my study, besides teaching four days per week at Meridale College, Lindy had just started teaching one day a week at her alumni university, Lamb University, as the chemistry method lecturer. Lindy chose to take this position as she was also considering commencing a PhD in science education.

Lindy's passion for and commitment to improving her knowledge of teaching science is indicative of excellent teachers. That Lindy had renewed her connection with Lamb University shows that she believes that the theoretical aspects of teaching science are relevant to her practice and that she wants to increase her knowledge of the theory of teaching and learning. Johnson (2009) found the desire to improve practice was common amongst effective science teachers and Wisehart (2004, pp. 46–47) would say she was, 'a reflective practitioner — living a life of inquiry, reading the research, analysing practice to make more of an impact on student learning'. In addition to improving her own learning, Lindy's work at Lamb University allows her to meet ASTA Standard 11 (ASTA, 2002) as she shares her expertise with the wider professional teaching community.

5.4 Conclusion

In summary, the evidence collected in this case study suggests that Lindy has a strong knowledge of science subject matter and pedagogies required to teach the Victorian Science Curriculum to her year 8 class. Her beliefs about the purposes and pedagogical approaches are appropriate to develop teaching and learning in an engaging way that has the attributes deemed to be excellent in the literature. She has a strong belief in students in year 8 enjoying science by asking questions and having the opportunity to find answers through inquiry. Lindy's personal knowledge of her school system and of the learning needs of her students allows her to differentiate her teaching to meet the needs of her students, including for example through purposeful structuring of group work and individual discussions with students during the lessons. Lindy's pastoral care beliefs align with those espoused by Meridale College. She believes that she is a teacher of students with personal development needs, not just of science as a subject, so she is conscious of her students' needs and provides them with life-long learning skills. Lindy is committed to her teaching and spends time in reflecting upon her students' learning and providing them with effective assessment and feedback. Being a lifelong learner was reflected in her continuing efforts to become a better teacher by seeking to understand the latest educational theories and by experimenting with her pedagogical approaches to teaching science.

The conclusions established about Lindy in this chapter are that relationships with students and colleagues are central to her teaching. They are established and maintained through shared values, respect and active listening. Lindy is passionate about giving her students the tools necessary to become life-long learners of science, through improving their scientific literacy and inquiry skills. Finally, Lindy believes in always trying her best. She constantly uses critical reflection of her knowledge and practice to direct her own professional learning and to ensure she provides the best learning opportunities for her students. From the interviews, observations, and reflections from her students, and comparison of these findings with the analytic frames used in my study, I was able to conclude that there are multiple factors involved in making Lindy an excellent teacher.

Chapter 6

Background context, knowledge, personal attributes and beliefs of an excellent science teacher - William

6.1 Introduction

In the next two chapters, I provide a deep discussion of the background, attributes, beliefs and practices of the second excellent teacher, William (pseudonym), to deepen my analysis of the complex range of personal and professional factors involved.

This chapter focuses on William's past contextual experiences. Analysis of the data is in terms of the first two research questions:

1. How do personal and contextual factors influence the development of excellent teachers' knowledge, personal attributes, beliefs and practices?
2. What do excellent science teachers believe about teaching and learning science in secondary school?

William was identified by more than one science teacher educator as an excellent science teacher, according to my selection criteria. He has been a teacher at Sandhope College for thirty-three years. The school is a co-educational government secondary school in suburban Melbourne about half an hour's drive from the central business district. As with Lindy, William's story is constructed from data drawn from semi-structured interviews, classroom observations and documentation collected from William and his students. My analysis was conducted through drawing on literature pertinent to the importance of personal and professional attributes in excellent teachers and consideration of the theoretical frameworks discussed in the literature review. This included the *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006), and *Framework for examining beliefs* (Fives & Buehl, 2008). I have drawn on these sources to identify, analyse and discuss key themes related to the professional and personal attributes, beliefs and practices that emerged from the data in relation to the above research questions.

I begin this chapter by discussing William's experiences as a student at secondary school and then at university and as a teacher. In chapter 7 analysis is provided of the extent to which his personal background and attributes have influenced his teaching practice. Finally, I discuss William's beliefs about science and how it should be taught to students at year 10 and draw conclusions about the influence of William's prior education and teaching experience on his beliefs about teaching science.

6.2 Past contexts

6.2.1 Experiences as a student

6.2.1.1 Secondary school

William grew up in suburban Melbourne and attended the local technical school[18] from years 7-11 in the 1970s. He says he was not a good student since he has ADHD, although this was not diagnosed until he was an adult. William thinks his teachers had a hard time to keeping him on task in the classroom. When I asked him about his memories of learning science in years 7 to 10, William, in his often-used colloquial Australian style responded,

> *I must have been away with the budgies. I don't know. I wasn't motivated. I remember going into the science room in year 7 and nearly vomiting because of the gas smell. …the teachers were hopeless …all I remember is writing boards and boards of notes. I honestly have no idea what we did* (Ch6_1).

However, William reported that he was good at and enjoyed the kinaesthetic subjects since he,

> *enjoyed carpentry, heavy metal and sheet metal work. They were very hands-on, and I am a very kinaesthetic, hands-on person* (Ch6_2).

William reported that his experience of science at school was not a positive experience commenting, *I don't think I saw a Bunsen burner*, reflecting his desire for science to be hands on.

These recollections indicate two points of interest. First, the change in teachers' knowledge of students and learning. In the 1970s, teachers would have had little knowledge of ADHD as it

[18] Technical schools in Victoria provided vocational education for girls and boys in years 7-11. Compared to secondary/high schools of the time, which focused on external academic exams, the courses were practical and led students directly into the workforce rather than to university.

was poorly understood by medical experts and therefore rarely diagnosed until later (Lange et al., 2010). Also, the emphasis in secondary school science in the 1970s tended to be on learning facts and regurgitating them in an exam (Fensham, 2006; Rennie et al., 2001; Yager, 2000). This meant that teaching tended to be transmissive; listening to the teacher, writing notes from the blackboard and answering questions from the textbook. William's ADHD would have made it difficult for him to sit for long lengths of time and so he has concluded that he was a poor student. Second, William showed frustration with his science teachers, as they only catered for students who learnt best through sedentary means such as reading and writing rather than kinaesthetic experiences. ASTA Standard 2 (ASTA, 2002) asserts the importance of teachers being able to make the content accessible to students by using a range of strategies to cater for how their students learn best. William's experiences as a student reinforce the view that teachers should understand the factors that help students to learn best.

By year 9, William had decided he wanted to become a carpenter, so most of his year 9 and 10 subjects were vocational and practical. However, in year 11, he changed direction and chose to study physics, chemistry and two maths subjects. With William's earlier account of his negative experiences of his time during middle school science, I expressed surprise in this change. William gave two reasons, neither of which related to his science studies in years 7-10. First, he described himself as the *dark horse in the family* as he was the only one out of his parents and six siblings to be poor at English. William explained that in his mind, this meant that he must have been good at studying the sciences. He said *it was just stuff I was good at. I didn't necessarily like it, but I guess you like what you're good at* (Ch6_3). Second, William's father was a school principal who instilled in him the importance of education. William said that, *to have an education was the 'bee's knees' – you could do whatever you wanted to do* (Ch6_4).

William struggled to learn at school and therefore did not enjoy his time there. Yet, he was still successful in the system, which may have been due to his parents' expectations of him combined with his own motivation. The influence of William's family is consistent with findings from the ASPIRES project (Archer et al., 2013), which found that parental attitudes to school and education are influential in a student's self-concept and in them choosing to continue with science in the post-compulsory years. Pursuit of a science education would have opened many career options for William. Israel, Beaulieu and Hartless (2001) found that students whose parents were involved and interested with their education and who had high academic expectations had higher academic achievement. William's family environment was very supportive and positive about education for the end purpose of attaining a better job.

Instead of pursuing the carpentry trade after year 11, William transferred to a technical college[19] to complete the year 12 Tertiary Orientation Program (TOP)[20]. William explained to me that this change in direction was because he wanted to *see how far he could challenge* himself in his studies. Whilst William chose to study maths and science in years 11 and 12, he did not describe himself as a good student, nor that he was motivated to learn these subjects. William recalled that he, *failed chemistry in year 12. I failed one of the two maths subjects in year 11. …I'm not a student by any means.*

This self-analysis of being a poor student along with his earlier observation of not being an easy student to teach, demonstrates that William sees the process of teaching and learning as a team effort, where both teacher and student contribute and that a student can be successful, despite not having excellent teachers. This is similar to Hattie's (2003) assertion that the two main contributing variables of student achievement are the student (50%) and the teacher (30%). It also shows that William undertakes critical self-reflection of his own strengths and weaknesses, an attribute common in 'good teachers' according to Devine et al. (2013). William's reference to his need and want to challenge himself is a theme that has continued throughout his teaching career. Hattie (2003) asserts that interest or urgency to improve is an attribute held by expert teachers and Altun (2017) agrees that this commitment promotes student achievement.

6.2.1.2 Tertiary education

With William's earlier aspiration of becoming a carpenter gone, after completing his Tertiary Orientation Program (TOP), he decided to pursue nursing, but was not offered a place in the course. It was interesting that William had a strong desire to work with people and make a difference. Instead, he started an engineering degree, but *went to the first lecture and walked*

[19] Technical colleges in the 1970s-1980s provided both vocational and tertiary education, mainly to students from technical schools.

[20] The Tertiary Orientation Program (TOP) was an alternative accreditation for senior secondary school in Victoria from 1972-1986 giving students access to tertiary studies.

out. William explained that he walked out because he knew straight away that he *had no passion for engineering*, as it was all based on theory. He was then offered a place at Rundle Teacher's College (pseudonym) to complete a Bachelor of Education to become a teacher of maths and chemistry. William thought this was a good option, because it aligned with his beliefs about education being important. He also *wanted to help the underdog*. He told me that his goal was to *make education more accessible, more exciting ...to give back to kids who struggle with education* (Ch6_5).

William recalled that he struggled with much of the education degree as it required a lot of reading and writing. One aspect of the course he described as being beneficial was school placements, where PSTs went as a small team to the one school. William explained that these group placements allowed for a lot of team teaching and opportunities to talk about and reflect on learning about teaching.

School placements provide authentic, hands-on opportunities for PSTs to focus on their development (Tillman, 2005). The opportunity to discuss practice and pedagogical issues with their peers exposes the PST to different perspectives and better understanding of teaching and learning. The team environment of William's placement provided a collegial atmosphere where PSTs could learn from each other. The experience also encouraged routines of critical self-reflection, which is still an important part of William's practice today (discussed in chapter 7).

6.2.2 Experiences as a teacher

6.2.2.1 Past experience

William went straight from Rundle Teacher's College to teach at Sandhope College where he has been teaching for thirty-three years. For the first five years of William's employment, in the 1980s, he taught maths and science from years 7 to 11. At this time, Sandhope College was a technical school, similar to the school William had experienced as a student. He recalls the school environment for teachers in those days was one where, *you were accountable to no one. In the techs, no one cared as long as the kids were behaving* (Ch6_6).

In the first few years, William said that to get his students to behave and be on task in their learning, he *needed to keep them engaged*. So, he *took them out to do stuff.* [He] *spent hours building models and setting up fish tanks to show the kids* (Ch6_7). During the initial interview, William said, *my pedagogy and stuff just came; I haven't done any study on it.* In further probing of this comment, William acknowledged that his teacher education at Rundle Teacher's College was good preparation since he learnt how to *access and analyse information quickly* and how to convert this into a form that was accessible to his students, which Shulman would identify as PCK (1987).

A number of points in the narrative above warrant further examination. First, as Sandhope College's student demographic was similar to his own experience as a student, William felt that he belonged at the school, and this increased his commitment and dedication to his work in teaching and preparing for his classes. Skaalvik and Skaalvik (2010) found that a teacher's sense of belonging to a school is positively related to their motivation, or commitment to their work; commitment being an important personal attribute of excellent teachers (Crosswell & Elliott, 2004). Second, the emphasis of the technical school system in the 1980s, was on retaining vocationally geared adolescents in the school system for as long as possible and giving them practical skills to proceed into the workforce rather than further education. Lindsay (1990) reported that individual Victorian schools at this time had autonomy over their curriculum and assessment procedures. This allowed William the flexibility to respond to his students' needs and to focus on teaching, learning and school -based assessment, rather than preparing them for external assessment requirements. Third, William's comments about the development of his pedagogical knowledge indicates that he considers his pedagogy to have come from his teaching experience, rather than from formal study. Morine-Dershimer and Kent's (1999) view of personal and context-specific pedagogical knowledge applies to William's early years of teaching. Context-specific pedagogical knowledge develops and is applied when the teacher reflects on classroom events and makes connections between their general pedagogical knowledge and their personal pedagogical knowledge (Morine-Deshimer & Kent, 1999).William would have acquired personal pedagogical knowledge during his initial teacher education. This was also influenced by 'what worked' for him as a learner and as a teacher. That William did not attribute the development of personal pedagogical knowledge to his initial teacher education in his initial remark, may be an example of what Hattie (2003, p. 8) called, 'automaticity' where his personal pedagogical knowledge is so 'personalized', he believes it is a part of him rather than attributing it to being learned. This is evidence that William meets ASTA Standards 3 and 4, in that he understands the contextual factors that affect his students' learning and designs learning programs to meet his students' needs and interests (ASTA, 2002).

William has taught other subjects besides maths and science. In the early 1990s, the Victorian government closed the technical school system. Sandhope College became a co-educational secondary government school, offering the VCE, and hence many new subjects were introduced to the school. William was asked to teach VCE horticulture and agriculture. Even though he had never formally studied these subjects, he loved gardening, so he agreed. He was happy to share with me that his students achieved *some really good results* in this subject. VCE students finished the school year early in term 4, six to seven weeks earlier than younger students. Not one to sit idle, William approached a couple of local primary schools and offered to teach science during this time. His offer was readily accepted, and he organized five other VCE staff to join him. *We taught every Wednesday for 7 years; 6 staff went in to teach 800 primary kids. It was massive.* Unfortunately, due to funding cuts, the Principal stopped this program. In the past few years and with a new principal in position, William has managed to reinvent his science in primary schools' program. (Discussed in the next chapter). Both teaching VCE horticulture and instigating the primary schools' program are further evidence of William's passion to share science with students and his energy and commitment to seeking opportunities where he can do so. It also shows his belief in the primary school program and his tenacity to start it again when given the opportunity.

6.2.2.2 Science in the middle years

From 1993 to 2002, William was based at the senior campus of Sandhope College, teaching years 11-12 and was still going to local primary schools to teach science during term 4. In 2003, the school Principal asked him to move to the years 7-10 campus so that new year 7 students would have a sense of continuity after having worked with William through the primary school science program. Along with a smoother transition for year 7 students, William said he was keen to move to the 7-10 campus to investigate comments made by students when they arrived at the senior campus that they *hated science* in years 7-10. William was concerned and explained that,

> *If a kid gets to year 10 and says, I don't like science because it's not my train of thought, then that's OK. But they've got to have loved what they did* (Ch6_8).

William told me that he purposefully changed the way science was taught, so the year 7-10 science program included many hands-on and practical learning activities.

For many students, the transition to secondary school can be daunting and having a familiar teacher present could assist students emotionally and academically. The Principal's decision appears logical, as William also had a proven record of engaging and supporting students with their learning in the primary science program. Osborne and Dillon's (2008) report recommends that science education for students before year 9 should focus on student engagement. They found that this is best achieved through, ''hands-on' experimentation and not through a stress on the acquisition of canonical concepts' (Osborne & Dillon, 2008, p. 19). William's previous success with engaging older students through 'hands-on' science learning meant that he could continue this approach with the students in years 7-10 to improve their engagement too.

After two years at the year 7-10 campus, William became the Head of Science; an indication that the senior leaders of the school respected the direction in which he was taking science. William now prefers teaching years 7-10 and *never wants to teach VCE again*. He expressed frustration with the emphasis educators and general society place on the VCE and how it influences what and how students are taught in the younger years. He said,

> *VCE only has one goal, and that's the exam and the ATAR score* (Ch6_9). *I don't care about the VCE. As long as the kids are passionate* (Ch6_10). *We have the highest retention rate into VCE sciences for the last 10 years, and that's been a deliberate thing for me; to make science number one here. We were known as a drama school, but that's no more. I've deliberately done that.*

Nevertheless, William is aware of the pressures on those who teach the VCE stating,

> *people in the community only care about the ATAR score. You can't take risks. You don't have the time to take risks because if it fails, you've just wasted time.*

William's teaching practice in years 7-10 is based on building his students' passion for science. He is aware, however, that this approach could be in conflict with the practice required when teaching VCE where good exam results and high ATAR scores are the goal. William's awareness of the difference in context is also evident in Corrigan and Cooper's (2013) findings. They found that an external factor such as the VCE exam, can affect a teacher's practice, and even be contrary to their beliefs about teaching and learning. However, William did not want to return to teaching VCE, so there is an alignment between his beliefs and practice which gives him a sense of consonance. William's comment also shows his determination to meet the challenge of improving students' experiences of learning science. This aligns with his approach to his own tertiary studies and athletics, (discussed earlier in section 6.2) where he did not want to be beaten by a challenge. William set himself the goal to improve students' attitudes towards learning science and, as the quote above states, is proud of subject retention rates and student feedback, that indicate he has been successful in his goal.

6.2.2.3 Planning to teach

William has designed units of science that meet the students' interests, while also meeting the goals of the Victorian Curriculum. At the school level, William led the science faculty to structure the year 10 program so that all students complete a common general science unit in first semester and then choose up to three science electives in second semester. The elective units include; medical science, 'chemics' (a combination of chemistry and physics), astronomy and marine science. As a demonstration of his commitment and passionate goal to motivate learner engagement, William researched these topics to find strategies that would engage the students and to ensure that his content knowledge was up to date. For example, one reason why marine science was chosen was due to the school's proximity to Port Phillip Bay, which afforded the opportunity for learning activities such as scuba diving and snorkelling to view underwater organisms and for the collection of water samples. Part of the 'chemics' course is for students to enter the Victorian Model Solar Car Challenge. William explained that this competition *provides excellent hands-on problem solving with an engineering slant*. Along with these electives, William has combined his primary schools' program with the science curriculum at year 10. Students who choose not to take a VET subject are able to take a science unit, teaching science to grade 3 students.

The year 10 electives are consistent with the rationale for the *Victorian Curriculum: Science* as it allows students to 'investigat(e) universal mysteries, make predictions and solve problems….make informed decisions about local, national and global issues' and 'nurture their natural curiosity about the world around them' (VCAA, 2017e). Corrigan, Buntting, Jones and Gunstone (2013, pp. 3, 5) would explain that William and his colleagues have designed the year 10 course based on their beliefs about the 'knowledge of worth' for their particular students; interpreting the *Victorian Curriculum: Science* so that students 'appreciate science and its usefulness in their …world'. This structure allows students the opportunity to choose units based on interest and need and thus improve motivation to learn. All four elective units involve students in authentic science experiences.

At an individual class level, William's skills and the breadth of his teaching show that he differentiates learning for students including for those who struggle academically, have different interests in science, or are academically talented. Besides teaching mainstream science, William teaches in the SEAL[21] program. William commented that the SEAL classes involve,

> *very different teaching. They're slightly different kids. You've got to give the students the same opportunities, do the same stuff, but you've got to change what you give them. …they ask questions.*

No matter what the year level though, William tries *to make science exciting, make kids question and …it's very practically based* (Ch6_11).

Hattie (2004) reported that expert teachers plan, adapt and improvise, responding to the students' needs and as the situation arises. William is conscious of catering for students with differing levels of ability and interest in science. William's ability to know his students and to cater for their differences is consistent with the ASTA Standards, specifically Standard 2, in that he, 'understands that knowing his students is foundational for effective teaching and learning', he develops activities that, 'are responsive to the different needs of his students' (ASTA, 2002, p. 13). He also meets ASTA Standard 3 (ASTA, 2002, p. 14) since he 'understands that these needs will be affected by the different learning styles and backgrounds of [his] students'.

The science faculty at Sandhope College offers extra-curricular activities for students, so William started offering year 8 and 9 students a chance to learn robotics, one lunchtime per week. William talked with enthusiasm about how one group of year 8 students (five girls and four boys) won the Victorian and then the National Robotics Competition last year and would be representing Australia at the International Robotics Competition in Denmark later this year. They were the only secondary school from Victoria, competing against teams from eighty different countries. He explained how this success inspired this group of students saying,

[21] SEAL - Select Entry Accelerated Program in Victorian schools which caters for students who have been identified as having exceptional academic ability and are capable of high academic performance.

> *The kids are so passionate; they were just doing everything. They spent countless, frustrating hours designing, building and programming the robot. Our one lunchtime a week, increased to three and we also met after school.*

The team, supported by the school community, raised $45 000 through fundraising so that they could travel to Denmark with William and two parents as chaperones. In a news article on the school website, William wrote, ‘they demonstrated collaboration, respect, integrity, inclusion and innovation’. The article describes the competition in Denmark which has four parts: the programmed robot ‘solves a set of missions’; the team presents a project where they have investigated a real-world problem and designed a possible solution; demonstrate ‘team values’ and be interviewed to ensure their work is completely their own (Sandhope College website).

The robotics program and the associated competition provides evidence of William’s dedication and commitment to his students learning science, not just within their classroom program. The inquiry-based approach promotes perseverance, problem solving, collaboration, creativity, all of which are important skills for the 21st century (STAV, 2008). In re-visiting William after the end of the study, I found out that the success of this one team in the robotics competitions and the yearly success of the year 10 students in the Victorian Model Solar Vehicle Challenge has enthused many students at the college to participate in these programs. The lunchtime robotics program has gained popularity and William told me it catered for around fifty-five students in years 7-10 over three lunchtimes per week. The school’s success in science-based competitions within Victoria, Australia and in international contexts, is a great motivator for students to keep learning. Through reports in the school newsletter and the local media, Sandhope College’s science program has gained a good reputation and students are excited to be a part of it. Sullivan (2011) posits that one of the aims of teachers and curriculum should be to convince students that they can learn, in the hope that they will continue to learn and adapt to challenges when they arise. Furthermore, Tytler et al. (2008) found that activities like competitions and parental support, interest and expectations are all influential in engaging students in science.

To add to William’s reputation as an excellent science teacher, he was awarded a commendation in the Prime Minister’s Prize for Excellence in Science in 2018. These awards recognise all the best scientists and science educators from around Australia. Skallerud (2011) found a positive correlation between a school’s reputation and parent loyalty. William’s award and the public recognition of him being an excellent teacher increases parental loyalty and their expectations of their child's success and enjoyment of science. This also motivates students to approach their science classes in a positive manner.

This section has shown that William is a very experienced teacher of science, with 33 years in the classroom thus far. Although research has shown that many teachers teach as they were taught (Schneider et al., 2013), William has chosen only those strategies that worked for him as a learner and, with thirty-three years of evidence, also work for his students. He learns and has always learnt best through practical, hands-on activities. As he did not learn from the 'chalk and talk' approach used by his science teachers, William does not use this approach. William has initiated projects, such as teaching science in local primary schools and taken risks by teaching outside his field of expertise, such as VCE Agriculture. To do so has shown that he is a self-motivated, life-long learner. William's case thus far demonstrates that his practice correlates with the ASTA Standards (ASTA, 2009) which states that highly accomplished science teachers design contextualised programs and provide students with opportunities to develop their interests. Making learning relatable and authentic for students is important. Past research (Newmann et al., 1996; Tytler et al., 2008) has found that student academic achievement and student attitudes to learning improved when students' work was valued beyond school, such as by parents and the school community. In William's case, this is demonstrated in the robotics and solar vehicle competitions and in using the local marine environment as the basis for scientific inquiry. William's development as a teacher includes years of practical experience and critical self-reflection.

6.3 William's personal attributes

6.3.1 Authenticity

William referred to two aspects of his life which have influenced his approach to his work as a teacher and to life in general: his religious faith and his involvement with athletics which both impact on his teaching. William's family regularly attended church and he continues to be heavily involved with his church through various roles including as a youth leader, church councillor and preacher. William believes that rather than choosing to become a teacher, it was a calling, as he said that,

> *I'm a Christian. I believe in my faith that if I pray and ask for guidance, I'll get it. I believe I was led to [teacher's college].*

Even so, throughout his undergraduate teaching degree, William still had doubts about whether teaching was for him, but again, he prayed for spiritual guidance.

> *I said to God, give me five years in teaching and then put me somewhere else if you don't want me here. I've been waiting 33 years for that. I love it. Once I got into teaching, I knew that's where I wanted to be. I was guided there by my faith. I've loved it ever since* (Ch6_12).

Singapore's National Institute of Education (NIE) Dean of Teacher Education reflects that, 'teaching is a calling, and effective teachers have a unity of purpose in their personal aspirations, beliefs, interests and competencies with a view of impacting future generations'. Liston and Garrison (2004) proposed that those who feel teaching is a calling have a passion and readily commit their time and energy to it and Faull (2008) found passion to be a characteristic of exceptional teachers. Fives and Buehl (2008) found that some teachers believe that teaching is a calling, but their study did not investigate if this meant that these teachers also believed that their ability to teach was innate or a gift from God.

The other part of William's life that has impacted on his approach to teaching is his participation in athletics, since his parents involved him in athletics from a very young age. William explained that this was probably because he was hyperactive and needed an outlet for his energy. He continued with athletics into his twenties and competed in distance running at an Australian national level. William learnt a lot from his athletics including perseverance, competitiveness and drive. William explained that *in distance running you get to a certain point where it hurts, and you push through it.* He equated this attitude to how he persisted through his tertiary studies, which he didn't enjoy, but finished, commenting that,

> *I pushed through it. I like a challenge and I hate losing. To fail something, it hurts* (Ch6_13).

William still uses the pursuit of excellence and competitiveness from his athletics as a model to critique his teaching. He said that,

> *Every lesson is a challenge - a bit like running. I don't like to lose. When I come out of a lesson, I'm very critical of myself. Whether you see it or not, I say, 'that was awesome' or 'that was terrible. What went wrong?' And I analyse it* (Ch6_14).

In another interview, William raised the connection between his running and teaching commenting that, in competitive running,

> *I wouldn't win but do the best I could. The next challenge was to run a PB [personal best]. ...It's a bit of integrity - what you give is all of you. Same as in teaching - I give my best* (Ch6_15).

Research has shown that setting high but reachable goals motivates performance and encourages excellence due to increased persistence and effort (Locke & Latham, 1985). By setting the personal goal of ensuring that his students succeed, combined with William's intrinsic 'calling' to help his students succeed, has a positive, flow-on effect on his students' own expectations of their learning. ASTA Standard 5 (ASTA, 2009) states that when the teacher and students have the ability and resolve to succeed, then the learning environment is positive and purposeful.

A point of difference between Lindy and William is that he had no personal experience of working in any science-related industry. Besides teaching at Sandhope College, William has been a brick labourer and volunteered as a coach for the local hockey team. It might be considered that his lack of practical scientific experience in a scientific field, could impact on his science content knowledge and the applications of science in the real world. However, the interviews provided evidence that William is aware of and attuned to science knowledge in everything he encounters. For example, he is an avid reader of the newspaper and regularly finds articles relevant to topics he teaches. William loves to use contemporary issues in science in his lessons; relating current events and discoveries to the science he is teaching his students. This addresses a concern raised by Rennie et al. (2001) about school science not being relevant or engaging for students. William's use of science in the media aligns with the aim of the Australian science curriculum (ACARA, 2012a) for students to understand applications of science in their everyday lives.

Another example where William learned about science from his life experience, was when he experienced a heart attack four years prior to my study. William said it changed his life in ways he would not have considered. His short-term memory has been affected and he has difficulty remembering students' names. He shares his first-hand experience of the event with students by explaining the biology of the heart and body. He also captures students' interest when he recalls that the paramedic who attended him was a past pupil; the pride felt by William when one of his students went into a scientific or medical field and, then came to help him was immense. He also told me that the foreman in charge of building the new science facility was a past student whom he taught in 1998. William proudly told me,

> *I taught him horticulture/agriculture. He's now got kids and he told me he loves working in the garden with them. 'You taught me so much', he said. That's the passion. You want to give them that passion* (Ch6_16).

These sorts of connections make science real and relevant to students. Sharing his own life experiences and his pride in past pupils, along with his longevity at the school creates a sense of community and belonging for his current students. Faull (2008) reported a similar result in her research on exceptional teachers that is consistent with ASTA Standard 5 (ASTA, 2002) which states the importance of a sense of community for students to feel supported and safe.

6.3.2 Passion

William loves being in the classroom and teaching. William's father was a school principal and his brother has also become a school principal. He has been asked why he is not a principal, but William explains that he has never been interested. He said, *I'd be dead in a year. I love what I'm doing* (Ch6_17). He added that *there is always a direction*, meaning that he always sets goals; again, an attribute he learnt from his experience in athletics. This was reinforced in William's comment that,

> *When I was a first year out teacher, I remember a teacher who was about the same age as I am now and thinking, 'I can't wait to be where you are, just walking into a classroom'. But every class I teach, I have to prepare and plan for. It's hard work. It's good work. Challenging. Won't be beaten on it* (Ch6_18).

William shared that preparing a new unit of work can sometimes take 200 hours of reading and research to ensure that he understands the concepts and can choose appropriate learning experiences for his students. *I love inventing new things and new ways of teaching*, he said. William believes he is practical and if he were a principal, he would not be as successful or as content with his work.

William's longevity in the classroom is indicative of his preference for working with students. He perceives himself as being *practical, not academic*. However, one definition of academic is being 'interested in or excelling at scholarly pursuits and activities' (Oxford English Dictionary, 2018). Considering how much reading and research William does to ensure he excels in preparing to teach a topic, it could be concluded that he is indeed 'academic'. Furthermore, Hattie's (2003) view is that in teaching, it is not the amount of [content knowledge] held, rather it is the extent to which new knowledge is integrated into the existing body of knowledge that makes a difference to teaching practice. William consistently upgrades his knowledge of the topics he teaches. Arzi and White's (2007) findings indicate that teachers like William are always adding to their content knowledge, and they have the experience and knowledge of teaching science which allows them to quickly identify and deal with students' alternative conceptions. William's practice is guided by his personal pedagogical knowledge which is influenced by a combination of his past experiences, beliefs and his context specific knowledge.

William is passionate about science and teaching science. This is evident in previous quotes: Ch6_10, Ch6_12, Ch6_15, Ch6_16 and Ch6_17. Furthermore, as mentioned in section 6.2.1, William has attributes common with having Attention Deficit Disorder (ADHD): high energy, and difficulty maintaining focus. William explained that he finds,

> *it's great to have it [ADHD]as an adult as people think you've got a lot of energy. ...and they call me the mad scientist, but I'm not really, I'm just ADHD. ...the kids don't see me with ADHD. They see me as passionate. Passion promotes passion and the kids will take it on* (Ch6_19).

When a teacher's passion for teaching and the subject is obvious to students, a positive rapport and relationship between teacher and student is developed (Buskist, 2004; Keeley et al., 2016). The TALIS report states that a positive teacher-student relationship promotes student commitment to learning (OECD, 2010). Finally, in the ASTA Standard's vision statement, (ASTA, 2002, p. 9) a highly accomplished science teacher is one who combines, 'knowledge and expertise' and 'brighten this with their passion'. William's belief about passion in teaching is discussed further in section 6.4.1.

6.3.3 Commitment and drive

One consequence of William's pursuit of keeping active and mentally stimulated as a science educator has been his initiative to start the local primary schools' science program, which has been running for many years. It has meant that William has a strong reputation amongst parents and students in the local community, as a teacher who is committed to science education.

Quote Ch6_7 demonstrates how William has always spent time beyond the school day to make resources to enhance his students' interest in science. He laughed when he told me,

> *I can be driving and see something on the side of the road, and I'll stop and grab it because I know I can use it for school. ...I love inventing things and new ways of teaching* (Ch6_20).

As Head of Science for years 7-10, William says he has *had the chance to influence* the approach to teaching science. For example, whilst he was involved in the redesign of the science laboratories, William ensured that there was no teacher's desk or chair in any of the rooms, saying, *I hate it when they sit. Teachers should stand up and move around a lot* (Ch6_21). When the VCE teachers at the other campus complained that the students coming into year 11 did not have a particular skill, William said, *you are teachers too, you teach it to them.* Although he sounds critical of these teachers, he has listened to them. For example, part of the new VCE requires students to be able to design an experiment. *So that's what we're introducing this year in years 7-10. So, when they get to year 11, they know how to do it.*

William believes that his approach to teaching works and said, *the feedback has been good* from his students, their parents and from the school leadership. Over the years, William has encouraged the school to employ new graduate teachers. He believes that by mentoring and supporting them in their early career, they have continued to teach at the school for several years and have contributed to the science program. William told me *it's been an opportunity to share and to 'give back'. ...I think what I've learnt should be shared* (Ch6_22). As Head of Science he also represents his teachers at the school's domain leaders' meetings. For example, the science faculty's latest concern is the need for more contact time with students so that they can include more of the official curriculum. So, William has been advocating for change to the timetable. William admits that he has been fortunate to have the support of the school leadership. *I get away with a lot*, he said. Besides a few years where the primary schools' program did not run because of funding cuts, no principal has rejected any of his ideas. He says this is *because I think they value what I do. And they cringe. ...As a principal, you know who is good, and who is slack. .... I work my butt off and it's for the kids* (Ch6_23). William is aware that his long association with the school is an advantage as the school community, teachers, parents and students recognize the energy and passion he has for teaching the students science.

William’s behaviour is consistent with ASTA Standard 11 (ASTA, 2002, p. 25) as he, ‘supports the professional growth of colleagues’ and always working for improvement in students' science education’. William’s commitment to his job has its effects within his classroom, the science faculty, and in the local primary schools, both on teachers and students. Crosswell and Elliott (2004) identified the link between a teacher’s commitment and their passion for teaching and their students and this is certainly evident in William’s case. Furthermore, Altun (2017, p. 51) argues that teacher commitment, ‘inspires teachers to seek ways to enhance teaching profession and establish an effective learning environment to allow students to reach their targets’.

6.3.4 Challenges

Unfortunately, along with the drive and internal competitiveness to do his best, William admitted that he finds it difficult to *switch off* from school, intellectually and emotionally. *I haven’t shut down for 33 years. I love it. That’s just me. It can be obsessive.* William knows that he must deliberately plan holidays to break this obsession, such as going camping with his family to places where there is no internet connection or by building resources (for school). However, this requires, *a lot of deep thinking and problem solving*, evidence of his passionate commitment to be an excellent science teacher.

To try to create some work-life balance, William has become more involved with his faith and is *currently reading several books of Christian faith*, that *are not related to school or science.* Dinham (1997) found that many teachers’ personal lives were impacted upon by the their commitment to their profession. According to Hutton, (2015) having a work life balance is not only important for a person’s physical and mental health, but also improves work efficiency.

Throughout the time I spent with William, I found him to be genuine, curious and eager to be involved with my research. William creates a warm community and is respected by his students and within his school and the wider community as an excellent teacher. Primary students and parents look forward to having him as a teacher in the future, as he has made science fun and accessible for them already.

6.4 Beliefs

6.4.1 Beliefs about teaching, learning and students

6.4.1.1 Excellence and purpose

William initially found it interesting that he had been identified as an excellent science teacher to participate in my research study and asked questions about excellence that reflect views in the literature review that excellence involves many different factors and cannot be easily defined (Marshall, 2008; Tobin & Fraser, 1990). William thinks that an excellent science teacher: *has passion; loves the education process; loves imparting knowledge and sharing skills; is engaging; has a high regard for students; has a good relationship with students; is inventive, imaginative in their teaching; is always trying to improve* (Ch6_25).

This list is comparable to personal attributes discussed in research indicates about excellent teachers (Faull, 2008; Hattie, 2004; Walker, 2008). Interestingly, William's list does not include the professional knowledge of a teacher, involving knowledge of content, teaching and learning and students, which is the basis of professional teacher standards (AITSL, 2011; ASTA, 2009). However, whilst William sees personal attributes as important, he also believes that professional knowledge of a teacher is important (see Ch6_26nr and Ch6_27nr).

6.4.1.2 Preparation and developing engaging practice

The acronym William has devised for his PSTs about teaching indicates that he does believe professional knowledge to be important. The acronym is 'A PEN IS GREATED'. The letters represent the following:

- A – to be an A-grade teacher requires…
- P – preparation, preparation, preparation and then, more preparation
- E – ensure entry into the classroom is orderly and welcoming
- N – names, know the students' names
- I – ICT, use these tools appropriately
- S – start by summarizing the last lesson
- G – share the goals for the day
- R – remember, recount, revise to make sure students are up to date
- E – give real life examples and excite the students about the new topic
- A – assess the students' understanding

- T – make sure there is time for students to work on the task
- E – evaluate the students' learning
- D – dismiss the class.

This acronym reveals a lot about what William believes is important in teaching. First, it includes the same elements as PCK: knowing the content and how to teach it, knowing the curriculum goals and being able to plan lessons, communicating effectively, managing the class so that students can achieve the desired outcomes (Bransford et al., 2000; Shulman, 1987). Second, the emphasis on preparation in his acronym cannot be underestimated. It shows that William has a strong belief in teachers having professional knowledge – of the content and how to teach it. This is consistent with Hattie's (2004) findings that expert teachers organize and use content knowledge. It is also consistent with the first three ASTA Standards (ASTA, 2002): Standard one regarding knowledge of content; Standard two regarding his knowledge of teaching and learning; Standard three regarding his ability to design effective learning plans.

Some of William's beliefs have developed and been reinforced during his teaching career. As a beginning teacher, William believed that learning should involve hands-on activities as they engage students in their learning (see Ch6_7). This belief has its foundations in his own secondary education where he too had experienced success with those subjects that allowed him to learn-by-doing (see Ch6_2). William experienced positive consequences through his students' achievements and behaviour which promoted his belief of this teaching strategy during his early career. Similarly, Le Cornu (2013) found that positive relationships between teachers and students during a teacher's early career are very important for both students and teachers.

William recalls his first year of teaching when he worked with a colleague who had thirty years of teaching experience. He remembers thinking that he couldn't wait to be there and to just walk into a classroom without preparing. William laughs at this now (see Ch6_18). This again supports his emphasis on preparation, preparation, preparation. William continues to believe that this is what works and so spends a lot of time preparing for each lesson.

6.4.1.3 Relationships

William's beliefs about excellent teachers also have their foundations in his experiences as a student in secondary school. His memories of his school teachers are mixed. He described his year 11 physics teacher, chemistry teacher and one of his year 11 maths teachers as *hopeless*. To elaborate, he recalled a conversation with his chemistry teacher,

> *William: Why is one person's hair black and another person's hair blonde?*
>
> *Chemistry teacher: You do that in biology, but you didn't choose that so bad luck.*

In addition, William's description of his 'hopeless' maths teacher was that,

> *He threw chairs at me and everything. He couldn't teach. He didn't know his stuff. I just had no respect for him* (Ch6_26).

William's frustration was due to his perception that his chemistry teacher lacked interest in sharing his knowledge and his maths teacher lacked the ability to teach and had no respect for his students. These teachers are at odds with ASTA Standard 7 (ASTA, 2002) which states that teachers should make use of unplanned learning opportunities and ASTA Standard 2 and 5 (ASTA, 2002) that teachers should build positive environments for learning and are warm, supportive, secure and safe.

William could not recall a teacher who he would classify as excellent, but he respected one of his year 11 maths teachers, Mr Jones (pseudonym), describing him as a,

> *brilliant teacher. Knew his stuff. Very easy to understand. It was the highest maths you could do in the technical [school] system. I breezed through it. He was a good teacher. Very dedicated. Very caring; wanted to know that you were doing well* (Ch6_27).

This quote supports William's belief that a student's success is due to the teacher and student working together; a team effort. Furthermore, even though his recollections are of his maths teachers, they illustrate how William's beliefs are aligned with three of the ASTA Standards (ASTA, 2002) for excellent science teachers. First, ASTA Standard 1 states that teachers should have good, broad content knowledge. Second, ASTA Standard 5 states that the learning environment should be emotionally and physically safe for the students, where there is mutual respect between the teacher and students. Third, ASTA Standard 2 states the importance of effective classroom management and of communication in making the content comprehensible for students.

William has positive memories of his year 10 home room teacher, Mr Harrow (pseudonym). He describes him as, *a great person. He was an ex-priest. I could relate to that because I went to church. ...He mucked around, he was pastoral, he just spoke to you as an adult*. Similar to Mr Harrow, William has knowledge and understanding of his students. He explained how he weighs up the importance of the subject content compared to the realities of a student's life on a particular day. He said,

> *I remember trying to teach Pythagoras, but the kid didn't have anything in his stomach. Kids are funny animals. You can't teach a kid if you don't know them. You can't teach anyone without knowing them. Some do, but it's the relationship that is important* (Ch6_28).

William knew that this child did not have breakfast before school, so could not concentrate. These reflections indicate that William believes in the importance of the relationships between teachers and students. He believes teachers should be caring, approachable, have a positive rapport with their students and respect and encourage their students' curiosity. Walker's study (2008) found effective teachers 'dealt with students' problems compassionately [and] cultivated a sense of belonging in the classroom' (p. 64). William also learnt firsthand that hands-on activities are an important pedagogical approach for the learning of many students. He believes that there should be a lot of interaction between the teacher and the student in the classroom. This is shown in quote Ch6_21. ASTA Standards 3 and 4 (ASTA, 2002, p. 16) state that teachers should be, 'responsive to the different needs of their students' and have 'different learning styles'.

6.4.1.4 Assessment

William has strong beliefs about the importance of the use and role of assessment in teaching and learning. He believes that regular assessment of students' understanding is very important for both the teacher and learner to know if learning is occurring. William believes in regular formative feedback using a range of methods so students can demonstrate their understanding. He said,

> *There are many types of assessment – practical reports, hands on activities, mini assignments, discussions, oral testing where you just talk with the students. ...There's subjective proof as well.* (Ch6_29).

William expressed concern about the effect of summative tests and exams on the students' belief in themselves as learners, when feedback is only in the form of a mark. The origins of this belief might be from when he was a secondary student. As discussed in section 6.2.1.1, William struggled with written tests and exams, but this did not translate into an unsuccessful life beyond school for him. As he said,

> *I hate exams. I hate tests…. assessment can be dangerous. If a kid gets ten out of one hundred it can be very damaging, sending a message to the kid that he is useless at science and can make a kid hate science. …Are exams necessary? Only as training for VCE. ...I give written tests very rarely, until the kids get older. I'll rarely test the year seven students. ...I'm not saying I'm against tests, but it's just one form of assessing what a kid knows* (Ch6_30).

William is cautious about using assessments with students as he is concerned that their self-concept as a learner should not be damaged. However, rather than the type of assessment, it is more likely the type of feedback students receive that he is concerned about. A percentage score or a number alone does not give a student constructive feedback for pedagogical purposes. Barnes, Fives and Dacey (2015) report that most research has found that the majority of teachers are of the same belief as William; assessment should be for informing teaching and guiding learning rather than for accountability purposes. William explained that he did not like teaching to the test and he would rather build students' passion for science and learning and develop their intrinsic motivations to learn. In his position as Head of Science for years 7-10, William has been able to minimize the emphasis on tests and exams. His practice is more aligned with his beliefs that he can monitor student achievement by using other assessments such as outlined in quote Ch6_29.

6.4.1.5 Conclusion about William's beliefs about teaching and learning

A reasonable way to summarise this section about William's beliefs about pedagogy is by using some quotes William made during the case study,

> *Teaching is fun. Science is fun. It should be exciting, vibrant, involve thinking.*
>
> *It's all about the relationship with kids.*
>
> *In reality, it comes back to my faith 'you treat each other as you'd want to be treated yourself.' To be fair with the kids. ...I just love teaching.*

Teaching is about people. And about communication. If you can't communicate with kids, you shouldn't be teaching.

(Ch6_31).

What is prominent in these quotes is his passion and commitment for teaching, learning and for his students. Wilson and Mant (2011b) investigated teachers' beliefs about what makes exemplary science teachers. Their findings show many parallels to William's beliefs in that they believed exemplary teachers are:

- interested in their pupils as people and value them
- enthusiastic about science and communicate this to their students
- place significant emphasis on planning of lessons
- make the learning relevant to students lives

(Wilson & Mant, 2011b, pp. 116–118)

William's quote Ch6_31 combined with quote Ch6_12nr reinforces his Christian beliefs and how much energy he puts into maintaining positive relationships with his students, which he believes helps motivate students in their learning.

6.4.2 Beliefs about science

William believes that science is a unique and *amazing* subject for students to learn. He said,

Science will always be there. Look at the newspapers and what the government is saying. History has happened. You can study it, but you can't change it. In English you can talk about it or read about it. …in science you can actually do it. You can experience it and you can start to ask the questions why. It's just a different level of thought (Ch6_32).

This belief contrasts with how William viewed science when he was a secondary student. Section 6.2.1.1 showed that his view of science was then narrow and defined by the subject boundaries. Quotes Ch6_1nr and Ch6_2 show that William did not make connections between subjects; aspects of science would have been learnt in subjects such as metal work, but as they were not labelled as such, he did not see the connections. But now (Ch6_24) William believes science is everywhere and the purpose of learning science is to, *experience, appreciate and have awe* (Ch6_33). Whilst he wants this for his students, these are actually elements he practices in his own life saying, *you go out and have a look at a tree and* [pause], *just the amazement of what a tree is and all the things that it has.* These quotes are evidence of the passion he has for science; one of the affective characteristics research has identified with excellent teachers (Faull, 2008).

William believes that the purpose of teaching science is not just to transfer knowledge to students since learning science involves, *applying and challenging your knowledge … it gets the kids to think* (Ch6_34). He believes that although it might be easier and quicker to say, *this is how they [scientists] know it. This is what they did. Accept it,* it is better for students to learn by inquiry and to, *use discovery as this is what excites them*. He believes that science should, *make kids question*. William enjoys having the *license* to explore a science topic; to cultivate the students' curiosity by encouraging and teaching them how to find out information for themselves. William said, *it's giving them the ability to ask the question and to possibly research the question* (Ch6_35). When a student asks a question, he says to them, *'you've got your iPad, use it'*. William said that,

> *it would be great if your goal was to say to students, 'I'm going to tell you something you've never known before. You're going to come out with* knowledge you've never heard *of or seen before.' Wouldn't that be amazing?* (Ch6_36). ...*That's what teaching is about.*

William's beliefs about the purpose of teaching science are in accordance with the rationale of the *Australian Curriculum: Science*, where the emphasis is on scientific literacy and 'helping [students] to be interested in and understand the world around them' (Rennie et al., 2001, p. 466). It is also consistent with ASTA Standards 6 and 7 (ASTA, 2002) as he engages students in inquiry learning and encourages students to extend their own understandings of science.

Despite this, William acknowledges that this is contrary to what other educators might believe. He remarked that some members of the school community believe that preparing students for success in the VCE is the purpose of years 7-10. William counters this argument by arguing that if students do not enjoy or see the relevance of science during the compulsory years, they will not choose to study sciences in the VCE. William acknowledges the balance that is required and said that although, *there has to be some structure because there is a stepping up toward VCE, ...I hate a structured curriculum, ...because it is better to focus on what's happening in the classroom* (Ch6_37).William likes the flexibility of the Australian Science Curriculum to take advantage of what Berliner (2001, p. 145) calls ' teachable moments' for his students.

In line with how he learns best and his beliefs about science education, William has built the science course to be practically based. *We do thousands of experiments here [with] 25 classes from years 7-10. The kids love pracs, but you've got to get them thinking* (Ch6_38). This is consistent with Millar's (2010) contention that for practical work to be worthwhile, it needs to not just be fun and a change from book work, but it needs to also engage students' minds, and the development of skills and knowledge.

6.5 Conclusion

This chapter has discussed factors involved in the development of William's professional knowledge, personal attributes and beliefs about teaching and learning science. After thirty-three years of experience in the science classroom and in the same school, William has gained an excellent understanding of the general student population and of the contextual factors in the community. He is constantly seeking out new knowledge about science and teaching science, with the aim of improving the learning experiences of his students. This aligns with professional knowledge emphases identified by Shulman (1987), who says that teachers are constantly reflecting on their pedagogy and developing new understandings to improve their knowledge, and the ASTA Standards (ASTA, 2002) that state the importance of continuous learning for professional growth. William's affective attributes are consistent with those identified by Keeley et al. (2006) as corresponding to teachers of high quality. William articulated beliefs about the purpose of teaching and learning science and about how students learn best.

A final comment that William made provided an insight into his educational philosophy. He said that the students are,

> *what we're there for. Not only to teach them, but to get them to value knowledge. It's to make knowledge exciting. Teachers have the power. I can destroy a kid within thirty seconds, and I could make his life miserable. But to build him up, that can take a lifetime. If a kid can leave here, confident in himself and accepted by others, you've achieved what you need to achieve. ...I've seen kids who've come from this school who are great people in society now. Were they going to be great people anyway? Who knows? But we (teachers) have a great influence* (Ch6_39).

These comments sum up William's passion for teaching and learning and valuing of his role in students' lives beyond the teaching of science. He is cognizant of his responsibilities to his students and how their time in his classroom can affect them as people, now and into the future.

The conclusions established about William in this chapter are that he has a strong personal drive to guide students to succeed in their learning and a passion for sharing his love of science with his students. He also believes that hands-on activities are the best way for students to experience and learn about science. Finally, it can be concluded that William believes that learning is a process without an end point; all students can learn and learning is ongoing. That he is still learning and improving even after thirty-three years of teaching, is just one of the many reasons why he is an excellent teacher.

Chapter 7

Factors involved in an excellent science teacher's professional practice - William

7.1 Introduction

In this chapter, I identify and analyse William's current professional practice, particularly in his teaching of a year 10 science class. I begin by discussing his knowledge and beliefs about the curriculum and their relationship to his practice. I then discuss William's teaching and learning practices, reflective practice, and his relationship with students in the classroom. William's collaborations with colleagues in the school and with other professional communities are then discussed in relation to how this relates to his professional knowledge, beliefs and practice as a science teacher. The data analysed is again drawn from semi-structured interviews, classroom observations and documentation collected from William and his students. The *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and the *Framework for examining beliefs* (Fives & Buehl, 2008) continue to inform my analysis of excellence.

7.2 Analysis of William's teaching and learning practice

7.2.1 Current context

7.2.1.1 The school

Sandhope College [pseudonym] where William teaches had approximately 1000 students at the time of the study in years 7-12; with 58% in the middle bands of the ICSEA scale and 25% in the bottom band. This is average for Australian schools (ACARA, 2017). Eighteen percent of students come from families where English is not the first language spoken (ACARA, 2017). Years 7-10 are located on a separate campus to years 11 and 12. William is based at the year 7-10 campus and is the Head of Science for years 7-10. The median VCE study score in 2016 was 28, which is just below the state median of 30. The school offers senior students either the VCE or VCAL pathway, which includes ten VET options. Victorian schools who offer VCAL and VET pathways often do so to cater for students who prefer hands-on or more applied learning and do not plan to continue to university education. Students can also combine VCAL and VET courses with VCE subjects to keep their options open for further study. In 2016, approximately 35% of Sandhope College students went on to university and about 50% went directly to employment or continued with vocational training. The school follows the Victorian Curriculum in years 7-10, with a separate stream for students with 'high intellectual potential' (Sandhope College website) receiving enrichment. Selection into this stream is through an exam and observed 'exceptional abilities across their studies' (Sandhope College website). For science, this means that these students study the same curriculum as the mainstream but with greater depth and breadth of the topics. William teaches science in both the mainstream and the selective stream.

William's long-held belief in a hands-on approach to learning (see section 6.4.1.1) aligns with his current contextual reality of a high proportion of Sandhope College students choosing VET courses. His beliefs are aligned with his students' learning needs and have been reinforced throughout his 33 years at Sandhope College. Being aware of and responding to students' needs has been identified as a quality of effective science teachers (Fitzgerald et al., 2013). Furthermore, research has found there are advantages for individuals and society if students stay in education to the end of year 12 as the transition to work is smoother and they have more options for post-secondary education (Lamb, 2011).

7.2.1.2 The science building

The science faculty occupies a recently renovated building, named the Science Academy, chosen by William to indicate the building was a place of learning. As the Head of Science, William was one of three staff members involved in designing the layout of the building; its spaces, facilities and features. On entering the building, there is an open, natural light-filled foyer. On one set of shelves are cut out wooden letters spelling inspirational words such as 'ACHIEVE' or 'REACH' (see Figure 1). William changes these words every two weeks or so. He loves hearing students' responses when they notice a new word is on display. The foyer is also filled with a range of three-dimensional science models which include a life-sized papier-mâché shark's head and a model of a single engine plane hanging from the high ceiling (see Figure 2). Some of the models have been sourced or made by William during his holidays (see Ch6_20). There are glass cabinets with jars of biological specimens and shelves with science books and students' work. On the walls of the science foyer there are colourful posters of animals, certificates awarded to students for achievements in science competitions and photos of students who have won science awards. William proudly pointed out the most recent award and accompanying photo of a group of year 8 students who won the National Robotics

Competition and would be representing Australia in Denmark later in the year as year 9 students (see section 6.2.2.3).

Figure 1 Inspiring sign in the foyer of the science building sends a message to students

Figure 2 Papier-mâché models and life-sized diver in the science building foyer

These models and pictures are all visual reminders to everyone, especially to students, entering the building that science is everywhere in real life. Every direction you look is an example of where science is found and how students can succeed in science. It is a display of William's beliefs about science, as expressed in quotes Ch6_23 and Ch6_24nr. Adoniou (2017) argues that displays can send a message about what is valued. In this case, the celebration of effort, positive attitudes to learning and examples of science in the real world, promote engagement and learning in science (Cheryan et al., 2014). That William created many of the models himself shows that William has a strong personal commitment to maximizing the impact of the learning environment in the science building. He believes that the learning environment must demonstrate to students that science is everywhere and stimulate their interest. Crosswell and Elliott's research (2004) showed the positive relationship between a teacher's commitment and passion for teaching and student achievement and attitude towards school. The display of certificates and awards shows that William is obviously proud of his students' achievement and is excited about how this will promote science amongst those students and the student body, now and in the future. Tytler et al. (2008) reported that student involvement in science-based extracurricular activities has been shown to influence students choosing to pursue science beyond the compulsory years.

There were three science laboratories – one with an open plan design with only a waist-high bookcase separating it from the foyer and two that could be seen through floor to ceiling glass doors and windows. There is a small meeting room attached to the foyer, which has been called the 'Think Tank'. This room can seat about ten people and can be used by staff and students as a breakout room to collaborate on small projects. The science faculty staff room opens from the foyer. Students readily came to the door to speak with teachers during recess and lunch breaks. I observed some teachers in the foyer assisting individual students during break times and before and after school. The glass windows and doors create a sense of shared space throughout the area. William told me this was a deliberate design of the building explaining that is provides,

> *deprivatisation - no narrow corridor between classrooms. Three big lab benches in each lab. ...The students have got to see it, feel it, breathe it* (Ch7_2).

The open physical plan of the science faculty building reduces teacher isolation and creates a sense of community – both of which, according to Hord (Hord, 1997) promotes on-going collaboration and professional learning for the teachers. That students feel welcome in this environment exposes them to opportunities to discuss both science and learning outside their timetabled classrooms. As a result, students, teachers and visitors have a sense of belonging to the science faculty community, which research suggests is important in promoting learning (Kearny et al., 2007; Paige & Lloyd, 2012; Walker, 2008).

7.2.2 Planning and teaching

The sequence of lessons I observed were part of a unit of work on genetics. The focus was for students to:

- understand that, 'the transmission of heritable characteristics from one generation to the next involves DNA and genes (VCSSU119)'
- 'communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations (VCSIS140)'

(VCAA, 2017e)

Students were learning how to use punnet squares to understand and solve problems involving genotypes and phenotypes. The year 10 class consisted of 16 boys and 10 girls with diverse interests and academic strengths.

7.2.2.1 Prior to the lesson

It was evident that William pays close attention to planning and setting up a positive learning environment before teaching. He had moved the class from his usual laboratory so that another teacher could use it. Whilst he moved the furniture, he stood back occasionally, explaining that he was *playing out the lesson* in his mind. Some tables were arranged in groups of four, others were in a long line, others were on their own. William then explained what he had planned for the lesson. Students would be introduced to using punnet squares, following on from the last lesson where they had discussed alleles and fertilisation. He expressed some concern that some students might be uneasy as it involved some mathematics, but from past experience, he thought they would be able to *rise to the occasion*.

William's mental plan of the lesson, including the physical layout of the room, was consistent with Borko and Livingston's (1989) findings about expert teachers, who allow for more flexibility to respond to the diversity of students' needs during the lesson. ASTA Standard 5 (2002, p. 17) asserts that, 'accomplished teachers of science create and maintain intellectually challenging, emotionally supportive and physically safe learning environments'. William's arrangement of the seating showed that he had a plan for where students would learn best; considering students being able to collaborate and focus on the task whilst feeling supported by those sitting near them. This planning also reflects ASTA Standard 3 (2002, p. 14) showing he knows how the ‘social dynamics of groups of friends and of the class as a whole operate and how to use these to shape effectively the mood and functioning of a class’.

William had four worksheets of different colours: white was the introduction to terms then green, yellow and red with increasingly difficult problems respectively. The colours represented traffic lights and would allow him to see across the room and quickly gauge what level the students were working on. The problems on the red worksheet were *challenging*, but William thought there would be about six students who would *rise to the red*. He anticipated that most students would have started the yellow worksheet by the end of the lesson. The sheets were separate, and students would only receive the next sheet, once they had completed a level. William found these worksheets on the internet and has been using them for several years. They were based on the cartoon character, SpongeBob SquarePants, ‘Bikini Genetics’. He then showed me a stuffed cushion-sized, soft toy of SpongeBob which he uses in the lesson to help motivate students.

Having the SpongeBob cushion in the classroom conveys to students, and reflects William’s belief, that learning should be fun. Walker (2008) and Keeley et al. (2006) both list a sense of humour as an important teacher quality. The TIMSS survey also sees bringing interesting materials to class as a good practice, as it reinforces learning (TIMSS & PIRLS International Study Center, 2012). By using the different worksheets, William showed awareness of the academic needs of the students, and his capacity to provide pathways where they could all achieve success by the end of the lesson. Similar to Lindy, William did not have a written plan for the lesson, but he clearly described his learning intentions. William’s mental plan for how the lesson would progress showed he could anticipate his students’ performance and respond accordingly. Hattie (2003) identified this anticipation as a skill of expert teachers. Shulman (1986) also identified the view that expert teachers build flexibility into their planning of lessons to respond to individual students’ needs in practice, whilst still considering the concepts and purpose of the lesson.

7.2.2.1 During the lesson

William was organised and started teaching as soon as students were settled in their seats. The lessons were 90 minutes. Within the first ten minutes, William had clearly communicated the learning intentions, the task to be completed and his belief that students would succeed. In the first lesson, the first sheet he gave students (on white paper) was a list of vocabulary for the unit of genetics.

> *Remember about a month ago I said vocabulary is important? After today we have one more concept to learn and that's it. Today you'll be using five of these words in solving problems* (Ch7_3)

In this lesson, William then explained the progression of the three coloured sheets to the students.

> *I'm going to challenge you with something today. They're traffic lights. The 'red' sheet is a bonus. I believe that at least half of you will get up to this one. I'll work through the first sheet with you. The first ten minutes is crucial. If you get this, you'll be cruising. ...There's a little bit of mathematical thinking today, but I think you'll rise to the occasion* (Ch7_4).

Another clear instruction he gave was,

> *This is a key thing for your genetics [unit]. Please ask as many questions as possible, make sure you're talking to the person next to you* (Ch7_5).

The next 10 minutes of the lesson was spent working through the first couple of problems on the worksheet as a class. William used the whiteboard and asked questions for students to voluntarily answer. He inserted real life examples to help explain the terminology such as, *your mum is one metre tall, your dad is 2 metres tall, what height are you? ...you meet your friend's mum and notice that they look similar ...my wife has got quite large eyes* (Ch7_6). If a student was not paying attention, William did not pause or deviate from teaching, he just addressed his next sentence to that student by name such as, *so Jamie this one will be heterozygous*. This was enough for Jamie to refocus his attention to listen. Once he felt students were starting to understand, William ran the discussion of working through the next example by directing questions to particular students, involving all areas of the room. By this stage, students were asking questions about real life examples of inheritance related to the theory. William responded to them all, even if it was briefly. Students told me that they always feel challenged in science saying, *if you need to be extended, he'll give you harder things to do ...he knows your limits* (Ch7_7). The students were unanimous in describing the clarity of William's explanations and his knowledge of science.

This lesson extract demonstrates some of William's qualities that are consistent with Keeley et al. (2006): he communicates effectively by speaking clearly using precise English and using examples; he encourages and cares for his students; he sets clear goals for students; promotes class discussion; respectful of his students as learners. William also believes in relating science concepts to students' every day, as real-life examples maintains his students' interest in learning. This aligns with the *Australian Curriculum: Science,* which is not just aimed at preparing students for 'science-related careers' but also giving future citizens the skills and knowledge to fully participate in society (ACARA, 2012a).

William provides a list of the vocabulary and terminology for students which is consistent with ASTA Standard 1 (ASTA, 2002) as a common language of science gives students access to new ideas. Goodrum Hackling and Rennie (2001) emphasise the importance of students being proficient with using scientific language to understand scientific concepts. William emphasises the use of this vocabulary when he speaks to students, by saying key words slowly and/or by adding the definition (see Ch7_3). William's attention to the language of science is also indicative of his pedagogical content knowledge (PCK) (Shulman, 1986), as he enacts his knowledge of the literacy needs of his students and combines this with knowledge of the curriculum and knowledge of how to teach these students.

William conveys to students his belief that learning can be a challenge, showing respect for his students' abilities, whilst also sending the message that he believes they will be able to complete the set task. Marsh and Craven's research (2006) shows that positive self-concept is highly correlated to high academic achievement. Setting the red sheet as a bonus indicates to students that they should be proud of reaching that level. Altun (2017) reports that committed teachers show that they care about their students' development and this promotes student achievement. William uses positive language to motivate his students (see Ch7_4). Furthermore, Johnson (2009, p. 298) argues that, 'students who believe that the teacher cares about them and is interested in their success will try harder'. Coe et al.'s (2014) quality teaching framework describes the importance of a classroom environment which affirms the importance of students' self-worth, whilst always setting high expectations of students to achieve more; showing a belief in a growth mindset (Dweck, 2015).

Research also shows that cooperative learning improves students' achievement, persistence, and increases motivation (Gull & Shehzad, 2015; Hattie, 2009; Slavin, 2016). William's emphasis on the progression of the class discussion is an example of ASTA Standard 2 (ASTA, 2002) that is supported by Smart and Marshall (2013). He engages the students in discussion by providing a scaffold to support their conceptual understanding (see Ch7_3). I observed that as students gained confidence, they chose to ask questions that showed they were connecting theory to their real-life knowledge.

The remainder of the first lesson involved individual work, with students engaged with tasks on worksheets sometimes consulting with others sitting near them. William interacted with each student as he walked around the room. He provided positive support to those who needed extra instruction and for those who were showing competence. William's students reported that this one-on-one assistance is typical in his science classes, and they found this valuable for their learning. One student commented that William,

> *casts a net of general information over everyone and gives us all the information. Then if anyone gets stuck, that's when he'll do one-to-one. ...he breaks it down so it's easier to understand* (Ch7_8).

Students told me that the ways of learning in William's class include one-on-one instruction and whole group discussion followed by hands-on activities, video or visual presentations and internet research. Students also said they like that William does not follow a *rigid schedule*, since, *he has a rough design and he's willing to change that for each class or each student* (Ch7_8). This illustration aligns directly with ASTA Standard 9 (ASTA, 2002, p. 22) which states, 'highly accomplished teachers of science use a wide variety of strategies, coherent with learning goals, to monitor and assess students' learning and provide effective feedback'. William is able to monitor and provide feedback to each student as he works with them. It is interesting to note that William's students acknowledge the flexibility in his lessons which is indicative of his belief in the importance of flexibility to cater for his students' learning needs (See Ch6_37).

About an hour into one of the lessons observed, William digressed from individual work time for about ten minutes and had the students perform a role play at a restaurant. He had been helping two of the weaker students when one of them sniffed loudly. William offered his hanky which they all laughed about, and this led the conversation to personal etiquette. William involved about three students in a role play, with two having dinner and one as the waiter at a restaurant. All the students in the class stopped work and watched and listened as William guided the students through the niceties of how to deal with a runny nose when at a restaurant. He made a quick reference to science by referring to another use of a clean and ironed hanky – can be used as a clean cloth to apply pressure to a wound for first aid. It was very humorous, and students enjoyed it. After this digression, William explained one of the questions to the whole class and had them all volunteering answers. He then directed them back to individual work. I noted that students were enlivened after the role play and were more focused on their work. During the post-lesson interview, William told me that he had noticed that some of the students had started to slow down and he felt they needed a break. He said *their brains were not working ...so why not teach them about relationships* (Ch7_9)?

This episode demonstrates two points about William. Firstly, that he can quickly recognise when his students are not focused on their work by reading, what Berliner (2004b) referred to as, their non-verbal cues. Secondly, William believes that besides teaching students about science, he can contribute to their personal growth and prepare them for life beyond school. ASTA Standard 3 (ASTA, 2002) states that teachers understand the developmental and contextual factors that influence their students' learning. William knows that many of his students might not have experienced dining at a restaurant or been exposed to these social conventions at home, (See Ch6_28 and Ch6_31nr). William believes that for students to learn, a positive personal relationship with the teacher is needed. This is consistent with several factors in Walker's (2008) characteristics of effective teachers: humour, sense of belonging and displaying a personal touch.

7.2.3 Assessment of, for and as learning

William's students noted the importance to them of the one-to-one time in class as they were able to receive feedback on their progress. Students also appreciated William's quick return of their work, which was usually the next lesson, with comments about where they lost marks and how they could improve next time. This practice aligns with William's belief in the importance of formative assessment and constructive feedback for students (see section 6.4.1.4).

During a post-lesson interview, I asked William if he thought students had improved their science knowledge during the lesson, William's response was,

> *We really haven't nailed it yet. ...Some will have got it and will stick with it. Some would have no idea. But they've been exposed so, remember some parts and they can go away and look it up if they want to* (Ch7_10).

Using the pronoun 'we' in this quote shows William's belief in the student-teacher relationship is important for learning to be successful; (See Ch6_25 and Ch6_28nr).

Besides learning outcomes directly related to the Victorian Curriculum, William's beliefs about science and learning science were apparent in his students reports to me about what they thought about science. Firstly, one of William's beliefs about teaching science is for students to understand the relevance of science in their current lives and possibilities for the future, (See Ch6_32). William's students say that science for them is: *the foundation of the world; used to save lives; part of everyday life* (Ch7_11). Secondly, William believes that students should be challenged (see Ch6_34). William's students said science is: *the key to any question; challenging; using our brain* (Ch7_12). Finally, William believes that learning should be enjoyable and accessible to all students (see Ch6_31nr and Ch6_38). His students' most common responses to describe learning in his class included that it is: *fun; interesting; hard; active; helpful;* and involves *creative ways of learning* (Ch7_13). The overall rationale for the ASTA Standards (ASTA, 2002, p. 8) states that science teachers should enable students to 'explore the world of science in constructive and exciting ways' and 'to think logically and rationally about issues'. Furthermore, ASTA Standard 4 (ASTA, 2002) highlights the importance challenging students at the appropriate level, the use of real life contexts to make learning meaningful and to allow students to make connections to their own world.

7.2.4 Relationships with students

In my observations, William displayed a relaxed, respectful rapport with all his students. He used their names during group discussions and individual work and showed a genuine interest in them as individuals. Students reported that they have never see William angry. If they do not submit work, he listens to their excuse and sets up fair consequences. For example, he might give a student the chance to submit the work the next day before sending an email home to parents. One student told me he had lost his work, so William helped him to look for the sheet rather than repeat it. Students like that he is organised with record keeping and always remembers to follow up on work he has asked them to complete, showing them that their work matters. ASTA Standard 2 (ASTA, 2002, p. 13) states that teachers should, 'establish constructive interpersonal relationships and use this knowledge to build positive environments for science learning'.

William believes that knowing about his students' backgrounds and personal interests allows him to better cater for their needs. After one lesson, he expressed his frustration with three students, not knowing if their lack of engagement in the work was due to their lack of confidence or due to laziness. He said, *I just want them to take a risk and have a go* (Ch7_14). He described what he knew of one of these students, Josh [pseudonym]. From the time he was in year 8, Josh's reputation at school had been poor, with other students being fearful of him, whilst teachers found him to be confrontational in class. William said he had been trying to connect with him. He found out Josh enjoyed boxing, so William talked to him about that in the schoolyard. William understands that Josh does not like studying, perhaps because he has not experienced success, but knows he can learn as he is studying the (hands-on) VET Electrical Industry subject. All William wants is to give Josh enough confidence to just try to learn and submit work for assessment. William's outline of Josh's story shows many similarities with his own experience of secondary school. His approach to Josh demonstrates his goal of being a teacher (see Ch6_5) who supports students who struggle. ASTA Standard 2 (ASTA, 2002, p. 13) states that teachers should 'establish constructive interpersonal relationships and use this knowledge to build positive environments for science learning'.

During another post lesson interview, William again reflected on the same three students who were not working well. Although their behaviour was not a distraction for other students, William showed frustration at the time he needed to spend on keeping them on task; it was taking away from him working with the other students. In the post-lesson interview, William reflected,

> *I'm going to have to pull them aside and have a word - not discipline. But just to tell them 'you're capable of doing this'* (Ch7_15).

He continued by explaining,

> *They're just not interested. So, the thing is to keep a relationship with them. ...relationship building. ...I appreciate kids who try. The worst type of kid is one who's got ability and just doesn't use it. Now that could be personal problems, home problems, authority problems* (Ch7_16).

Students reported that he relies on trust and a positive relationship with students. One student said,

> *there is a lot of respect for him within the school, so I don't think he needs to yell. He just needs to say, 'that's enough' and students listen to him. ...He's built up that reputation over the years. Just the way he acts and the way he teaches* (Ch7_17).

Each time William spoke of the students who were not making progress in class, he showed genuine concern about trying to find a solution by trying to understand their behaviour and by strengthening his relationships with them.

William's classroom management practices are proactive, starting with his selection and detailed planning of learning activities and including his attention to the physical layout of the classroom and focus on students. He is proactive in his movement around the classroom and encouragement of individual students. Watson and Battistich (2006) state that this is a key characteristic of community based classroom management. According to Stronge (2007), these are all strategies used by effective teachers in classroom management.

7.3 Collegiality, collaboration and personal practice

In 2018, William received a commendation in the Prime Minister's Awards for Excellence in Science. In reporting this award, the local newspaper, 'The Sandhope News' [pseudonym] (2018) printed an article quoting William as saying: *Different challenges keep me fresh ...it also helps to be surrounded by great students and staff.* This section about William's collegiality within and beyond Sandhope College provides evidence of these and other beliefs in practice.

7.3.1 Within the school

Professional growth is important to William, who says of excellence, that he is *not quite there yet* (Ch7_18). William reported that he has learnt and continues to learn from his teaching colleagues. As the science teachers share the same office, there are many passing, informal conversations that occur at recess, lunchtime and after school. William said these discussions allow for shared teaching ideas and resources, as a sense of support when things go wrong and celebration of successes. As well as informal collaboration, the science faculty have staff meetings where the focus is on planning for each class and year level. William told me that one day in each term holiday, the science teachers come to school and have a six-hour meeting. This is when they do most of their planning of units for the next term, building on experiences and sharing their knowledge to improve the unit of work from the previous year. He explained that their aim is to deliver an exciting, hands-on, flexible curriculum successfully and that requires working as a team. There is no formal team teaching, but as the science area is so open, teachers observe each other teaching. If classes are scheduled at the same time, they have the option of combining them to explain a concept. According to William, this practice is not unusual for the school and is promoted by the principal. He said, *you've got to have a* *curriculum written, but let's focus on what's happening in the classroom* (Ch7_19). This practice is consistent with ASTA Standard 10 (ASTA, 2002, p. 24), which states that highly accomplished science teachers, 'regularly learn from colleagues through collaboration on professional tasks and seek advice from other teachers'. Hord's (1997) landmark review of professional learning communities cites many examples of how positive professional learning communities and improved practice occur in environments where isolation is reduced and collegial planning and reflection is increased.

Although William believes that teachers should always be improving their practice, he finds the administrative requirements of documenting professional learning hours for Victorian teachers to *be offensive*. Besides a current working with children police check, the Victorian Institute of Teaching (VIT) requires teachers to have at least 20 days of teaching and 20 hours of professional development based on the APSTs per year (VIT, 2018). William argues that he would complete far more than the 20 hours of professional learning activities through reflective practice, research of content and strategies for teaching in preparing for lessons. He claims it is the quality of the development that is important, rather than the quantity. This is consistent with Timperley's view (2012) that professional development should be focused on teacher needs and teachers want it to be directly applicable to the classroom. In addition, Coe et al. (2014) state that it is the quality of the learning rather than the quantity that makes a difference to teacher quality.

When William received the Prime Minister's Awards for Excellence in Science, he said, *it was nice to be recognised but humbling; we have so many great science teachers and I'm just one of them* (The Sandhope News, 2018). This evidence illustrates that William has two personal attributes of excellent teachers: critical self-reflection and authenticity (Faull, 2008; Keeley et al., 2006). Even after thirty-three years of teaching experience, William believes he still has more to learn about being a better teacher. He believes in life-long learning, not just for his students, but also for himself (see Ch6_25nr and section 6.5). Keeley et al. (2006) listed humbleness as being an important attribute of excellent teachers. Even in receipt of such a distinguished award, William did not brag and gave credit to the other reward recipients.

7.3.2 Partnerships beyond the school community

7.3.2.1 Primary schools' program

As discussed in the last chapter, sections 6.2.2.1 and 6.3.3, William has developed relationships with the local primary schools where he offers support to their science program. Currently, one part of the program is taught by involving year 10 students in teaching the students. For this, he asks the grade 5 and 6 students to write a list of science topics they want to know more about. William's year 10 students collate the lists and plan to teach a topic in the top ten. At other times, William plans and presents the primary unit himself. He described to me his approaches in teaching a grade 3 class. Firstly, he asked the grade 3 teachers to choose a topic. They asked him to explore 'hot and cold'. So, during his first visit, grade 3 students learnt how to use thermometers. Next, students investigated what happens to temperature when something is wet, and what might happen in real life if students were hiking in alpine country where the temperature can change quickly. His last session focused on creating an artificial campfire in the school hall with audio of crickets chirping in the background. Students sat around the fire, discussed the usefulness of fire and how Aboriginal people made fire, then finished by roasting marshmallows, making popcorn and talking about how heat is involved. William explained that these three sessions took about 20-30 hours to research and prepare and commented that *the end justifies the means* (Ch7_20).

The primary school teachers are very grateful for William's program. One principal wrote in the newsletter that William was able to,

> *...capture the interest and spirit of everyone present. He challenged individuals and groups and strongly encouraged them to consider and inquire. His presentation was really impressive and entertaining* (Ch7_21).

The primary school students spoke positively about science. I interviewed some year 6 students who had experienced the primary science program when they were in years 3 and 5. In terms of the topic of heat they could recall developing understanding of different states of matter, how convection currents are involved with flight, and how rocks can be formed from cooling lava. The students told me that sessions with William were interesting and fun because he made science easy to understand, did not talk much – because he asked students lots of questions instead, and all the experiments could be repeated at home because materials could be easily bought.

The illustration of this primary science unit shows William's knowledge of the curriculum and his ability to use it as a framework to prepare units in science. In particular, the unit described addressed the following aspects of the *Victorian Curriculum: Science*,

- Physical Science: Heat can be produced in many ways and can move from one object to another; a change in the temperature of an object is related to the gain or loss of heat by the object (VCSSU063)
- Science Inquiry Skill: Use formal measurements in the collection and recording of observations (VCSIS068)
- Science as Human Endeavour: Science knowledge helps people to understand the effects of their actions (VCSSU056)

(VCAA, 2017e)

Having the year 10 students prepare and present the science topics for the primary students is beneficial to both age groups. Research has shown that cross-age teaching has many advantages for both the teenager and the young person with the teenager benefitting from improved knowledge and attitudes to school (Russell et al., 2002). ASTA Standard 4 (ASTA, 2002, p. 16) also states that, 'highly accomplished teachers, recognize that students can be teachers as well as learners and make use of' this. The primary schools' program demonstrates William's belief in his role and responsibility to his community. William has persisted with maintaining this partnership with the local primary schools, with a few forced breaks, over the last twenty-five years. As discussed in section 6.3.1, William believes that teaching is a calling. The program allows him to contribute positively to the science learning of younger members of the community whilst building PCK and confidence for the primary school teachers to teach science. Liston and Garrison (2004) would refer to this as William's passion for educating other people. Finally, this program is an exemplar of ASTA Standard 11 (ASTA, 2002, p. 25) as he is actively involved with the wider community, promoting 'professional growth of colleagues' to ultimately 'improve the quality and effectiveness of science education' for their students. This work with the community emerged as a highly significant factor in his reputation in the local community as an excellent science teacher.

7.3.2.1 Pre-service Teachers

William contributes to the wider professional community by being involved in initial teacher education in partnership with science education academics at Markle University. After having mentored many PSTs and new graduates, William felt that he could do more.

> *My role as an educator now, is to educate the educators. It's my job to pass on what I know. … You want to give back. You want to give the newbies the best start possible. They're apprentices* (Ch7_22).

Based on this, William approached the Faculty of Education at Markle University and asked to be involved with teaching PSTs. Besides co-teaching the university students with the university academics, William has involved other teachers in his faculty and together they supervise about 20 students during their school placement at Sandhope College. In an article written about the program in the local newspaper, 'The Sandhope News' one quote shows how William sees his students in years 7-10 being beneficiaries of the program, *instilling fun, encouraging love of science in future teachers would permeate through to children, thereby making them far more likely to go on to tertiary education* (The Sandhope News, 2016). A second quote from the article adds to our understanding of his approach to teaching, stating that *his way of teaching is to allow freedom of expression, bringing a bit of creativity in what is often considered a staid subject.* In one of our interviews, William said the program improved the reflective practice of the science teachers at Sandhope College and of the visiting PSTs. There is collegiality where, *everyone feeds off one another…It's a real learning thing* (Ch7_23). William claims that he has learnt a lot from this program, asserting that all teachers *should have a 'PST attitude'; recognizing that teaching is an ongoing, learning profession* (Ch7_24).

The PST students were based in the 'Think tank', described in section 7.2.1.2. When I visited, the whiteboard showed evidence of collaborative planning of units of work that the PST students were actively using in their teaching. I noticed the interactions between the PSTs and science teaching staff were friendly and professional. The PSTs felt supported and challenged. One PST said, *I've learnt more in the last 3 weeks than all semester*. The University academics who worked with William found that the partnership helped in bridging the theory practice gap and promoted the notion of teams in teaching (R. Cooper, personal communication April 5, 2018).

William's involvement with Markle University and initial teacher education is consistent with ASTA Standard 11 (ASTA, 2002). The partnership has had positive implications for the PSTs and Sandhope science teachers and students, including William's own professional development. William's reason for initiating the partnership again shows his belief in the importance of giving positively to the educational community (Liston & Garrison, 2004).

7.4 Conclusion

The evidence collected in this case study demonstrates that William is an excellent science teacher. He uses expert professional knowledge of curriculum and pedagogy and has a strong capacity to inspire and motivate students. He has strong beliefs about how to encourage his students to enjoy and engage in science by giving them opportunities to ask questions, find answers and by making connections to real life. William's thirty-three years of experience of teaching at Sandhope College has meant he has a clear understanding of the backgrounds and learning needs of his students. He differentiates the curriculum and the learning activities to meet the needs of his students. Positive, respectful relationships with his students and colleagues are central to William's approach to his work. He is not only a teacher of science, as he also provides development of personal capabilities in his students. He develops their life skills through explicit teaching and his modelling of respectful behaviour, passion, care for others and humour. William is a committed and passionate educator who spends time critically reflecting upon his students' learning and providing them with effective feedback and learning opportunities.

This chapter shows that William's teaching practice includes multiple elements of the framework I have used to examine excellent teachers, including expert professional knowledge and positive personal attributes. In addition, there is clear alignment between William's beliefs and practices. For instance, William's practice demonstrates his belief in life-long learning for himself and his students. This is shown firstly in his planning, where he is critically reflective of his teaching practice and the learning practices of his students. He uses his reflection to adjust future lessons in order to improve his students' learning. He seeks out opportunities to keep up to date with real-life examples of science, so he can share this knowledge with his students, relating it to the topic of study where possible. Secondly, the findings from my interviews with William and his students, and observations of his teaching demonstrate that he believes in the importance of knowing his students. William also believes that by making learning enjoyable, everyone can learn. He provides opportunities for his students to experience success by making knowledge accessible and by giving them prompt, constructive feedback. It is evident that his students appreciate his belief in their capacity to learn. The data shows that he wants to develop his students' curiosity and confidence, so they will also become life-long learners like himself. The evidence shows he believes in honest, respectful relationships and clear communication. This directly contrasts with his own experiences as a student of science in years 7-10.

William's passion for science and for teaching adolescents is evident in his beliefs and practice and commitment and drive to improve learning experiences for his students and people beyond the school community. His belief in 'teaching as a calling' is strongly evident, as he devotes a lot of time and energy to ensure students are engaged and learning. All of these factors demonstrate the many reasons why William is indeed an excellent teacher.

Chapter 8

Background context, knowledge, personal attributes and beliefs of an excellent science teacher - Hannah

8.1 Introduction

In the next two chapters I provide a deep discussion of contextual factors, attributes, beliefs and practices of the third teacher, Hannah (pseudonym), to deepen my analysis of the complex range of personal and professional factors involved.

This chapter focuses on analysis of Hannah's personal contextual background in terms of the first two research questions:

1. How do personal and contextual factors influence the development of excellent teachers' knowledge, personal attributes, beliefs and practices?
2. What do excellent science teachers believe about teaching and learning science in secondary school?

Hannah is a science teacher at Menna College (pseudonym). She was identified for my study by a science teacher educator who had seen her present a professional development program. Her inclusion in my study was further supported by the being a past Victorian nominee for the BHP Science Teacher Award[22] and receiving a commendation in the Prime Minister's Prize for Excellence in Science Teaching. At the time of my study, Hannah had been teaching for twenty-five years, the last fifteen years at Menna College; an all-girls, kindergarten to year 12, private school in suburban Melbourne. In this chapter, Hannah's story is constructed from data drawn from semi-structured interviews, classroom observations and documentation collected from Hannah and her students. My analysis was conducted through consideration of the theoretical frameworks discussed in the literature review including the *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006), and *Framework for examining beliefs* (Fives & Buehl, 2008). I have drawn on these sources to identify, analyse and discuss key themes related

[22] The BHP Science Teacher Awards recognize, 'outstanding contributions made by classroom teachers to science education' (BHP, n.d.). Each state's Science Teacher Association is invited to nominate a teacher to be considered for the award.

to the contexts, personal attributes and beliefs that emerged from the data in relation to the research questions.

I begin this chapter by discussing Hannah's experiences at secondary school, then at university and as a teacher. This discussion is then drawn on in the following chapter to assist my analysis of the extent to which her personal background and attributes have influenced her teaching practice. Finally, I discuss Hannah's beliefs about science and how it should be taught to students at year 9 and draw conclusions about the influence of Hannah's prior education and teaching experience on her beliefs about teaching science.

8.2 Past contexts

8.2.1 Experiences as a student

8.2.1.1 Secondary school and up-bringing

Unlike the first two case study teachers, Hannah grew up in a small country town in regional Victoria, about two hundred and fifty kilometres from Melbourne. Although she was the eldest of five daughters, she said that she had,

> *a very sheltered upbringing, on a small farm in the middle of nowhere. You didn't see anyone* (Ch8_1).

As the eldest, Hannah was deemed to be *the responsible one*. Although *not a tom-boy in any respect*, as she had no brothers, it was expected that she would help her father on the farm including *driving the tractor and truck* from an early age (Ch8_2).

Hannah did not have a choice of schools, attending the only secondary school in the area. She remembers some of her teachers, but rather than having a favourite, she says, *I respected some more than others ...the ones who knew more than the textbook* (Ch8_3). One such teacher was her year 12 maths teacher, who was *a very clever mathematician*. Even so, she now reflects that he was not a good teacher, as most students could not understand his explanations.

> *I remember having to explain it to the people around me. I really enjoyed that 'translation' as I like to call it, of what he was saying into something they could understand or make it relevant to them* (Ch8_4).

She recalls a *fantastic* year 9 science teacher who would *play devil's advocate by arguing the world was flat, or round* as this engaged the class in thinking about the evidence (Ch8_5). In her first lesson of year 11 biology, her teacher enacted a surprise event where another teacher shot him with a starter pistol in the classroom. He then asked students to list their observations of the event. He did this to make the point that scientists make discoveries by taking note of the unexpected.

> *It was those two experiences that I remember. I don't remember anything else of my science at secondary school. But I learned that there could be more than just the book work.* (Ch8_6).

Hannah's parents' interest in education was influential on her pathway at school. When she was in year 12, there were only about forty students, as many students left school before then, returning to work on the family farm. This had also been the case for Hannah's father's generation, however, he maintained his interest in science and completed a correspondence course in electronics whilst Hannah was in year 9, so was clearly a role model for the importance of lifelong learning. Hannah's mother was interested in language. *We'd always say that mum had the English and dad had the Science (*Ch8_7). As she grew up, Hannah thought she wanted to become a librarian, as she loved books.

> *We'd have the mobile library visit the town once a week. I'd ride the seven kilometres to town, borrow as many books as I was allowed. When I was in year 9, I started reading the encyclopedia during school holidays because I was bored. There was no internet. I loved reading. ...Books were special in my family* (Ch8_8).

Work experience in a library at year 10 quelled the idea of becoming a librarian for Hannah.

> *I decided it was pretty boring waiting for someone to come in and read a book and decided I needed something more. ...My mother encouraged me to go with my strengths* (Ch8_9).

From year 10 on, she particularly enjoyed maths and science at school. In years 10-12, whilst other girls planned to be nurses or teachers, Hannah aspired to a career as a research scientist. Interestingly, she did not really know what this entailed.

> *It wasn't what you would see on the TV in those days and it wasn't anything I had experienced, but I knew it was a possibility. I just liked to explore things. I was curious. I just wanted to find things out. That was a part of my reading too. It was partly my parents' influence and the prestige.* (Ch8_10).

Having her father learning electronics whilst she was studying too, added to Hannah's interest.

> *I was influenced by my father being so curious, wanting to know more and him saying there is more to learning that what you are doing in the classroom* (Ch8_11).

On occasion, when her father was struggling with the maths in his course, he would explain the problem to Hannah, who would take the problem to her maths teacher.

> *The teacher would solve it, explain it to me and I'd explain it to my father, until the teachers couldn't solve the problems anymore* (Ch8_12).

When Hannah studied electronics as an elective unit in year 12 physics, her father lent her his books to help her learn. Without her father's support, it would have been difficult.

> *My teacher asked to borrow my father's books, so he could understand what I had written* (Ch8_13).

These recollections show that Hannah had a thirst for knowledge and developed a broad general knowledge by being an avid reader (see Ch8_8). Her parents' interests and curiosity led her to develop effective communication strategies where she could understand a problem by listening and then explain the solution to others (see Ch8_4, Ch8_7, Ch8_11, Ch8_12). Hannah's parents encouraged her to think beyond the farm and to keep learning in the future. Although neither of her parents had a science-related qualification, her father actively sought opportunities to learn about it. This is consistent with Archer et al. (2013) who found that parental attitudes are influential on a student's self-concept. Archer et al. (2013, p. 3) recommended that stereotypes of scientists being male and 'brainy' hindered girls in particular from having science aspirations. Hannah's work on the farm and her isolated up-bringing meant she was not exposed to these negative nuances (see Ch8_1nr, Ch8_2, Ch8_10).

8.2.1.2 Tertiary education

Teaching was not Hannah's first career choice. In line with her aspirations, when applying for university Hannah *just chose the science courses* (Ch8_14). She attended university and completed a Bachelor of Science. The move from her small country town to Melbourne was a big move both personally and academically.

> *Coming down to University was a bit of a shell shock. I didn't know much besides what I could experience in my course. Doing research again was a very sheltered environment again* (Ch8_15).

Her undergraduate subjects included three of the four branches of the *Victorian Curriculum: Science* (biology, chemistry, physics). Although she had focused on physics and chemistry in year 12, at university *she kept choosing the subjects [she] liked* and ended up doing a lot of biology, developing a passion for neuroscience. Hannah could not recall any specific teacher during her undergraduate education; it was the science that she found interesting. She successfully applied for the Honours program, majoring in neuroimmunology.

After this study, Hannah decided she needed some work experience before starting a PhD. She worked as a scientist in the endocrinology laboratory of a major city hospital. At the end of the two years, she was offered a PhD in endocrinology, but declined this offer.

> *I didn't think I was emotionally ready for a five-year program; I didn't have the drive to commit to three to five years either. I was only twenty-one ...I was engaged to be married.*

Hannah wanted to start a family but knew this would require taking time off and if she *left research for twelve months it was really hard to get back in* (Ch8_16) So, in consideration of her personal priorities at the time, she decided to leave her research job and pursue a career in teaching. In 1991, Hannah enrolled in a Diploma of Education studying the method subjects of general science and biology. She was impressed by the teacher educator who taught her about teaching science.

> *He was very enthusiastic about teaching science and was very much into 'hands-on' science. This resonated with me because that's the way I saw science, as hands-on and relevant. ...He talked about the reasons for experiments; what the students would learn from doing it* (Ch8_17).

Just recently, Hannah completed a Certificate in Educational Neuroscience, which combined her knowledge of teaching with her knowledge of neuroscience. One of the aims of the course is to enable participants to, 'critically reflect on their own teaching philosophies and practices' (Course Overview).

Hannah's concerns that she raised about balancing a family and being a research scientist (see Ch8_16) are widespread. Research has shown that whilst 50% of early career science researchers are female, only 17% are female at the senior level (SAGE, 2016). One reason for this is time-out for family leave (SAGE, 2016). Choosing to teach as a 'second-career choice' is quite common, and this is the case for 51% of teachers (Wyatt-Smith et al., 2017, p. 34). Wyatt-Smith et al.(2017) also found that once they started in the profession, many of their participants also found their passion for teaching (see Ch8_20). Hannah's undergraduate major in neuroimmunology meant she had a good basis to understand educational neuroscience. Research indicates that educators need this background knowledge to be able to understand how the findings of neuroscience might impact pedagogical practice, if it is to be useful in their teaching (Howard-Jones, 2014). The emphasis on hands-on activities and on relevance (see Ch8_17) is consistent with Hannah's learning experiences with her father (see Ch8_11nr). Highlighting the importance of considering the learning that can occur from an activity, is consistent with research findings of good science teaching (Abrahams, 2011; Abrahams & Millar, 2008).

8.2.2 Experiences as a teacher

8.2.2.1 Past experience

Hannah's first teaching position was as a six month long-service leave replacement for a general science teacher at a suburban secondary school. When she became pregnant with her first child, she became a stay-at-home mother. Within two years, she had a second daughter and two more children followed in the next five years, but even though she was busy with family responsibilities Hannah's interest in science never waned.

> *Having come straight from my research, I still had that enthusiasm for science and curiosity. Being home with my children all the time just exacerbated that ...I wanted to share that with my children* (Ch8_18).

Although Hannah did not actively plan learning activities for her children, she would follow up on conversations they would have. For example, when her daughter was two years old, they were talking about the colours of flowers. She learnt that her daughter did not understand that there were different shades of pink. So, Hannah organized an activity with classifying pencils into their colour groups. *It was important as it changed how I saw people perceive things* (Ch8_19). At the same time, the internet became more freely available, which allowed Hannah to explore young children's perceptions about the *natural environment and science of the everyday* (Ch8_20).

Besides sharing her *love of science* with her own children, for the next 10 years whilst she had young children at home, Hannah did casual relief teaching (CRT) in a number of schools and private tutoring. Her CRT work was mainly at a school very near her parents' new home in country Victoria, a ninety-minute drive from where she was living in suburban Melbourne. The school, Crossley College (pseudonym), would phone Hannah at 7am in the morning and she would have the children packed up and be on her way to teach by 7.30am. Her mother would look after the children whilst she worked. *Once I started, I found I loved the teaching and sharing of my passion* (Ch8_21). Hannah taught subjects other than her science during her CRT work. She connected with students by sharing that she was a science specialist, but also explained to them other disciplines were useful too.

> *In English I said, 'I'm a science teacher, but this is how I use English in science, this is why you might be doing it this way'. ...I'd use the real-life applications to get the kids to do the work* (Ch8_22).

Hannah's time with her own children allowed her to develop her knowledge of learners and how to develop their knowledge further (see Ch8_19, Ch8_20). ASTA Standard 2 (ASTA, 2002, p. 13) states that this facet of PCK is an important attribute of excellent science teachers. This time allowed her to reflect on science education from a teacher's perspective, developing her knowledge of how young children's conceptions develop. Hannah's CRT work occurred very early in her teaching career. Research has found that CRTs who are also novice teachers often feel isolated and lack access to professional development (McCormack & Thomas, 2005). This was the case for Hannah, since her access to professional development was further limited while she was caring for her young family. However, Hannah was used to being isolated and was an independent learner due to her childhood on the farm (see Ch8_1). Hannah's childhood love of reading and her innate curiosity were also valuable in guiding her students' learning during short episodes of covering English and maths classes (see Ch8_4nr and Ch8_10nr). Drawing on her past experiences, Hannah's approach to her CRT work showed her adaptability and confidence to teach in different contexts. Nicholas and Wells (2017) reported on the importance that CRTs place on personal experiences to increase their understanding of how to teach. Thus, although her science specific PCK might not have had special attention during this time, Hannah's CRT experience improved her general pedagogical knowledge.

In 2003, after her last child started kindergarten, Hannah started teaching at her current school, Menna College. Hannah initially taught general science from years 7 to 10. In the first few years she found it was a *pessimistic faculty; everyone was doing their own thing* (Ch8_23). Hannah described the Head of science as a poor leader and a poor teacher. She had *been at the school for thirty years*, would *not allow* anyone else to teach her senior biology class and she *only gave students bookwork* (Ch8_24). Hannah found the Head of science to be *passive-aggressive.* Hannah *avoided her* by taking on different roles within the school. At different times, Hannah was the Head of year 10 and Head of the year 9 program, which included running the Duke of Edinburgh Award[23]. In one year, she attended seven school camps and hikes with year 9 students.

Hannah started writing textbooks in 2006. This venture started slowly and unexpectedly when she accompanied a colleague to a meeting with the publisher. She put forward the idea that it would be good to have *a chapter for years 9 and 10 that covered the chemistry needed as a basis for year 11 biology* (Ch8_25). The publisher then asked Hannah to write the chapter and then she was asked to write the teacher notes to accompany the textbook. Since then, Hannah has been involved with contributing to textbooks for years 5 to 10 science and years 11 and 12 biology. In the last couple of years, she was approached to author a series of science books for years 7 to 10 science. She discussed the presentation and content of the books with the publisher so that they were *from a teacher's perspective* (Ch8_26).

> *Writing the textbooks allowed me to put my thoughts in order and work out what's important and what's not for kids to know. It extended my understanding. The heading of each chapter reflected the key concept in just a few words* (Ch8_27).

Hannah's multiple roles at Menna College meant that she gained an understanding of her students' cultural and contextual factors. In her roles as heads of year and leadership of the Duke of Edinburgh Award, Hannah learnt about her students' interests, home environments and what motivates them to learn. She commented that this helped her teaching. As stated in ASTA Standard 3, this 'is foundational for effective teaching and learning' (ASTA, 2002, p. 14). Her professional learning also grew since writing the textbooks gave Hannah the opportunity to develop her PCK of general science, since it gave her an explicit reason to reflect on what, how and why she teaches science. This is consistent with Schneider and Plasman's (2011) conclusion that reflection is essential for teachers to organize their ideas in ways to develop their PCK.

In 2010, the Head of science left the school and Hannah was appointed to the position. She thinks it was good timing that the first draft of the *Australian Curriculum: Science* was released

[23] The Duke of Edinburgh's Award is an international program aimed at 14-24-year old youth to empower them to reach their full potential (*Duke of Edinburgh's International Award*, 2019).

in the same year. This gave Hannah validation for the changes she felt needed to be made to the science curriculum at Menna College.

> *I made the pracs a priority. We needed a consistent approach. We created a standardized marking scheme for pracs from years 7 to 12* (Ch8_28).

Throughout her seven years as Head of science, Hannah has introduced many new ideas to the faculty such as the Scientist in Residence[24] program and Enterprise education[25]. These will be discussed further in the next section, 8.2.2.2.

Along with being Head of science, Hannah also had the opportunity to teach VCE biology. At the same time, Hannah's daughters were students in the primary section of Menna College. She was disappointed by the lack of science learning for her children so offered the primary teachers her assistance. Her daughters' teachers accepted her involvement and then a few more teachers agreed. After a year of helping the primary teachers, the school added year five and six science to Hannah's timetable. She also continued to help teachers at other year levels in her spare periods. The Early Learning Centre (ELC) teacher sought out Hannah to discuss how she could help her students to *use their imagination and initiative ...to explore and try different things* (Ch8_29). After another year, the school added working with the ELC students to Hannah's timetable.

Hannah's new roles within the school and in writing textbooks led her to work with the Science Teachers Association of Victoria (STAV) and the Australian Science Teachers Association (ASTA) for several years. After finding out how little support primary teachers get in science, Hannah offered to run a workshop each term for primary school teachers for STAV (Ch8_30). She has also presented workshops at the STAV annual conferences. Hannah was also a reviewer of VCE Biology exams for STAV. Finally, she was part of a team at ASTA that curated resources and provided online assistance to science teachers through their website.

[24] The Scientist in Residence program (now renamed STEM professional in schools program) partners a research scientist with a school for a period of six to nine weeks with the purpose of enhancing science education (CSIRO, 2018).

[25] Enterprise education focuses on helping student to develop life and employment skills such as financial ability, teamwork and communication (Foundation for Young Australians, 2017).

To add to Hannah's reputation as an excellent science teacher, she has received a number of commendations: Highly commended in Prime Minister's Prize for Excellence in Science (twice), Victorian nominee for BHP Science Teachers Award, Winner of the Science Teacher Award from the Australian Academy of Science.

This section demonstrates that Hannah's excellence has developed through her own passion and commitment and involvement in science education beyond her classroom practice. Hannah has been teaching for seventeen years and has been recognised within and beyond her school community as an excellent science teacher. When she has seen a need to develop the scope of her own professional learning, she has initiated projects both within her school and beyond; supporting teachers to improve their teaching and learning practices to maximise student learning. This is evidence of achievement of ASTA Standard 11 (ASTA, 2002, p. 25), since Hannah clearly works to, 'improve the quality and effectiveness of science education'.

8.2.2.2 Planning to teach

Hannah understands that teachers are constantly busy and that preparing good lessons and units of work takes a lot of time. Her extra-curricular work with primary teachers in her own school, and with ASTA, STAV and with writing textbooks (see section 8.2.2.2) involved sharing her content and pedagogical knowledge to help teachers prepare effective science lessons. *...some teachers aren't aware of the curriculum and just don't have the time. ...the key concept needs to be made clear* (Ch8_31). Hannah approaches her own planning with this in mind. She said that,

> *I'm trialling new things and modifying them to make sure they work for other teachers. ...I trial things with certain goals in mind ...not just what but how it is taught* (Ch8_32).

Hannah has designed many units of work, catering for students and teachers from ELC to year 12. The best demonstration of her planning priorities can be found in the presentation of the series of science textbooks she has authored for students learning science in years 7-10 in Victoria (see Ch8_26). The publisher's website describes the textbooks as having practical tasks that promote inquiry learning and each double-paged spread consists of:

- clear, accessible language for students
- one concept to be learned in one lesson
- links to real world applications
- questions to check understanding

The structure of her textbooks is consistent with the *Australian Curriculum: Science* as each section incorporates the three strands: science for understanding, science as human endeavour and science inquiry skills (ACARA, 2012a).

In her classroom teaching, Hannah uses PowerPoint presentations to assist her in planning for lessons. She explained that besides *organising [her] own thoughts* on the concept, they form a *basic set of notes* for students. The PowerPoints allow her to seamlessly show animations and videos during the lesson.

> *I'm aware of the principles of psychology and neuroscience and education, where you're more likely to get their attention, more likely to have memory of a particular event if you have pictures whilst you're talking and minimal writing. I never have more than one sentence per slide* (Ch8_33).

The lessons at Menna College are 75 minutes long. Hannah explained that most of her lessons have a similar structure: first a review of the homework via class discussion; second, a class discussion of a new concept via PowerPoint presentation; third, a hands-on activity to reinforce the concept. Hannah describes her teaching as a,

> *Socratic style of teaching, where you ask questions and push their understanding of the concepts that you're teaching them or of what they already know* (Ch8_34).

Besides planning to address the knowledge and skills of science, Hannah also plans for students to develop or apply general capabilities, particularly, critical and creative thinking, and personal and social capability. Thus, her units of work involve collaborative group projects. She told me that STEM projects allow her to combine the concept, hands-on activities and the general capabilities and relate it to real life. For example, when studying ecosystems, the STEM project for her year 9 students was to develop a vertical garden for the school. Hannah said that her students,

> *needed to maximise the productivity of their garden using everything they'd learnt about what plants and ecosystems need. They had to calculate the productivity increases ...design what it would look like* (Ch8_35).

Hannah's planning shows that she is cognizant of the rationale of the *Victorian Curriculum: Science* as it requires students to, 'solve problems, …make informed decisions about local, national and global issues' and 'appreciate science and its usefulness in their …world' (VCAA, 2017e). Her planning also considers other areas of the Victorian Curriculum such as the cross-curriculum priority of sustainability, so students are asked to consider the issues around their garden in terms of an 'environmental, social and economic system' (VCAA, 2017a). The interdisciplinary nature of the projects is consistent with research findings linking neuroscience and education (Robinson, 2017), which demonstrates Hannah's knowledge in this area. Finally, the projects are evidence of her meeting ASTA Standards 4 and 5 (ASTA, 2009) as they show that Hannah designs learning tasks to challenge and engage her students and uses a range of human, environmental and physical resources to enrich their experience.

This section has shown that Hannah demonstrates excellence in her planning, teaching and communicating science in schools from prep to year 12. Hannah makes use of students' personal interests and authentic situations to motivate and engage them in learning. Pedagogies that involve challenging, authentic problem solving with intellectual rigor have been shown to be particularly important for engaging middle school students (Tytler et al., 2008). Alsop (2007) also suggests that exemplary teachers consider their students' emotions, such as their interests and enthusiasm in their planning as this encourages deeper cognition in the learning process. Furthermore, Hannah's experiences of Socratic-type discussions with her students promotes deep learning as students are encouraged to examine their assumptions and question their reasoning, as advocated by Hattie (2015).

8.3 Personal attributes – experiences from Hannah's past

8.3.1 Authenticity

My initial impressions in meeting Hannah were that she is pragmatic, organized and committed to her work. Her recollections of her childhood are of being responsible and practical from an early age (see Ch8_2nr) and this has continued into her adult life while she worked full time and raised four children. In her own words, *I just love what I do* (Ch8_36).

Hannah has a genuine interest in improving the learners' experiences. Whenever she has seen a problem affecting her learners, Hannah has been pro-active in finding a solution and facilitating quality learning episodes for those involved (see Ch8_18, Ch8_25, Ch8_29, Ch8_30). Hannah shares stories from her own life with her students. For example, Hannah told me about one of her STEM projects where she had her students apply for 'positions' within their groups (such as communicator, safety officer, engineer). To explain her reasoning to her students, she shared a story about her sister who had applied for an international position.

> *My sister was head hunted for an international job. It was between her and a male. ...The head-hunting company said she was the best one for the job, but unless she sold herself then the male would get it. ...it's something that you have to be able to do. It's not showing off ...be aware of your strengths and know how to present them* (Ch8_37).

Hannah's leadership of the science faculty is in stark contrast to the previous Head of science (see Ch8_23, Ch8_24). Hannah told me she is *big on the personal approach* (Ch8_38). As there is no central work area for the science teachers, she *catches up* with every science teacher once or twice a week by visiting their offices. Hannah asks how they are going and what activities they are doing with different year levels. She gives the teachers feedback and encourages them to share good ideas with other members of the team. She makes suggestions for activities that might be good for them to try. Hannah told me that she found this approach helped her build a cohesive team from *a group of different personalities*.

This high level of involvement demonstrates that Hannah forms working relationships with her students and other teachers by showing that she cares. By sharing stories from her own life with her students (see Ch8_37), Hannah shares part of herself and makes a connection with them. Frego (2006) reported that being open and trusting shows that you genuinely care and this a great motivator for learning. ASTA Standard 11 (ASTA, 2009) states that a staff culture where the sharing of collegial advice and encouragement is promoted improves the quality of the science education. This is further supported by research which reports that a sense of belonging promotes teacher well-being, professional development and innovation (Blackmore, 2004; Lomos et al., 2011).

8.3.2 Passion

Hannah's parents were passionate and curious people, interested in reading and improving their understanding of the world. This impacted on Hannah significantly as she too developed a passion and curiosity for learning, particularly about science (see Ch8_8nr, Ch8_10nr, Ch8_11nr). Hannah's passion for teaching also had early beginnings. Whilst at school, she helped her peers understand maths and loved it (see Ch8_4nr). Her passion for science continued in her tertiary years. She recalls a small research project during the third year of her science degree. I could hear the passion in her voice, even though twenty-five years have passed. She remembered that, *It was working with rats' brains, looking at neurology and neuropharmacology. It fascinated me.* (Ch8_39).

Hannah shared her love of science with her children when they were pre-schoolers (see Ch8_18nr). This time also ignited her passion for teaching science (see Ch8_21). From them, she learnt how important her passion for teaching science was for her children's learning.

Having my children made me understand that the most important things in teaching are consistency and curiosity/enthusiasm (Ch8_40).

Hannah said she did not have a favourite year level to teach.

I teach everything from 3-year olds to year 12 biology. I don't have a favourite year level. I love the intellectual challenge of year 12, ...but each time you teach something new, it's exciting (Ch8_41).

When asked about her favourite science topic to teach, Hannah said *I like them all. There are different things to all of them* (Ch8_42). Nevertheless, she admitted that years ago she found earth science was *hard to get your teeth into. ...I found it dead boring* (Ch8_43). Hannah *played around* with how she taught it and was *thrilled* when she heard a student saying, *I never thought I'd be interested in rocks, but gee they're interesting*. Hannah commented, *if I can find that passion, then that needs to be passed on* (Ch8_44).

In ASTA's vision for their standards, they state that, 'highly accomplished teachers of science, have a passion for science, for learning and for growth' (ASTA, 2002, p. 8). Hannah sees passion as being a very important part of being a teacher as it ignites students' interest in learning. This is also consistent with research (Hudson & Kidman, 2008; Keeley et al., 2006; Vasquez, 2008).

8.3.3 Commitment and drive

Hannah has always been responsible and committed to her pursuits, again an attribute promoted by her parents (see Ch8_2nr). This was evident in her work on the farm and even in her bike rides to the library (see Ch8_8nr). Hannah told me she worked long hours to write the textbooks whilst she was also teaching full time and raising four adolescents. At the same time, she was also involved with running workshops for STAV, reviewing VCE Biology exam papers and other work (see Ch8_30nr). She explained that for most of this work, her primary motivation at the time was financial, as she had separated from her husband. However, there was also an internal drive where she *prided herself on getting everything in on time* (Ch8_45). In her last series of four textbooks, Hannah wrote one every two months. *I took on things because of the money, but now I do it because I like doing it* (Ch8_46).

When the past Head of science took extended leave before resigning, Hannah wrote lesson plans for the CRTs who were covering the teacher's year 12 class. She confided in me that the school administration appreciated her efforts and she thought it could have been a factor in her being appointed as the Head of science. As the Head of science, she has always looked for ways to improve the science experience for all the students. Hannah provided a unit on year 9 electricity as an example and said,

> *Often, I'll trial things in my classroom before I pass it on to other teachers. ...that year I used the STELR*[26] *equipment and trialled an activity - who can produce the most power for the cost of the equipment? It worked well, and the girls seemed to enjoy it so then I got the other teachers to use it the following year* (Ch8_47).

It has been reported that growing up on a remote family farm instils a strong work ethic is children from an early age (Friedman, 2000). There is always work on a farm and it never ends. Children learn to do their work efficiently; they learn to solve problems creatively. These traits have allowed Hannah to contribute to many aspects of education – within her school and the professional community. Her goal in each situation is to improve the science education experience for children – whether they be the students in her class, the school community or students in other schools. Hannah's behaviour is consistent with ASTA Standard 11 (ASTA, 2002, p. 25) as she, 'supports the professional growth of colleagues' and 'always working for improvement in students' science education'. Interestingly, Hannah's commitment to her work also became her passion (see Ch8_46). This is consistent with Crosswell and Elliott's (2004) findings which show a strong connection between a teacher's passion and commitment to the profession.

[26] STELR is hands-on, inquiry-based science laboratory equipment produced to assist in teaching STEM topics in the Australian Curriculum (Australian Academy of Technology and Engineering, 2019)

8.4 Beliefs

8.4.1 Beliefs about teaching, learning and students

8.4.1.1 Excellence and purpose

Similar to William and Lindy, Hannah was sceptical about why she would be considered as an example of an excellent science teacher for my study.

> *I don't see myself as excellent. I see myself as something that needs to keep on improving*; *I'm continually learning* (Ch8_48).

When reminded of the awards she had been nominated for (see section 8.1), Hannah smiled, and said, *I tend to come second*, *...never believe your own publicity as that's when you'll make mistakes* (Ch8_49).

Hannah believes that her role as a teacher is to *make the link between the concept and real life* (Ch8_50). To do this, she uses a combination of strategies: storytelling, explicit instruction and *helping students to remember things in different ways* (Ch8_51). Hannah thinks raising her own children has influenced her teaching, in that she learnt that the most important thing she can do is be consistent and the most important thing she can encourage is curiosity and enthusiasm for learning. I contend that these beliefs had their origins in Hannah's own upbringing as her father in particular was curious and loved learning (see Ch8_8nr, Ch8_10nr). Additionally, Hannah enjoyed learning when she was a student when her teachers promoted curiosity and thinking (see Ch8_5, Ch8_6).

Hannah is similar to William and Lindy in her bewilderment about being considered an excellent science teacher for my research. Hannah's reasons for denying her own excellence demonstrate her beliefs in life-long learning and critical reflection (see Ch8_48). Hannah believes her self-reflection on her practice is guided by her knowledge of how the adolescent brain learns, giving her empirical evidence for her pedagogical decisions (see Ch8_33). Furthermore, self-reflection has been identified in the literature to be an important feature in the development of effective teaching (Gess‐Newsome & Lederman, 1995; Goodrum et al., 2001; Schön, 1991). Her belief that she should inspire her students' curiosity and appreciation of science in everyday life is consistent with the goals of the *Victorian Curriculum: Science* (VCAA, 2017e). As ASTA Standard 4 (ASTA, 2009, p. 16) states, highly accomplished science teachers, ‘use real life contexts to make their students’ learning meaningful and to enable students to develop connections with their own world and personal experiences’.

8.4.1.2 Preparation and developing engaging practice

Hannah’s childhood on the farm taught her about real life and to be practical. She believes this has helped her with teaching science.

> *I always try to bring real life examples in and being on the farm you're exposed to an awful lot. You don't realise how much until you start talking about it. ...it's the story telling that makes it real, rather than just a list of facts you have to memorise* (Ch8_52).

From her own experiences as a student in secondary school, Hannah believes that learning is more engaging for students if there is more than just book work involved (see Ch8_6nr). Thus, she believes that it is important to share everyday examples with students, no matter what topic they are learning (see Ch8_22). Hannah told me that the foundation for planning is for the lesson to be *less time writing, more time doing, talking, listening* (Ch8_53).

Hannah has a strong belief in teaching by inquiry, incorporating Socratic questioning into her classroom (see Ch8_31) and hands-on activities (see Ch8_11nr). Hannah believes that STEM projects are the best way to incorporate this approach; making connections to real life and involving hands-on activities. Besides learning about the science concepts, Hannah believes that students should also learn generic capabilities, ready for future work.

> *I thought about what explicit skills we can teach. It includes being able to work in a group, be able to give and take feedback, being able to plan out projects, being able to give presentations, being able to 'sell yourself'/apply for a job* (Ch8_54).

To incorporate these beliefs into her lessons, Hannah’s planning considerations are complex. Her planning requires her to have a comprehensive understanding of the scope and sequence of the whole curriculum so that she can integrate skills and knowledge from other learning areas into her lessons. She requires a rigorous understanding of the science concepts and she needs to know everyday examples that are the best illustrations of the concepts. Finally, Hannah also needs to know her students’ interests and abilities to ensure it is all delivered with relevance. In other words, for Hannah’s beliefs to be seen in practice, requires her to demonstrate the skills and knowledge stated in all of ASTA Standards 1 to 8 (ASTA, 2009).

Hannah believes that homework plays a role in learning. In planning homework tasks, she draws on her knowledge of neuroscience, so it is the *right type ...consolidates the key concepts covered in the classroom*. In an opinion piece for a blog, Hannah wrote that homework should:

- *be relevant to the concept being taught in class*
- *get parents involved in sharing of information*
- *be pitched at a student's age and skill so there is a high chance of success*
- *be checked with the students afterwards so it becomes a part of long-term memory*

(Ch8_55).

Hannah's belief in regularly checking homework is consistent with Devine et al.'s (2013) research. where female teachers in all-girls' schools also believed this is part of good planning. Interestingly, they found this was not the belief of teachers in other contexts such as all boy or co-educational settings (Devine et al., 2013). Designing homework where parents can be involved is consistent with Hannah's experiences as a child, where both her parents were interested and involved in her studies (see section 8.2.1.1) and in Hannah's joy in her own children's learning (see Ch8_18nr). In her summary of educational research on effective homework, Carr (2013) asserts that the right type and amount of homework has a positive influence on achievement. She states that the homework should be explicitly related to the classwork and provide teachers with feedback about student understanding (Carr, 2013).

8.4.1.3 Relationships

Respect is an important aspect of Hannah's beliefs about relationships. During her own secondary schooling, Hannah did not respect many of her teachers. Those that did have her respect had it because of their knowledge (see Ch8_3) and ability to challenge her thinking (see Ch8_6nr).

Hannah found the experience of moving to Melbourne from her small, rural town for university to be very daunting both personally and academically (see Ch8_15). She told me that throwing herself into her coursework and then her research, helped her find a purpose and a sense of belonging. Hannah did a lot of CRT work in her early career at Crossley College (see section 8.2.2.1) where she developed a sense of belonging due to the long association with the school and its similarity to her own secondary school in the country. This sense did not continue when Hannah moved to teach at Menna College. Here, she felt isolated under the leadership of Head of science of the time and the school's context was unfamiliar to her previous experiences. Together, these experiences influenced her current approach to relationships with her colleagues and students. Firstly, Hannah's current description of how she leads the science faculty highlights her belief in the importance of personal relationships and the importance that everyone feels that they belong (see Ch8_38). Secondly, Hannah believes in explicitly teaching teamwork skills to her students (see Ch8_54). Olitsky (2007) found positive, sustained student engagement in learning when there was a sense of belonging to a community. This is consistent with ASTA Standards 5 and 11 (ASTA, 2002), as she ensures that both her classroom and the science faculty have a sense of community which are warm supportive and mutually respectful.

8.4.1.4 Assessment

Hannah believes that success is individual and *is not one particular mark*. She lists several criteria that are indicators of successful learning:

- *a positive comparison to previous learning*
- *ability to re-engagement and trying harder after a 'failure'*
- *ability to apply a science concept in the outside world*
- *asking more questions*

(Ch8_60)

The application of science to the outside world is an important indicator of learning for Hannah.

> *I had one student who went snorkelling and came back really excited, showing me a picture of the air bubbles under the ocean. She told me, 'I realised that was from cellular respiration'. So that's success for me, but I find it is success for them because they're applying it, which means they're remembering and understanding it* (Ch8_61).

Hannah believes in using many types of formative feedback. The STEM projects require students to *give and take feedback* (Ch8_56). One of Hannah's year 9 students told me that Hannah read a draft of a practical report and gave her feedback, so she could modify it before finally submitting it.

Hannah is conscious of assessment being objective and evidence based. This is demonstrated by her first priority in becoming Head of science – standardising assessment of practical reports from years 7 to 12 (see Ch8_28).

Hannah's use of STEM projects allows her students to give and receive feedback during the learning process and also provides Hannah with on-going data to support further learning. Matese, Griesdorn and Edelson (2002) suggest that such authentic assessment practices are critical for inquiry-based learning to occur. Hannah's beliefs in assessment, along with her beliefs about giving her students practical, real-life tasks, means the focus is on developing her students' understanding and skills so they can keep improving.

8.4.2 Beliefs about science

Many of Hannah's beliefs about science developed during her childhood. Growing up on an isolated farm, she spent time with her father doing practical tasks around the farm and talking with him about all things involving science (see Ch8_2nr, Ch8_11nr). Both her parents instilled a respect for knowledge in Hannah; books were special, and learning was an opportunity (see Ch8_8nr, Ch8_12nr). After experiencing boredom during work-experience in a library, Hannah changed her career plans from librarian to science researcher. Although she was not sure about what a researcher did, it appealed to Hannah as she was curious, and it sounded prestigious (see Ch8_10nr). These parts of Hannah's story show that she believes that knowledge is powerful; it gave her leverage to go to university, leaving the farm-life behind her. Her pursuit in being a research scientist shows that she believes that science gave her the opportunity for an interesting and academically challenging career. This new purpose heightened her interest in science in the senior years of secondary school and was accompanied by interesting teachers and experiences. Before this, her experience of school science was not memorable, challenging or relevant (see Ch8_6nr). Hannah believes practical and real-life applications are important aspects of science.

> *I've always tried to make it relevant to what they might see or experience in the real world as much as possible. Otherwise you're just learning bits of information* (Ch8_57).

She believes that connecting each science concept with a real-life example is important in allowing her to share her passion for science and create curiosity amongst her students (see Ch8_21nr, Ch8_55).

Hannah loved learning science at university and then working as a scientist in the laboratory. These experiences emphasized two things. Firstly, that science requires understanding rather than memorization of facts. Secondly, scientists work on projects in teams and so inquiry and collaboration skills are important. Hannah believes that the STEM projects allow students to do learn science and address both of these aspects.

> *Our STEM projects are relevant to the curriculum and relevant to the students and I'm finding the students are responding really well. ...scientific literacy is being able to read about it and talk about science and to understand it. ...Inquiry is about giving them the knowledge of what we know then going, 'what if...?'. ...exploring the limits around a particular concept* (Ch8_58).

Hannah believes science should prepare her students for participation in society.

> *You've got to have a basic understanding of what not to mix in the bathroom. You've got to ...be able to argue the Big Bang Theory ...understand the big things or else you can't effectively begin to discuss intelligently science in the outside world* (Ch8_59).

Her textbooks for middle school science promote the skills and knowledge that will help students in their VCE studies (see Ch8_25nr). This shows Hannah believes that middle school science should prepare students for further studies in science.

Hannah's beliefs about the purpose of science education are like Lindy and William's in that she emphasises scientific literacy and the skills that will assist them to keep learning. This is consistent with recommendations from research for school science (Rennie et al., 2001) and the rationale of the *Victorian Curriculum: Science* (VCAA, 2017e).

8.5 Conclusion

This chapter has discussed Hannah's professional knowledge, personal attributes and beliefs about teaching and learning science. Besides having an excellent knowledge of science taught in school, she has an extensive general knowledge due to her love of reading. Hannah's pedagogical knowledge has developed through the writing of textbooks for students and the presentation of teaching workshops, particularly for primary school teachers. Her involvement with professional science education organisations is one way for her to keep abreast of current debates about teaching science in schools, but she has also been an active contributor to these associations. Hannah is critically reflective of her practice and is constantly looking for ways to improve her teaching so as to maximise the experience for her students. These are all professional attributes identified by Shulman (1987) as being critical for effective teaching and learning. Hannah's passion for science and for sharing this passion with her students is the most pronounced of her personal attributes. This passion is a driver for her commitment to teaching and her positive relationships with her community. Furthermore, these attributes are all consistent with Keeley's findings in teachers of high quality (Keeley et al., 2006).

The conclusions established about Hannah in this chapter are that she is an excellent teacher who has a passion for sharing her love of science with her students through real life scenarios involving scientific inquiry and hands-on projects. She also has a strong commitment to sharing her science pedagogy with other educators so that they can also impassion their students for science. It can also be concluded that Hannah believes that all students should understand the big ideas of science, since they provide such critical understanding about the world, whether they aim for a career in science or not.

Chapter 9

Factors involved in an excellent science teacher's professional practice - Hannah

9.1 Introduction

This chapter continues the discussion about Hannah, my third case study teacher. I examine Hannah's knowledge, beliefs and current professional practice, particularly in teaching science to a year 9 class. The data is analysed to provide insights into the first and third research questions.

1. How do personal and contextual factors influence teachers' beliefs and practices?
3. How are the beliefs of excellent science teachers demonstrated in their professional practices and classroom teaching?

I begin by discussing Hannah's knowledge and beliefs about the curriculum and their relationship to her practice. I then discuss her practice in terms of teaching and learning, reflective practice and her relationship with students in her classroom. Finally, Hannah's collaboration with her colleagues within the school and with other professional communities are discussed in terms of how this relates to her professional knowledge, beliefs and practice as a science teacher. The data analysed is again drawn from semi-structured interviews, classroom observations and documentation collected from Hannah and her students. The *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and the *Framework for examining beliefs* (Fives & Buehl, 2008) continue to inform my analysis of excellence.

9.2 Analysis of Hannah's teaching and learning practice

9.2.1 Current context

Menna College is a complete contrast to the secondary school Hannah went to as a student (see section 8.2.1.1). Situated about 25 kilometres from Melbourne, Menna College is an all-girls, kindergarten to year 12 independent school, with year 10 school fees being in the top twenty most expensive schools in Victoria (Menna College fee schedule, 2018). It has approximately 1000 students in years 7-12 with 29% of students in the middle bands of the ICSEA scale and 70% in the top band which is above average for Australian schools (ACARA, 2017). Twenty-three percent of the students have a language background other than English. The median VCE score in 2016 was 34 which is above the state mean of 30 and as such has a reputation of being one of Melbourne's leading academic schools (Menna College community report, 2017). In 2016, 98% of Menna College students went on to university. The other 2% chose vocational training (Menna College community report, 2017). Menna College's mission statement is, 'to prepare our students to aspire to excellence, to make a difference and, as global citizens, to rise boldly to the challenges of their times' (Menna College community report, 2017). The school follows the Victorian Curriculum from prep to year 10. It offers an extensive range of extra-curricular experiences which include sports, the arts, Duke of Edinburgh's Award, volunteering in the community and international experiences (Menna College website). Menna College has made a commitment to promote STEM careers for their students, so have a 'culture of engagement and excellence in STEM studies' (Menna College website). Besides the compulsory core science in years 7-10, students can participate in marine studies and competitions run by Engineers Australia, BHP and during Science Week.

Menna College's science faculty is well equipped and supported by a full-time laboratory technician. The layout of the laboratory is standard with table and chairs in the middle of the room and eight large workbenches around the outside. There are enough laboratories for Hannah to teach all her classes in the one laboratory, allowing her to display some items that reflect her personality and interests (see Figures 3-5). Hannah sometimes uses these objects during lessons and students are permitted to touch or 'play' with them. They are a way for Hannah to send the message that *learning and having fun go together* (Ch9_1). As an observer, I noted the displays collectively represent girls in science, the branch of physics and affirmation that scientists can be geeky and socially awkward and laugh at themselves. Walker (2008) and Keeley et al. (2006) both list a sense of humour as an important teacher quality. Although Hannah is the senior biology teacher, the items around her classroom tend to promote the physical sciences. Research indicates females are underrepresented in the physical sciences (Ceci et al., 2014). Hannah is aware of this research and, particularly with Menna College being an all-girls school, tries to address this imbalance by having items of that promote curiosity.

Figure 3 Front of room showing figurines from 'The Big Bang Theory' and a Foucault's Pendulum

Figure 4 A female hand puppet dressed in a laboratory coat

Figure 5 A model cabin built by a year 9 student and used for experiments in a unit on energy

9.2.2 Planning and teaching in practice

9.2.2.1 Prior to the lesson

The main sequence of lessons I observed were part of a unit of work on chemistry. Students were given an imaginary scenario where they were chemical engineers in the Research and Development Department of a factory and Hannah the CEO of the company. They were given the task to improve the quality and quantity of a chemical product. Students were to work in groups, generating biofuel from cooking oil. They had three lessons to consider the variables such as temperature, time for reactions and amount of reactant. At the end, students were required to produce a 'report from the department' for the CEO of the company, with a recommendation of how to maximise the quantity and quality of the oil. Hannah designed this activity with a chemical engineer who was a Scientist in Residence (see section 8.2.2.1) working at the school in the previous year.

The links to the *Victorian Curriculum: Science* are:

- Science for understanding: Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries (VCSSU115)
- Science for understanding: Different types of chemical reactions are used to produce a range of products and can occur at different rates; chemical reactions may be represented by balanced chemical equations (VCSSU125)
- Science inquiry skills: Questioning and predicting (VCSIS134); Planning and conducting (VCSIS135 and VCSIS136); Recording and processing (VCSIS137); Analysing and evaluating (VCSIS138); Communicating (VCSIS140).

(VCAA, 2017e)

In addition, the structure of the project explicitly involved developing skills and knowledge from other learning areas in the Victorian Curriculum:

- Personal and social capability: Evaluate own and others contribution to group tasks, critiquing roles including leadership and provide useful feedback to peers, evaluate task achievement and make recommendations for improvements in relation to team goals (VCPSCSO050).

(VCAA, 2017c)

- Ethical understanding: Investigate how different factors involved in ethical decision-making can be managed by people and groups (VCECD023).

(VCAA, 2017f)

This project highlights three of Hannah's beliefs in practice. Firstly, the task gives students the opportunity to investigate and draw evidence-based conclusions, communicate about science and understand the world. It is consistent with Hannah's beliefs about science (see Ch8_58) and with Crawford's (2007) assertion that teachers need to teach students *about* inquiry, *through* inquiry and *by doing* inquiry. Secondly, besides developing students' inquiry skills and knowledge, the task provides an opportunity for students to develop general capabilities such as collaboration and decision-making (see Ch8_54nr). Not only are group work skills an important part of how scientists work, research shows that it is particularly useful in engaging girls in science, appropriate for Menna College (Tytler et al., 2008). Lastly, the task's scenario is a real-life issue. Students use everyday materials (for example cooking oil) and investigate a current environmental issue (earth's fuel reserves). The imaginative scenario involved students in preparing a report for a company to improve a product. Research has shown that adolescents are more intellectually engaged and interested when applying their knowledge to real-life problems (Campbell et al., 2011; Tytler et al., 2008). Further to the educational research just cited, the strategies used, such as collaboration, real life issue and intellectual engagement, are all found to be effective by educational neuroscience research as well (Robinson, 2017). Finally, Hannah's practice is also consistent with ASTA Standards 6 and 7 (ASTA, 2002) as she develops her students' curiosity and makes meaningful connections between science, other curricula areas and current topics of debate.

9.2.2.1 During the lesson

Before observing each lesson, I conducted a pre-lesson interview with Hannah and asked about her plans for the lesson. She always gave me a detailed response of what the students had done previously and how this lesson was related to it.

> *This is the third lesson on generating biofuel from cooking oil. ...They have to increase the quantity of biofuel they produced in the last lesson and they have to increase the quality of it as measured by density. ...The first lesson was about organisation ...and linking it to the concept they'd learnt, how enzymes/catalysts worked* (Ch9_2).

Like Lindy and William, Hannah did not have a written lesson plan, but she told me her class PowerPoints act as prompts and she modified them for each lesson *depending on where the girls are at*. Hannah's students told me they like how structured the lessons are.

> Student 1: *She puts a lot of work into the PowerPoints. There are always diagrams and things that move that help us to learn better* (Ch9_3).
>
> Student 2: *I love how structured our lesson are. ...We start off writing notes and I love having those notes ...Then we do an experiment to fully understand what we're doing. She makes sure everyone understands before she moves on* (Ch9_4).

Hannah had a mental plan rather than a detailed written one, which is consistent with expert teachers examined by Hattie (2003). Flexible lesson plans allowed them to anticipate student needs and be able to respond so that teaching and learning stayed on track. Hannah's students' comments confirm that this is the case in their lessons.

As the students arrived at the laboratory, I observed that Hannah greeted them as they entered. The girls were quick to settle and were ready to listen. No time was spent on administration such as taking attendance; it was straight into the lesson. One particular lesson was the second is a series for making biofuel. Hannah asked the students how their experiment went in the last lesson. The reply was some nervous laughter and murmurings from the students – obviously they had encountered some problems. Hannah responded with a story. She said that,

> *when I was working in the laboratory, the first time I ran an electrophoresis gel (similar to the chromatography you did in year 7), I connected the wires the wrong way. I lost a whole week's work! ...So, accidents happen, especially the first time you try it. So, quick check with your neighbour, what went wrong? How can you fix it?* (Ch9_5).

Hannah then gave students a couple of minutes to discuss the issues they had in the last lesson with making biofuel for the first time. Each pair then contributed an idea for how they would improve their method. Hannah's story and the time given for students to share their solutions created a positive working environment, where mistakes were accepted as a part of the learning process. This is consistent with ASTA Standard 5 (ASTA, 2002, p. 17), as the classroom is 'intellectually challenging, emotionally supportive', 'purposeful and learner-centred'. Hannah sharing her experience and empathising with her students' uncertainty and disappointment with their own experiment, is an example of her authenticity and knowledge of science – both important characteristics of excellent teachers (Brookfield, 2006; Faull, 2008).

Continuing with this lesson, Hannah reminded students of the chemistry behind what they were doing in making biofuel. Students already had this on a handout, but Hannah explained what was happening at the molecular level. Her oral explanation was accompanied by diagrams on the whiteboard. This took no more than a couple of minutes, but in addition, she instructed students to try to imagine what was happening to the molecules when they were performing each step of their experiment. Hannah then gave an overview of the remainder of the lesson: students had ten minutes to prepare their mixtures for the water baths; whilst the mixtures were in the water baths students would return to their chairs for a five-minute class discussion about how to calculate the quality of their biofuel (twenty minutes); they would then finish their experiment (twenty minutes). These instructions were finished with a final reminder for the 'safety officers' to ensure everyone wore protective clothing and that chairs were pushed in. During the hands-on activity, I observed all students were on task. There were minimal questions asked of Hannah, probably because this was the second time that they had performed the experiment. Hannah only interrupted the students twice during the activity. On both occasions, she readily got their attention by saying, *eyes on me please. Eyes on me* (Ch9_6). Her information given was delivered succinctly so that students could return to the tasks quickly.

For Hannah to direct students to think about what was happening at the molecular level during the experiment, shows that she knows the importance of students being 'minds-on' during hands-on activities and this is supported by research (National Research Council (NRC), 1996; Rennie et al., 2001). Additionally, students had already performed the experiment once, so instead of thinking about both the manipulative skills *and* linking their observations to theory, during today's task, they could take more notice of the latter. This shows that Hannah prevents cognitive overload during practical tasks by adding to the cognition one step at a time; the first lesson was performing the experiment whilst this lesson was to consider the science concepts involved. Abraham and Millar (2008) found this is an important pedagogical consideration so that the learning demand on students is manageable. Hannah's practices are consistent with ASTA Standard 6 (ASTA, 2002, p. 18), since she allows her students, 'to approach knowledge and experiences critically, recognise problems, ask questions and pose solutions'.

Whilst the students were doing the experiment, Hannah circulated around the room, stopping briefly at each group's work bench to monitor learning. Sometimes she would just ask an open question like, *how are things going?* or giving a hint for *something to consider* which would improve their experimental technique (Ch9_7). For example, the mixture in one group's test tube was not completely immersed in the water bath. Instead of telling students what to do, Hannah posed the question, *if you were sitting in the bath tub up to your waist, would your upper body be warm?* (Ch9_8). Students knew immediately what the problem was, why it was a problem and how to fix it. Another example was when a student asked about what would happen if she added more ethanol to the cooking oil. Instead of just telling her the answer, Hannah asked the student about the role of the ethanol in the reaction and then posed an analogy of the children's game, 'Oranges and Lemons'[27].

> *If you have more catalyst, it's like two people chopping off peoples' heads so it will be faster, and you get more heads in the end. And the chopper doesn't change; it never gets blunt* (Ch9_9).

In the interview after this lesson, Hannah explained her actions.

> *I don't directly answer questions often. Any question they give me, I break down into smaller questions and get them to answer the smaller questions until they've answered the main question themselves* (Ch9_10).

Hannah's interactions with her students during this lesson are consistent with her belief in being a facilitator of learning, rather than a transmitter of knowledge. She engages students' minds by asking questions that provide a scaffold for them to logically connect their knowledge into better understanding the concept. Hannah's knowledge and passion for neuroscience (see Section 8.2.1.2) means that she is conscious of how the brain processes information and this informs her pedagogical practice. Her use of analogies to help students understand a concept shows a deep pedagogical knowledge and is consistent with ASTA Standard 2 (ASTA, 2002) as she chooses analogies to make the content more accessible and interesting.

The end of this lesson was interesting to observe. Hannah gave a warning when there was ten minutes left of the lesson, adding the instruction, *plan*, implying they did not need to pack up yet, but needed to consider whether they should start the next step. The students kept working

[27] 'Oranges and lemons' is a children's singing game in which the players file through an arch made by two of the players. On the last line of the song, these players drop their arms and 'cut off he head' of the player under the arch (Kiddle Encyclopedia, 2019).

on their task. When there was five minutes left, Hannah gave another time warning and a reminder of what needed to be done to pack up the equipment. She was immediately approached by one student who asked if they could stay five minutes longer to finish their experiment. Hannah assented and then said, *thank you for asking* (Ch9_11). At the end of the lesson only one group had packed up and were ready to leave. It was lunchtime, but Hannah did not rush them. Two groups decided they wanted to finish what they were doing, to which Hannah replied, *that's why a lot of research scientists don't work 9am-5pm* (Ch9_12). The last group left the classroom more than fifteen minutes into their lunchtime. I noticed that as each student left, whether on time or later, they all said, *thank you Ms Smith* [pseudonym] (Ch9_13).

That students chose to continue their experiment into their lunchtime shows how invested they were in the task. Additionally, Hannah's willingness to allow them to stay back and finish shows her commitment to her students' learning. The importance of teacher commitment to improved student achievement has been well documented (Altun, 2017; Crosswell & Elliott, 2004; Mart, 2013). Once again, her interactions with the students demonstrate her authenticity as she shares a personal story and promotes mutual respect and politeness, consistent with research of excellent teachers (Faull, 2008). As ASTA Standard 5 (ASTA, 2002, p. 17) states, Hannah's classroom is a place where, 'relationships are warm and supportive and characterised by mutual respect, cooperative behaviour and a sense of community'.

One lesson observed started by the whole class reviewing the answers to homework questions. These questions were from the student textbook. This type of homework is common in Hannah's class. According to her students: *homework might be 4-5 questions or a paragraph or two summarising what we did in class; the questions are all related to what we did that lesson, which is really useful* (Ch9_14).
It was obvious that all students had attempted the homework and were ready to discuss it. Students took turns in raising their hands to read what they had written for their homework, elaborate on answers given by others or respond to related questions that Hannah posed. Hannah's students told me that she always reviewed the homework and how this helped their learning: *...the next lesson we'll correct it all, and she'll make sure we understand it; ...we do the questions to reinforce what we learned* (Ch9_15).

Hannah's students saw the purpose of the science homework, which was to review the previous lesson and to consolidate their understanding of the concept. Hannah's use of homework is consistent with her belief that it should be to review the lesson and be checked afterwards so it is revisited again to aid understanding (see Ch8_55nr). The high compliance of students completing the homework is not a surprise, as the academic expectations from parents and teachers is high at Menna College. In addition, Hannah told me there were only two students in this class who were *really weak*, and the majority were *highly able*. Carr (2013) suggested that if homework was both relevant and achievable, then it was effective at improving student learning. It also shows that Hannah is aware of research showing that homework that it too time consuming or too difficult can have negative effects on student well-being and engagement (Galloway et al., 2013).

As students had arrived for this class, Hannah asked one of them to put a plastic cup on the desk in front of each student. Whilst the discussion about homework occurred, Hannah walked around the room. Each time a student made a contribution to the discussion, she put a counter in the cup on their desk, and the end of the lesson, these were counted. On this occasion, students with fewer than three counters for the lesson had to write a summary paragraph of the concepts introduced in this lesson for homework. Sometimes, Hannah organizes the 'counter system' as a team-based activity. Other times, those with more than ten counters are able to choose a small prize, such as an item of stationery with science images on it. Afterwards, Hannah explained that,

> *The counters help me to keep track of who is participating in class ...and gives everyone the opportunity. It's in a non-threatening way because they can choose when they are going to contribute* (Ch9_16).

Besides the teaching and learning strategies described above, I also observed Hannah use others such as mind maps, role plays, videos and animations. Hannah's students told me that even if it is just twenty minutes of a lesson, there is always a hands-on activity to complement the concept they are learning. They said discussions occur regularly; as a whole class or in small groups. The students also shared that Hannah always gives examples of where the concept is evident in the real world. I asked the students about the PowerPoints that Hannah prepares for each class. From observation, I had noted that these formed the basis of discussion rather than just a one-way transmission of information. Hannah's students' comments corroborated with my analysis.

Student 1: *When she explains things from the notes, she says, 'discuss it with your partner' then if you got it right, 'high-5 if you got it right' and then everyone gives each other a high-5 (laughter from other students), and then we move on.*

Student 2: *I like how she gets us to explain to each other in our words* (Ch9_17).

Students reported that they write a whole laboratory report about once per term. Some parts of the laboratory report are written during class time, but they are usually completed over a number of homework sessions.

Student 1: *By the end of writing up a prac, I actually really understand it.*

Student 2: *Yeah. Even the 'introduction'. I like it because we do a lot of research online and go through our notes* (Ch9_18).

This section has shown that Hannah's classrooms are interactive and hands-on, highlighted her belief in active learning and collaboration (see Ch8_53). Her strategies promote inquiry and student engagement in their learning, which research has found to be critical for optimizing learning conditions (Bransford et al., 2000; Weimer, 2013). Hannah's strategies aim to give students confidence to be involved in their learning (see Ch9_16), promoting independence and interest in learning. This is consistent with ASTA Standard 5 (ASTA, 2002, p. 17) as she promotes, 'intellectual risk-taking and persistence'.

9.2.3 Assessment of, for and as learning

During the lessons observed, Hannah provided many opportunities for formative assessment. Quotes Ch9_14 and Ch9_17 are evidence that Hannah relies on students to provide and receive peer feedback to increase their understanding. Instead of directly answering a student's query about something they should already know, Hannah tries to use questions to guide the student to figure out the answer themselves (see Ch9_10**,** Ch9_24**).**

Hannah uses strategies to inform her teaching through students giving her feedback about their understanding. One student commented that,

She'll ask everyone, by asking us to have 'thumbs up' if we've got it, 'thumbs down' if we need another example or for her to explain it some more, or 'thumbs sideways' if we're unsure (Ch9_19).

Hannah told me she also checks students' understanding by *listening to their answers and checking how confidently they talk to each other or offer answers* (Ch9_20). She also explained that when she gets student to give 'high fives' (see Ch9_17nr) it gives her *immediate feedback of what percentage of the class understood the question* (Ch9_21).

Hannah gives explicit feedback to students about their learning. For example, during an experiment, I observed Hannah stop near a group of three students who were discussing how to improve their experiment. She tells them exactly what they did well.

> *Can I just say, you do my heart good by talking about the variables, or using all the science language? It makes me feel good. You've made my day. Thank you* (Ch9_22).

Hannah also uses explicit feedback in her written comments on summative tasks.

> *Your report indicates that you have a good understanding of the key concepts of electron shells and how they are applied to fireworks. Things to consider in your next report are: include the why/because in the hypothesis; include how the controlled variables are controlled; provide evidence to support your answers in the discussion section.* (Ch9_23).

Quote Ch9_20 also illustrates that her feedback is always given positively. Another example where Hannah framed her feedback to encourage students was when a group produced a biodiesel sample with high contamination and the students were disappointed. Hannah responded,

> *That's OK, but I probably wouldn't put it in my car. But it gives you a starting point. Think about what you're going to do to improve it next time, rather than, 'this is no good'. What are you going to do about it?* (Ch9_24).

This section demonstrates Hannah's belief in using a range of feedback strategies to inform student learning (see Ch8_56) and her belief in being explicit in her language (see Ch8_51). Formative assessment is integral to Hannah's pedagogy as it is part of all aspects of tasks she sets and how she structures the class. Furthermore, many questions require students to apply science their understanding to the real-world. This illustrates her belief in science education not just being a collection of learned facts (see Ch8_52). ASTA Standard 9 (ASTA, 2002, p. 22) states, 'highly accomplished teachers of science use a wide variety of strategies, coherent with learning goals, to monitor and assess students' learning and provide effective feedback'.

9.2.4 Relationships

I observed Hannah's classroom to be a place of mutual respect where everyone is made to feel valued and included. On my first day, Hannah introduced me to the students and reassured them that I was observing her teach, rather than them learning (to which they all smiled or giggled). Hannah role-modelled tone and language that was cordial and respectful (see Ch9_11, Ch9_22). During the lessons observed, there were many examples of Hannah interacting with the students as individuals, small groups and as a class. The groups for the biofuels experiment were organised so one student had the role of 'communicator' who was meant to be the only one who could approach Hannah for advice. The communicator could only do this if the whole group had discussed the problem and it was still an issue. This strategy freed Hannah up to monitor and interact with groups in her own time (see Ch9_7). Hannah's students agreed that she is always positive, and they appreciate her enthusiasm too.

> Student 1: *She's always there to help. She's always walking around the classroom making sure everyone is understanding what they're doing. She'll explain what we're doing, but still getting us to work it out ourselves, but still being there in case.*
>
> Student 2: *She's always positive so we're always excited to learn more.*
>
> Student 3: *I could just tell that this is something that she loves doing. She finds in interesting* (Ch9_25).

During the discussion of homework, Hannah would draw attention to a student's response so that all students could recognise why it was a good explanation.

> *Read it out again because I really like what you said …. It was really good because it asked you to compare and so you mentioned both of them* (Ch9_26).

She also encouraged students to collaborate and participate.

> *Choose a friend to help you. ...This question is for those who have only got 1 counter in their cup* (Ch9_27).

Further to these observations, Hannah told me of a past class discussion when she was reviewing answers to a test with a class. She noticed that one student seemed upset.

> *She didn't do very well on the test. So, I caught her eye whilst I was saying, 'even if you're disappointed with your result, give yourself a pat on the back because we actually only had a short time to study this topic and every result was respectable when you take that into account'* (Ch9_28).

Hannah's classroom is very inclusive, where everyone has their strengths, and everyone is on a learning journey. Hannah's interactions and manner with her students show her care and respect for them as young people in her care. She creates an environment where it is safe for students to be and the focus is on learning. This is similar to the reassurance she found when she threw herself into her own tertiary studies (see Ch8_15nr) and is consistent with her beliefs in a respectful community (see section 8.4.1.3). Hannah's relationship with her students is consistent with the findings of Bolshakova and Johnson (2011) who found that student outcomes were enhanced by teachers who created classrooms with a sense of belonging; where relationships were respectful and supportive. Furthermore, the vision for the ASTA Standards (ASTA, 2002, p. 9) states, that the 'mutual trust and respect between teacher and student ...draws upon a wide range of knowledge and expertise ...to develop agile, critical and questioning minds'.

Hannah will often share stories from past experiences relevant to the topic being studied, which creates a connection with students. For example, before students started making biofuel, they had to 'apply' for roles within their group – two engineers, communicator, safety officer and a scribe. Some students found it difficult to talk about and their strengths. Hannah retold a story about her sister, so they would understand the importance of being able to 'sell themselves' (see Ch8_37nr). Further examples of Hannah sharing stories from her own life is evident in quotes Ch9_5 and Ch9_12. The students I interviewed appreciate this sharing. One student commented, *she always tells us extra things. ...she tells us stories about science and it's really cool. I really like the way she puts stuff into the real world* (Ch9_29). The students also respect her past experience and knowledge. They know that she is the author of the textbook they use. During the focus group, one of the students commented, *...she wrote the textbook. For all of Australia, or Victoria. And it's really good. It's because she explains it so well* (Ch9_30).

Students' comments about their science lessons, show that the real-life scenarios are critical to their interest, understanding and appreciation of science in their own world. Two students commented,

> *the stuff that we're learning we connect it to the world and what's happening and also to experiments. We're understanding how things work; ...it's really helpful to learn like that because you are constantly applying it* (Ch9_31).

Hannah's passion for science and learning was also evident to a student who travelled on a school trip with her to Malaysia.

> *You can just tell how much she enjoys it. It was really interesting for us ...She always had really interesting points to add that we wouldn't have thought of if it wasn't for her. ...She's excited to tell us* (Ch9_32).

Students' experience of learning science is consistent with Hannah's belief about her role as their teacher in connecting their learning to real life (see Ch8_50). Hobbs (2012, p. 724) concluded that a teacher sharing stories, 'gives the subject personal meaning'. Brookfield (2006) states that students value teachers who are open and honest and who make them feel confident that what they are learning is substantial. Hannah does all of this through her personal stories and connections to real life. Hannah's story telling is another way for her to share her passion for science with her students (see Ch8_21nr and Ch8_44). ASTA Standard 8 (ASTA, 2002) describes the importance of the teacher giving students confidence to use their knowledge in the future. Furthermore, ASTA Standard 3 (ASTA, 2002, p. 14) states how highly accomplished teachers can 'shape effectively the mood and the functioning of a class'.

9.3 Collegiality, collaboration and personal practice

Hannah has been at Menna College for fifteen years. During this time, she has been involved in many aspects of school life. As described in section 8.2.2.1, she has held formal positions of responsibility; Heads of year, running the Duke of Edinburgh Award program and her current role as Head of science. Hannah has also been involved outside of her job description by working with the primary teachers at Menna College to improve the junior science program and attending school camps and trips. I observed two other aspects of her collegiality. Firstly, although there is no central work area for science teachers (see section 8.3.1), a graduate teacher had been employed that year and Hannah requested that she share her office space. This new teacher told me that although her first year had been a steep learning curve, Hannah had been a fantastic support.

> *She's so busy but always makes time ...gives me advice when I want it. She's been amazing. So supportive and always so positive* (Ch9_33).

During science week, Hannah organized for all the science teachers to provide a staff morning tea. Hannah did all the setting up before the recess break. It included conical flasks of colourful solutions and dried ice billowing over the table. The staff not only enjoyed the food but also the fun decorations. Hannah made a short speech where she acknowledged the science faculty as being a *great team of teachers* (Ch9_34).

This shows evidence that Hannah understands the importance of a professional learning community (Hord, 1997). As faculty leader, she is a role model for other teachers. She consistently shows her dedication to improving the experience of science within the school for both teachers and students. Lomos, Hofman and Bosker (2011) found that collaborative faculties such as this were associated with successful schools and higher student achievement. Her actions are consistent with ASTA Standard 11 (ASTA, 2002), which states the importance of a positive and supportive staff culture in best practice.

Hannah's involvement with supporting science education beyond Menna College has been discussed in Chapter 8. To reiterate, Hannah has been actively involved in science education at both the Victorian (STAV) and National (ASTA) levels. She has provided leadership by providing professional development opportunities through initiating workshops, presenting at conferences and preparing online, interactive material for teachers from ELC to year 12. Hannah has written science textbooks for students and teachers in schools and she has written opinion pieces to add to educational debate about topics such as homework and science communication skills.

Hannah's involvement with science education beyond her immediate job is consistent with ASTA Standard 11 (ASTA, 2002) as she works collegially with the wider community to promote the quality of science education as well as keeping abreast of contemporary issues in education.

9.4 Conclusion

The evidence collected in this case study demonstrates that Hannah is an excellent science teacher. She has excellent pedagogical content knowledge. Hannah believes in teaching beyond the *Victorian Curriculum: Science* to include general capabilities for life-long learning success. She is a strong proponent of life-long learning and this is seen in her zeal for creating new units of work and sharing her knowledge with other teachers, so they also can improve their students' experiences. Hannah has strong beliefs about utilising pedagogical approaches that engage adolescents, so she uses problem-based or inquiry methods with lots of discussion and collaboration so students to think deeply about concepts. There is mutual respect between Hannah and her students, which means her classroom is a safe and challenging environment. In addition, Hannah is critical of her own practice and is always looking for feedback to improve her own students' experience of science education. Moreover, Hannah is passionate about science and about sharing it with others. This passion is demonstrated in her commitment to her work and the time and effort she dedicates to improving her teaching practice. Hannah uses her passion to enthuse her students to understand the role science plays in their lives.

The conclusions established about Hannah are that she is an excellent teacher who has a strong commitment to doing her best and contributing to make science education engaging for students. This means she is always striving to improve her understanding of how students learn and to create authentic, contemporary inquiry-based projects. Her passion for science and for sharing her love of science with others is an important factor that enthuses students and teachers around her to learn more about science. Finally, Hannah's relationship with her students in based on mutual respect and genuine interest in her students' learning.

Chapter 10 Discussion

10.1 Introduction

In this study, I have analysed the factors that have influenced the beliefs and practices of three excellent science teachers. Although their life journeys, contexts, professional knowledge and personal attributes have some similarities, there are variations in the relative significance of the factors involved in the development of their excellence. In this chapter, I provide a synthesis of key findings about each person and draw some conclusions about how knowledge, personal attributes and beliefs are influential for each of these teachers.

10.2 Professional knowledge

10.2.1 Knowledge, beliefs and practices of science and education

The ASTA Standards state that highly accomplished teachers need to have deep subject matter knowledge (ASTA, 2002). In my study, all three teachers demonstrated that they had deep professional knowledge through the formal qualifications in science they acquired early in their careers at the tertiary level, that they continued to apply and develop as classroom teachers in schools. Lindy and Hannah both majored in science in their undergraduate degrees, with the addition of an Honours year which required them to complete a scientific research project. Both Lindy and Hannah's science degrees focused on areas of biological and chemical science (see sections 4.2 and 8.2). William completed a Bachelor of Education, with majors in chemistry and maths.

In my study, I found frequent examples of the teachers' capacity to use their theoretical knowledge of science concepts and to transfer this in their practice through authentic application to real-life. I observed all three teachers refer to everyday instances of the science concept in their excellent classroom practice, in order to build their students' conceptual understanding. An example is Hannah's biofuel project, which was based on a scenario where her students were put in the role of being researchers for an industry. They needed to consider what factors could provide a sustainable supply of high quality and economically viable fuel for the family car. The problem-solving task encouraged them to apply their understanding of catalysts and chemical reactions whilst considering the implications for their family and future. This showed how Hannah provided students with an authentic application of the concept they were studying to maximise their understanding.

Lindy also used authentic approaches to build conceptual understanding, such as in the change of state unit where she allowed students to choose which material to heat and cool. In groups of three, students designed and carried out their investigations over a period of a few lessons. They were given time to reflect on their design and to make changes. This showed how Lindy provided students with the opportunity to learn and improve from mistakes and understand the process of science inquiry.

In one genetics lesson I observed, William had discussions with his students during the unit about which diseases and health conditions are due to a person's genetics. This demonstrated that William does not just rely on knowledge of science from his tertiary studies, as he did not study any biology whilst at university, but that he is always learning and increasing his science knowledge. It shows that he enacts his belief in being a life-long learner by researching the topics that he teaches. (Ch6_25nr and section 6.3.2). All three teachers expressed the view that that they link their everyday experiences to science; they are curious and constantly seek to understand new phenomenon when they encounter it and want their students to also be engaged Both their formal and informal learning of science aided these teachers in planning and conducting their lessons. Interestingly, William, Hannah and Lindy's approaches to their own learning is consistent with the aims of the Victorian Science Curriculum for students since they have,

> 'A solid foundation of knowledge of the ...sciences, including being able to select and integrate the scientific knowledge and methods needed to ...apply that understanding to new situations and events'. (VCAA, 2017e)

In addition to their formal science content knowledge, the teachers developed their knowledge of the scientific inquiry process, which is an important part of science teaching and learning. This aligns with a major aim of the Victorian Science Curriculum for students in years 7-10 to gain, 'an understanding of the nature of scientific inquiry and the ability to use a range of scientific inquiry methods (VCAA, 2017e). Lindy and Hannah had first-hand experience of scientific inquiry through their work in research laboratories prior to their teaching careers (see sections 4.2.2 and 8.2.1.2.). They both believe that students should learn about scientific inquiry through hands-on experiences in science classes (see Ch4_63nr and section 9.2.2). Although William did not have the same research laboratory experience, he believes in inquiry approaches and thinks students can learn best when he can link concepts to practical projects (see Ch6_34nr and Ch6_35).

Interestingly, all three teachers demonstrated high level knowledge of the Victorian Curriculum in science learning areas for years 7-10 and other areas of the curriculum up to year 12. This breadth of knowledge has been gained through teaching experiences and collaborations with teachers in other areas. Prior to becoming a teacher, Lindy 'communicated' science through outreach programs to the general public (see section 4.2.2). Lindy's knowledge of other subjects grew when she taught in the cross-curricular year 9 program at her first school, Firlake College (see section 4.2.3.1). She also has experience in teaching VCE biology and chemistry. In the first ten years of her teaching career, Hannah did CRT work and taught students in a range of subjects (see section 8.2.2.1). Besides teaching VCE biology, Hannah has done a lot of work with students and teachers in primary school science programs (see section 8.2.2.1) and her personal, voracious interest in reading added to her general knowledge. William has taught a range of maths and science subjects in the VCE and has worked with primary schools, their teachers and students in their science programs for many years. It was evident therefore, that another element of the excellence of the three teachers is their expansive knowledge of the scope and sequence of science learning that developed across the years and also their capacity to be engaged in integrated and subject based teaching at various year levels. All three teachers' depth and breadth of knowledge of the intended curriculum means they are innovative in their enacted curriculum, thereby designing units of work and lessons which are rich, intellectually engaging and authentic for their students.

Similarly, Arzi and White's (2007) longitudinal study of secondary science teachers, also showed an increased knowledge due their experience in teaching other subjects, however, they found that this knowledge tended to be *fragmented* according to the curriculum. In contrast, Hannah, William and Lindy's reflections on their past experiences meant that their classroom practice showed *integration* of their content knowledge. This allowed them to make links between and within concepts to aide in how they planned to develop their students understanding.

10.2.2 Knowledge, beliefs and practices of pedagogy

The ASTA Standards state that highly accomplished teachers know how to help others learn science (ASTA, 2002). My case study teachers all have formal qualifications in science education: Lindy and Hannah in teaching biology and chemistry and William in teaching chemistry and maths. However, in teaching years 7-10 science, teachers are often required to teach 'within-field' but 'out-of-discipline' (Arzi & White, 2007, p. 247). In my study, Hannah and Lindy were observed whilst teaching units of work in their disciplinary expertise of chemistry. In contrast, William was teaching a unit in genetics, which is outside his expertise of chemistry and maths. Based on their formal qualifications, their years of teaching experience and on my observations of their classroom practice, I concluded that all three teachers have excellent pedagogical practices when teaching the topics observed. All three demonstrated deep knowledge of the content and the capacity to use high-quality teaching practices that maximised student learning. They all planned their lessons to develop deep understanding of critical science concepts and questions through including engaging pedagogy; hands-on, inquiry-based activities, discussions of the concepts and links to real life examples (see sections 5.2.1.2, 7.2.2.1 and 9.2.2.1). Furthermore, they built multiple forms of formative feedback into their lessons to inform both their students and themselves about the learning progression and achievements of students. This is evidence of their belief in the effectiveness of these particular strategies (see Ch4_42nr, Ch4_63nr and sections 6.4.1.2, 8.4.1.2) and the alignment of their beliefs about planning effectively and building ongoing assessment into their teaching practices. My findings also show that the varied pedagogies impact on the students' engagement, enjoyment, understanding and appreciation of science (see Ch5_9nr, Ch5_12nr, Ch5_14nr, Ch7_11, Ch7_12, Ch7_13, Ch9_21 and Ch9_31). This demonstrates the enactment of these teachers' beliefs in their teaching and ultimately in the outcomes they believe are important for their students. These findings suggest that an alignment between a science teacher's beliefs about pedagogy and their pedagogical practices are important factors in their excellence.

10.2.3 Knowledge, beliefs and practices of past experiences and contexts

The ASTA Standards acknowledge the importance of school context in the work of highly accomplished science teachers, stating that teachers have 'rich and deep local knowledge about their students and the school community' (ASTA, 2009, p. 6). Whilst the teachers in my study all teach science in years 7-10, they teach in different schools with different student needs and expectations. In addition, the teachers have had experiences in their past contexts which influence their current beliefs and practices in teaching science.

Lindy and Hannah both taught in all-girls schools where girls were encouraged to pursue STEM. Lindy and Hannah planned to ensure their students enjoyed and experienced success in learning science, by including collaborative and problem-solving tasks. Tytler et al. (2008) reported that girls have a preference for collaborative learning and presenting the human side of STEM subjects positively impacts their career aspirations. This aligns with Lindy and Hannah’s own experiences of learning science and their subsequent experiences in scientific research. Both teachers experienced the excitement of investigating scientific problems at university and enjoyed the collaborative work during their work in their research laboratories. Meridale College and Sandhope College, where Lindy and William teach, have similar contexts to the schools that Lindy and William experienced as students. Lindy attended an all-girls catholic college and William a co-educational government school, both with low ICSEA ranks similar to their current schools. Furthermore, William has been teaching at Sandhope College for 33 years, so he is very familiar with this context. Their lived experiences give Lindy and William knowledge and understanding of their students’ lives and parental aspirations. They both believe they should attend to their students’ pastoral needs so that learning episodes can be more focused. They challenge their students to try their best as they believe in the role of education in opening choices in careers after school. Lindy and Williams’ lessons included explicit attention to vocabulary and literacy skills for their students as an added element in building their learning success.

Hannah’s experience as a student was quite different from students in her current school, since she was educated at a small, remote government school where the majority of students finished after year 10. Menna College is a suburban, leading private girls’ school with a high expectation of students’ academic paths leading to eal ty studies. But at the time of my study, Hannah had been a teacher at the school for 15 years and a parent, since her two daughters attended the school, so she had a strong understanding of her students and the school community. I observed evidence that Hannah’s relationship with her students was more formal and not as ‘outwardly pastoral’ as Lindy and William’s, but her students knew she had high expectations for them and was caring. She knew how to cater for every student’s learning needs, treat them respectfully and was excited by their achievements. These findings are in line with Kelly-Jackson’s (2011, p. 412) study, where the teacher was described as being ‘culturally relevant’ as she held her students and the community in high regard and believed that her students could be successful in life and learning.

Along with the knowledge of their current contexts, all the teachers have been influenced by past experiences. Beliefs are formed by past experiences and are influential in teachers’ actions in the present (Pajares, 1992). They reported that as students, their science classes in years 7-10 were boring and irrelevant. Their negative memories of their time in middle school science was partially due to the didactic teaching and memorization required by their teachers, but probably also due to their own interests and priorities at the time. All the teachers had career plans that did not require a knowledge of science: William planned to be a carpenter, Hannah a librarian and Lindy, a lawyer. None of them aspired to pursue careers in science until after year 10. But once they made the decision to be teachers, and became immersed in their practice, they enacted their beliefs about explicitly making science interesting and relevant to all students, so they can be motivated engaged learners who will develop into well informed, scientifically literate citizens. This aligns with the aims of the *Victorian Curriculum: Science* for students to develop, 'an 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' (VCAA, 2017e). Their beliefs and practices reflect Goodrum et al.'s (2001) view about the importance of student interest in learning science and developing a scientifically literate society.

Existing literature shows that past contexts impact on teachers' beliefs and knowledge. The contexts of the first five years of these teachers' careers were very different, yet particularly crucial in developing their beliefs and pedagogical knowledge. William was left to his own devices; as long the students were behaving (see Ch6_6), no one was concerned about how he developed and enacted his teaching practice. He discovered that the students enjoyed the hands-on, purposeful, authentic activities he planned, and were engaged in learning. Hannah's development during her early career was also with minimal guidance, as she worked as a relief teacher. She discovered that relating the topic to real life and explaining to students the relevance of the science to life, no matter what the subject, worked well with motivating student engagement.

By contrast, Lindy's first five years was rich with professional discussion, collaboration and reflective practice in the field of science. She was supported by other colleagues and her pedagogical knowledge was challenged. She was encouraged to take risks in her teaching. She learnt the importance of being flexible in her planning so that her students' progress can inform the direction of the lesson. Findings from past research have demonstrated the impact of the first five years of a teacher's career on their knowledge, beliefs and practice. (See for example, Johnson & Birkeland, 2003; Le Cornu, 2013). Lindy's experience corroborates research which reports on the positive effects of being part of a collaborative, professional learning community environment (Johnson & Birkeland, 2003; Le Cornu, 2013). Paniagua and Sánchez-Martí's

(2018) findings also support Lindy's early career experience as an ideal context in which to foster innovative teaching. However, Hannah's and William's autonomous experiences during their early career appear to contradict these findings. All three teachers developed beliefs and skills to be critically reflective and innovative in their current teaching practice. Lindy's different background context is an interesting outcome of my study which deserves further investigation to be understood more fully. But the evidence I found was that all the teachers had passionate commitment to planning effective and authentic lessons and had become reflective practitioners who knew how to engage their students actively in their learning. Further research on the ongoing influence of the first five years on experienced teachers' practice is warranted.

10.3 Personal attributes

10.3.1 Beliefs and practices: Passion

One of the visions in the ASTA Standards (ASTA, 2002, p. 8) is that science teachers, 'have a passion for science, for learning and for growth in the knowledge and capabilities of their students'. Lindy, William and Hannah's passion for science and for teaching science was indisputably evident to me during our interviews and to their students in their classes. All the teachers expressed the excitement they felt when their students understood a concept or asked a question relating the science to their everyday experiences. They all expressed pride in the part they played when they heard of a student choosing to study science beyond the compulsory years or a career in science. These teachers' passion for teaching science was evident in the way they described their preparation to teach. Although they all spent a lot of time in planning units of work (discussed in section 10.3.3), none of them expressed resentment, frustration or disdain for this part of their work. Instead, they spoke positively of their planning and the importance of making the unit engaging and interesting for the benefit their students' learning. Their passion for their work was recognised by their students, who commented that this stimulated their interest in learning science. Hudson and Kidman (2008) also found that a teacher's passion for teaching and learning science has a long-lasting influence on students' engagement and enjoyment of learning science.

10.3.2 Beliefs and practices: Reflective practice

ASTA Standard 10 (ASTA, 2002, p. 24) states that science teachers should, 'consistently, systematically and critically review all aspects of their practice to improve their students' learning'. All three teachers are highly reflective about their teaching practice. In every post-lesson interview with me, they articulated the strengths and weaknesses of their lessons. They were also highly reflective about the reasons for their planning decisions in the pre-lesson interview for the next lesson and were able to explain what actions they would take to ameliorate their concerns and make sure that they followed up on what students required to continue their learning progression effectively. Their reflections resulted in them using different strategies in the classroom, and was based on their beliefs, so Lindy, William and Hannah kept true to their belief that all students can learn. They all believed in keeping their pedagogical practices and scientific knowledge current (see sections 10.2.1 and 10.2.2). This was seen in practice by their choice of professional learning, reading material and the partnerships they made with colleagues and other parts of the education sector. By modelling their life-long learning, they show students how they too can progress in their learning. In comparing this to Bryan's (2003) supposition, that a growth mindset and life-long learning are vital, I also found that the teachers believed in these approaches.

Whilst it is agreed that critical self-reflection is an important attribute of excellent teachers (ASTA, 2002; Bahr & Mellor, 2016; Schön, 1991; Tobin & Fraser, 1988), these teachers also tended to aim for perfection. Perfectionism has been described as a positive attribute of innovative and excellent teachers (Evans, 2000) and it is consistent with my analysis of Lindy, William and Hannah's practice. However, perfection has also been described as unattainable in teaching due to the complexity of the work and of context and students (Fensternmacher & Richardson, 2005). William explained that there were times in his career when he found it difficult to stop thinking about his teaching and he realized this had an effect on his health. This is also related to commitment and drive which will be discussed in the next section.

10.3.3 Beliefs and practices: Commitment and drive

Lindy, William and Hannah's perfectionism is connected to their demonstration of a commitment to keep improving, and being the best they can be. All of them had parents who valued education and believed it was important to take advantage of the learning opportunities available. Their parents did not put barriers on the direction of their studies but encouraged them to always try their best and to ensure they enjoyed their pursuits. In addition, in William's case, his commitment to teaching is also influenced by his belief that his teaching is a calling from God. Liston and Garrison (2004) proposed that those who see teaching as a calling readily commit their time and energy to their work. Lindy's commitment is matched with her husband's, who she reported is also very committed to his work in the police force. Hannah's reasons for her commitment and drive in her early career was to support her children, since as a single parent, she wanted to ensure she had financial security for them. However, as her children are now in their twenties, Hannah explained that her continued commitment is because she enjoys the work. Other researchers have also found that commitment to and passion for teaching are common attributes of excellent teachers (Crosswell & Elliott, 2004; Mart, 2013).

As discussed in the previous section, commitment, passion and perfection are positive attributes, but whether these high standards can be maintained throughout a teacher's career is variable. At the time of my research, all three teachers were able to commit a lot of time to thinking about and planning their lessons. William and Hannah both had grown up children and Lindy's husband shared her passion and commitment for his work. One reason Lindy, William and Hannah are excellent is their ability to commit so much of their emotional and intellectual energy and time to their teaching and professional work. Day et al.'s (2006) findings show that a number of personal and professional factors can affect teachers' practice during their career. If life events change for any teachers, their ability to sustain commitment to their work can change.

10.3.4 Beliefs and practices: Communication and relationships

Clear communication is an attribute mentioned in many of the ASTA Standards (ASTA, 2002), which indicates how important this factor is in teaching science. My study provides evidence from observation and student anecdotes that all three teachers have highly developed communication skills. First, they have the ability to communicate the essential understandings of science. That is, they can explain the fundamental concepts, the modes of inquiry practices and understand the human characteristics of science. Second, they have the capacity to use a wide range of strategies to develop students' understanding, including personal stories, analogies and everyday applications of science. Third, they understand the importance of giving students the vocabulary and skills so they can partake in discussions about science and access science ideas, including general literacy, numeracy and interpersonal skills. Finally, they all communicated their enthusiasm and passion for science by making connections and explaining the relationships between ideas.

The important role of respectful relationships between teacher and students is emphasised by the ASTA Standards (ASTA, 2002) as it is identified in three of the eleven standards (2, 3 and 5). Lindy, William and Hannah all believe in the importance of respectful relationships with their students and demonstrated this in their practice. They all understood the variable emotional and intellectual needs of adolescent learners and showed flexibility in their teaching to encourage students to grow and develop in both respects. Their students reported that they thought the teachers cared about them as individuals. This is a factor that can be a contributor to students' motivation to learn; consistent with the *TALIS* report (OECD, 2010) which stated that a positive relationship between teacher and student directly influences student motivation and commitment to learn.

10.4 Conclusion

Friedrichsen et al. (2011) asserted that studying teachers' attributes individually does not show the whole picture. My study of these excellent science teachers shows that there is not one single factor that stands out as being more influential on their practice than the others. Although discussed separately, there are overlapping features between the factors. The lines are blurred, and as the statement attributed to Aristotle says, 'the whole is other than the sum of its parts' (SE Scholar, 2019). That is, each factor is influenced by at least one other factor, so these teachers' knowledge, skills, beliefs and attributes all contribute to the complexity of their practice, as well as the collective illustration of their excellence. In addition, each teacher's excellent practice is distinct, because of the alignment of their beliefs with their school context.

In this chapter, I have discussed the similarities and the differences in the factors influencing the professional knowledge, skills, personal attributes and beliefs of the three teachers I studied. In the final chapter, I draw some conclusions, discuss some implications of my findings and make some recommendations for further research in this area.

Chapter 11 Conclusion

11.1 Introduction

In this study, the three interpretive case studies examined factors involved in the development of the knowledge, personal attributes, beliefs and practices of three excellent science teachers of years 7-10 science. The aim of the research was to answer the following questions:

1. How do personal and contextual factors influence the development of excellent teachers' knowledge, personal attributes, beliefs and practices?
2. What do excellent science teachers believe about teaching and learning in science in years 7-10?
3. How are the beliefs of excellent science teachers demonstrated in their professional practices and classroom teaching?

This final chapter presents the overall conclusions and recommendations from the research. First, I discuss my findings within the terms of my research questions. Next, I discuss the significance and implications of my study. Finally, I comment on the limitations of my study and make recommendations for possible future directions for research in this field.

11.2 Summary of the findings

This study was an examination of factors involved in the development of excellent science teachers. Prior to this research, I had limited understanding of the complexities of factors influencing excellent science teachers and the impact of a person's beliefs in informing their practice. Through my literature review, I found that there is limited existing research on excellent science teachers' practice in the middle years, or on the role of their beliefs in the development of their practice. Therefore, a rationale for this study was to make an important contribution to research in this area through this investigation.

In response to research question one, the findings suggest that excellent science teachers' science content knowledge, combined with their understanding of how to enhance their students' learning of science are essential factors. The three teachers demonstrated high levels of pedagogical content knowledge (PCK) (Shulman, 1987), since they were vitally aware of the need to integrate their subject expertise and skills in choosing approaches to teaching that recognise the complexities involved in maximising student learning. Having high levels of

PCK includes being able to motivate and engage students, so they can understand complex concepts and achieve deep learning that achieves relational understanding and adaptive reasoning of the subject matter. The teachers made connections in their science teaching to contemporary, real life examples and applications that enhance students' interest in and understanding of the relevance of learning science. Excellent teaching of science also includes attention to building students' skills and understanding of scientific processes such as inquiry approaches to problems solving. All teachers in this study demonstrated their knowledge of inquiry in science through the opportunities they provide students to ask questions, investigate solutions and discuss explanations.

I found that the teachers used their pedagogical knowledge, drawing on a range of teaching and learning strategies to enhance students' learning in the collaborative and student-centred classrooms they developed. They showed that they constantly adapt their teaching methodologies to their current context. First, they responded to their students' academic abilities, goals, personal challenges and interests. Second, each teacher had highly developed knowledge of their individual schools. This includes the values and expectations of the school, the parents and the students. Last, they also understood and implemented the expectations and purposes of science education in the *Victorian Curriculum: Science*.

My case studies provided evidence of the importance of personal attributes for the realisation of being an excellent science teacher. In particular, there was strong evidence from all three teachers that a passion for science and for sharing the love of learning about science with others are crucial characteristics for excellent science teachers. Importantly, they all showed that their capacity to build relationships with their students is very strong. In addition, their practice involved regular and critical self-reflection which contributed to them seeking creative and innovative ways to improve the teaching and learning in their classrooms. The resulting implementation of innovations in their teaching, also required a strong and continuing professional commitment from these teachers, so they were constantly thinking about how they could improve their students' learning experiences.

In response to research question two, I also found that teachers' beliefs played an important role in their practice. Their central beliefs about teaching and learning had their foundations in past contexts, from their parents and past educational and work experiences. These beliefs were aligned with their current school contexts, including the schools' pastoral approaches and academic expectations. In response to research question three, I found these foundational beliefs were evident in their teaching practices; their learning goals, planning, choice of activities, classroom climate and their reflection on their practices. For example, Lindy and Hannah who had research experience, believed that problem-solving and collaboration are essential in science. They therefore planned for these activities to be a dominant feature of each topic so that students could explicitly develop these skills.

11.3 Limitations of the study

While the three case studies provided deep analysis of the factors involved in the development of excellence, there is no attempt to generalise from the findings, which could be different if other case studies were conducted, depending on the teacher's backgrounds, prior experiences and other factors. Furthermore, the research was conducted with three teachers who were teaching in three different schools: different school systems, and students with varying academic needs expectations and backgrounds (including ICSEA of students). However, the case studies do provide rich insights into the complexities involved in the development of excellence. This study has shown a strong alignment between the practices and beliefs of these teachers and the parameters of excellence provided in the frameworks I chose for analysis; the *National Professional Standards For Highly Accomplished Science Teachers* (ASTA, 2002, 2009), the *Teacher Behaviour Checklist* (Keeley et al., 2006) and the *Framework for examining beliefs* (Fives & Buehl, 2008).

I accept that in my role as researcher with many years of firsthand experience of teaching science in years 7-10, initial teacher education and leadership in schools, I brought my own beliefs to the study which may have impacted on the construction of interview questions, what I noticed, how I analysed the data and the conclusions I formed. To lessen these biases, I planned open-ended questions and phrased them in a manner that allowed participants to answer in an open-ended way. Following the interviews, I asked participants to review the interview transcripts for consistency. I also collected evidence from multiple sources including interviews with the teachers and students, classroom observations and collection of artefacts. I also ensured that I created trust and good relationships with the case study teachers and their students, so they felt comfortable with my presence.

11.4 Significance of the research and implications

The results from my study do reflect findings from past research and these are discussed in the following section, but the case studies that I conducted provide new insights into factors related to excellence in science teaching in years 7-10. Tobin and Fraser (1990) for example, reported that excellent science teachers' choice of learning tasks engaged their students' interests and improved their understanding of science. This was true for all three teachers, who demonstrated a strong focus on student engagement. Marshall (2008) found excellent science teachers taught using inquiry processes, were enthusiastic about science and promoted student curiosity; also evident in Lindy, Hannah and William's pedagogy and personal attributes.

Mansour (2009) explained that beliefs are critical influences in science teachers' lesson planning and classroom practice and this study has shown this to be highly significant. Mart (2013) found that being committed and passionate teachers is crucial in the development of student learning. In my study, students commented on the professional commitment of their teachers. The important role of personal attributes that I found to be a factor in the study is similar to the findings of other researchers (Bolshakova et al., 2011; Waldrip et al., 2009). Each teacher is dedicated to planning to maximise their students' learning, generous in giving their time to their colleagues, communities and to the profession; something which has been recognised through awards and community acclaim. Each teacher is also conscientious about continuing their ongoing professional learning. This commitment to continual self-improvement was not a burden for these teachers. It has its foundations in beliefs passed to them from their parents who believed in education and commitment to work.

However, the depth and specificity of my study has provided greater insights into how complex the factors are in the development and practices of excellent science teachers in years 7-10. The complexity is due to the interactions between each case teacher's knowledge, beliefs and personal attributes which ultimately affect their teaching practice. One finding is the repercussions of these teachers' beliefs, commitment and passion on the *quality* of their knowledge and therefore on the quality of their teaching. They viewed events in their everyday life through the lens of a science educator and used these insights in planning units for their students. For example, Hannah noticed her students being driven to school in cars and combined this with news articles about the need for clean energy alternatives. Students considered the science involved, their own understanding and thought more critically about their reliance on car transport. I found that all the teachers often considered the potential of how everyday events could be exploited to enhance their students' learning and their teaching program.

Another finding was that Lindy, Hannah and William all believed in striving for perfection and always focused on continuous improvement in their work. They all believed that students' learning of science in years 7-10 should emphasise the role of inquiry and that learning occurs best in a hands-on, collaborative environment, so this required high levels of planning to engage students in authentic and purposeful learning. Thus, their beliefs are integral to their choice and emphasis of science concepts, teaching strategies and class activities.

I also found that past personal contexts provided each teacher with experiences that improved their knowledge, influenced their current beliefs and developed their personal attributes. One example of this is their shared memories of their own science learning in middle school where science was irrelevant, boring and involved the transmission of irrefutable knowledge from teacher to student. These negative experiences influenced their belief in striving to engage learners, to ensure that their teaching and students' learning was active and collaborative, with many opportunities to learn through hands-on activities. Evidence of this was in their commitment to planning and the students' feedback about how much they enjoyed the class environment and teaching approaches.

A further example of the influence of past contexts is their early teaching careers, where they all had different experiences. Lindy was enveloped in a very professional and supportive learning community during her first five years of teaching. She was exposed to a lot of reflective practice and innovative ideas in both science and general education. In William's first five years there was no mentoring or collaboration and he was left to 'work out what works'. It certainly helped that the school William was working in was very similar to the one he attended, so he was familiar with the contextual needs and expectations of the students and community. Hannah's experience was very different, since her first five years involved casual relief teaching, across a number of learning areas, rather than just science. What she was to teach was already planned for her by the absent teacher. But Hannah's approach was to make the topic relevant to the students, so they had a purpose for their learning. Even though their early teaching careers were very different, they all included opportunities for these teachers to trial different pedagogies. When students gave them positive feedback, they were influenced to continue to advance their practices.

Finally, my study found that their current contexts enhance their capacity to be excellent science teachers. All three teachers are Heads of Science at their school, which means they can lead other teachers and enact their vision and beliefs about science and science education. They are able to enact their practice with freedom and authority. It was also evident that their beliefs about science education aligned closely with the *Victorian Curriculum: Science* rationale. They believe that the wonders of science should be accessible to all students and that scientific literacy and the application of this to science in real life are critical factors in the way they teach science. While all their schools were different contexts in terms of the systems (Catholic, government and independent), all three teachers were in schools that had a vision for maximising student learning and student engagement. These factors aligned with these teachers' beliefs and practices.

Figure 6 shows the interplay between the factors I investigated. The arrows indicate how each factor is influenced by another, but also interacts with others, demonstrating the complexity of factors involved in being an excellent science teacher. Beliefs are central in the diagram as they act as the filter and organiser of these factors and influence how, when and where the science teacher's knowledge and personal attributes are enacted. Contextual factors are identified as significant aspects of past experiences as well as the current teaching climate. Past contexts include individual, family, school and community. Current contexts include those at the individual and school level through to the school system and socio-political factors. The diagram is framed by the teachers' evolving enacted practice, demonstrating that the teacher's practice is not fixed and is always changing and growing. Although my study examined each factor separately, the diagram emphasises the holistic nature of excellence and the interdependence of the factors involved. The diagram could be useful as a reflective tool to help to understand the web of factors involved in being an excellent science teacher.

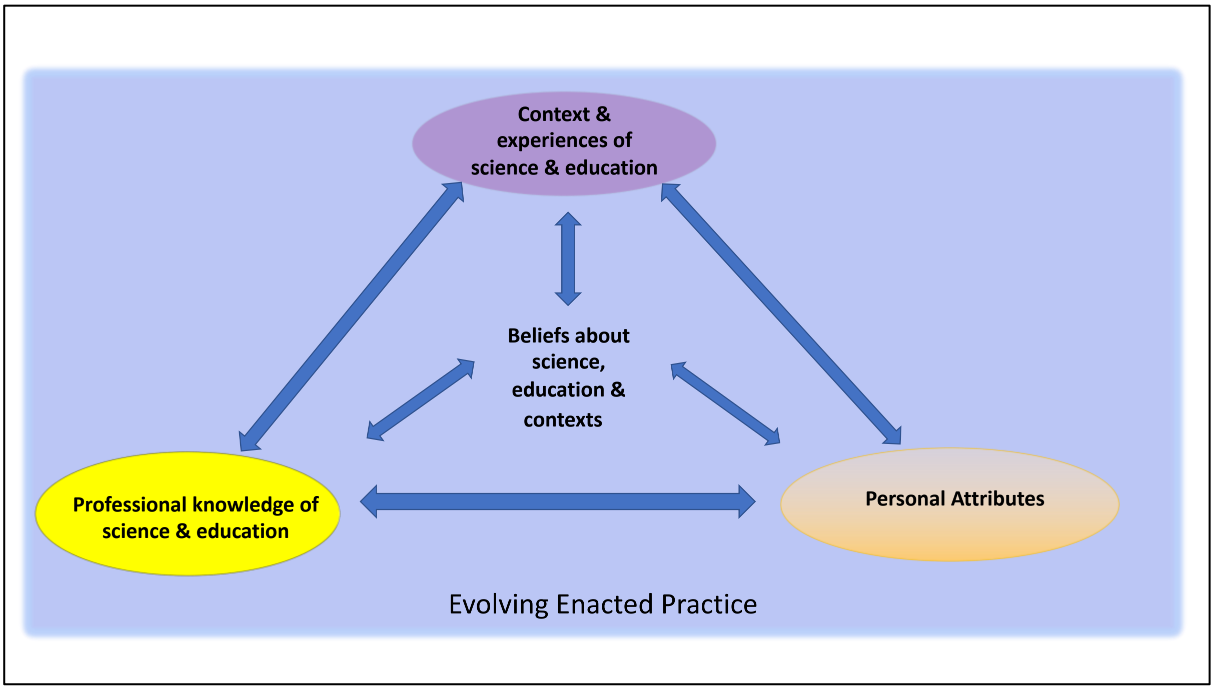

Figure 6 The interplay between factors influencing excellent science teachers (Burke, 2020)

11.5 Recommendations

A finding from my investigation, is that excellent science teachers demonstrate a high level of deep and current knowledge of the science topics they teach, knowledge of their particular students and knowledge of how to best engage their students with learning science. It is the quality of these teachers' pedagogical content knowledge (PCK) (Shulman, 1986) in their particular contexts that is significant. One of the current requirements to ensure that teachers meet professional standards related to knowing content and how to teach it, and knowing students and how they learn in order to retain teacher registration in Victoria, is for teachers to complete 20 hours of professional development activity every year (VIT, 2018). In my study, there was clear evidence that the excellent science teachers had high levels of PCK and catered effectively for the range of students in their class, but they were also keen to continue their learning. So one recommendation, to ensure the development of excellence, is that professional learning for science teachers be focused on building each teachers' PCK. For teachers to develop their PCK during professional learning episodes, they need opportunities to consider the interactions between the types of professional knowledge and their teaching practices. This can be achieved through collaboration and self-reflection upon the new knowledge. But they must also have the capacity to differentiate learning and provide experiences for students' current levels of understanding, so that their learning is maximised.

A further finding from my study is that the personal attributes of science teachers, particularly their passion and commitment for their work is a significant factor in excellence. Since 2018, throughout Australia, applicants for initial teacher education courses have had to meet non-academic entry requirements. Many tertiary providers use an online screening tool called CASPer® (Altus Assessments, n.d.) to assess students' attributes including their motivation to teach, interpersonal and communication skills, organization and planning and willingness to learn (Mayer, 2019). Whilst it is heartening that the importance of personal attributes for teachers is now recognized, there has been little research evidence to support the implementation of this prerequisite, nor has there been research into how these attributes develop throughout a teacher's career, through such means as further education, feedback and critical reflection. The findings from my study suggest that personal attributes are significant, so it is a positive direction that it is being recognised in the selection of pre-service teachers.

Another finding demonstrates the importance of beliefs in excellent science teachers. Therefore, a recommendation is that students in initial teacher education reflect on the influence of their own beliefs about science education and in ongoing professional learning programs, so that all science teachers have a better understanding of how beliefs influence their teaching practices. It is important for all teachers to appreciate that critical reflection is an important part of a teacher's practice so that their beliefs are articulated and can be challenged throughout their careers. Learning to critically reflect upon teaching knowledge and practice requires explicit instruction during initial teacher education. It also requires ongoing collaborative discussions about what works in teaching practices, use of evidence such as assessment data, and an explicit focus on self-improvement for all teachers.

My findings have elicited some areas worthy of further research, but which were beyond the scope of this current study. The three teachers in my study all sought to work in a collegial environment so the role of relationships with colleagues on the development of excellent science teachers would be an area for further investigation. Another area of study would be to examine the role that gender plays in an excellent teacher's practice as both Lindy and Hannah demonstrated a strong drive to strive for perfection in their work.

11.6 Final thoughts

My study of these three excellent teachers was inspiring to me as an educator and as a science enthusiast. The teachers' passion and capacity to provide their year 7-10 students with positive and challenging experiences in learning science means that their learners are curious and engaged learners. The following quotes capture some of reasons why these science teachers are excellent. They believe science should be relevant, collaborative and engaging and commented that,

> *Often students have this perception that a scientist works on their own, but no, it's very collaborative and the sharing of information and getting feedback from people is very important in allowing people (scientists and learners) to move forward.* (Lindy)

> *Science is fun. It should be exciting, vibrant, involve thinking. ... applying and challenging your knowledge; it's getting the kids to think.* (William)

> *I've always tried to make it relevant to what they might see or experience in the real world as much as possible. Otherwise you're just learning bits of information.* (Hannah)

In explaining their views on excellence in science teaching, Lindy said that *it is about trying new things …engaging all students, regardless of who they are …finding something that they love about science …and keeping learning with your students*. William said that *an excellent teacher has passion; loves the education process; loves imparting knowledge and sharing skills; is engaging; has a high regard for students; has a good relationship with students; is inventive, imaginative and is always trying to improve.* Hannah was modest about being named in this way and said, *I just love what I do ...I don't see myself as excellent …I need to keep on improving …I'm continually learning.*

Overall, the findings demonstrate the complexity of factors involved in the development of excellent science teachers' beliefs and practices. Each science teacher is excellent in their own school context and for their student cohort due to the interplay between their knowledge, personal attributes and beliefs. It is the web of connections between all the factors that contribute to the teacher's excellent practice. There is scope for further qualitative studies to investigate the relationships and intricacies involved in developing excellence. What is evident from this study, is that the three teachers all work to achieve stated aims of the *Victorian Curriculum: Science* 'to ensure that students develop an 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' (VCAA, 2017e). These excellent teachers also build their students' capacities to understand 'the nature of scientific inquiry and the ability to use a range of scientific inquiry methods, including: questioning; planning and conducting experiments and investigations …collecting and analysing data; evaluating results; and drawing critical, evidence-based conclusions' (VCAA, 2017e). These important aims help their learners to be creative and critical thinkers who can be lifelong learners and who know that the field of science can build solutions to some of the big questions facing the world now and in the future. But my study has found, that the factors involved in the development of a teacher's knowledge, skills and attributes, to achieve these aims in their professional practice, are complex and evolutionary, throughout the excellent teacher's career.

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Appendix A

Explanatory Statement for Teachers

Project: Case Studies of Excellent Science Teachers' Beliefs and Practices
(Project: Number: CF14/3873 – 2014002018)

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You are invited to take part in this study. Please read this Explanatory Statement in full before deciding whether or not to participate in this research. If you would like further information regarding any aspect of this project, you are encouraged to contact the researchers via the phone numbers or email addresses listed above.

Why were you chosen for this research?
You have been chosen to be a participant in this study, based on recommendation from either a teacher educator and/or a member of your school community. A request was made to identify excellent science teachers who currently teach years 7, 8, 9 or 10 Science. To undertake this study, I need your consent and the approval of your school principal.

What does the research involve?
The aim of this study is to investigate the factors involved in your journey to becoming an excellent science teacher, your beliefs about what is important in teaching science in years 7-10 and your practice in the classroom. The study will explore how you work in the classroom; what activities and teaching strategies you use and the reasons for your choices.

<u>The data collection involves:</u>

- A pre-interview demographic questionnaire for you to complete. This will take about 15 minutes to complete.
- An interview with you about your beliefs about teaching secondary school science. This initial interview will be audio taped and will take about 1-1.5 hours. It can take place at your school at a time convenient to you.
- A pre-lesson interview about your teaching and learning intentions of approximately 5-10 minutes before each lesson.

- Observation of you teaching a science class at years 7-10 over a 2-3 week period. The researcher will take notes on the teaching and learning activities that occur during the lessons.
- Follow up interviews with you about the different learning activities you chose for the observed lessons; your reasons for including them and your reflections on their effects. This would take about 15-20 minutes after each lesson observed. These interviews will be audiotaped.
- Interviews between the researcher and about 5 of your students to establish their perceptions and attitudes about their science classes and learning. The students will be chosen by the researcher in consultation with you to reflect a range of ability and interest levels. These interviews will be audio taped and be about 30 minutes.
- Analysis of your lesson plans and the teaching resources you selected to use during the observed classes.
- Analysis of work samples from the students who are interviewed.

Consenting to participate in the project and withdrawing from the research
To give your consent, please sign and return the attached consent form to the researcher. The study will be conducted during Terms 1-3, 2017. You have a right to withdraw from participation at any stage. The transcripts of interviews will be available for your review and you are welcome to elaborate on your statements.

Possible benefits and risks to participants
This research study will provide you with valuable insights into your teaching and learning as a science educator. The collection of data will require your involvement in an initial one-hour interview and 5 follow up interviews (approximately half an hour) after observed lessons. It will also require the collection of some teaching and learning artefacts involved in the lessons. There are no foreseeable risks to yourself or your students and all attempts will be made to limit the interruption to your work.

Confidentiality
Your identity and that of the school and students will be kept confidential and pseudonyms will be used. The research will be published in a doctoral thesis and may be used at conference presentations or in research articles.

Storage of data
Data will be stored in a password-protected folder on the researcher's personal computer, and only the researchers will have access to the data.

Results
The transcripts of interviews and observations of lessons will be available to you within a month of collection of data. This will allow you to make comments on what was observed, and these can be included in the research findings. You will be informed when the full thesis is completed, and access will be made available to you upon request.

Complaints

Should you have any concerns or complaints about the conduct of the project, you are welcome to contact the Executive Officer, Monash University Human Research Ethics (MUHREC):

Executive Officer
Monash University Human Research Ethics Committee (MUHREC)
Room 111, Building 3e
Research Office
Monash University VIC 3800

Tel: +61 3 9905 2052 Email: muhrec@monash.edu Fax: +61 3 9905 3831

Thank you

Chief Investigators' signatures

Associate Professor Libby Tudball Ms Joanne Burke

Appendix B

Teacher Consent Form

Project: Case Studies of Excellent Science Teachers' Beliefs and Practices

Chief Investigator:

Libby Tudball
Associate Professor
Faculty of Education
Phone: 9905 9160
email: libby.tudball@monash.edu

Joanne Burke
PhD Student
Faculty of Education
Phone: 0412 898 085
email: joanne.burke@monash.edu

I have been invited to take part in the Monash University research project specified above. I have read and understood the Explanatory Statement and I hereby consent to participate in this project.

I consent to the following:	Yes	No
• An initial interview followed by shorter interviews pre and post lessons	☐	☐
• Audio recording during the interviews	☐	☐
• Observation of my teaching during science classes	☐	☐
• In collaboration with the researcher, select 5 students from my class to be interviewed about their experiences in learning science	☐	☐
• Access for the researcher to my lesson plans and teaching activities	☐	☐

Name of participant: ___________________________

Signature of participant: ______________Date: ______________

Appendix C
Teacher Background Questionnaire

Teacher Background Information

Thank you for agreeing to be part of my research study. Before we have our first interview, it would be helpful for me to know some general background information about you and your experiences with science and teaching.

If you are unsure of a question or you do not want to answer it, please feel free to leave it out. There are no right or wrong answers.

Please bring your responses to our interview or scan and email it back to me.
----

1. Your preferred name: ___________________

2. Gender: Male ☐ Female ☐ 3. Age ________

4. Where did you study your secondary school education?
Victoria ☐ Elsewhere in Australia ☐ ________ Overseas ☐ ________

5. How many years have you taught in secondary schools (any subject)? ________

6. How many years have you taught secondary school science prior to this school year? ________

7. For each of the following science learning areas what is your own level of formal education?

Subject	Year 12	Undergraduate (indicate 1st, 2nd or 3rd year)	Postgraduate (indicate level)	subject specialism (Major(s)
Biology				
Chemistry				
Physics				
Earth Science				
Engineering				

8. What is the highest level of formal teacher education you completed? Please include details of year completed and teaching methods studied.

____

____

9. Besides teaching years 7-10, do you have another role in the Science Department or at the school (e.g.: Year level coordinator, Head of Faculty)? Please specify

____

____

____

10. What subjects have you taught in the last 3 years?

	2014	2015	2016
Primary			
Year 7			
Year 8			
Year 9			
Year 10			
Year 11			
Year 12			

11. Does your school use the Victorian Curriculum or the Australian Curriculum for Science?

____

12. Besides teaching in secondary schools, what other job experiences have you had?

____

13. Have there been any PL (professional learning) in the last 12 months that has impacted on your teaching (note: this could also include professional reading)? If so, please list and explain why it was useful and what it changed/confirmed (maximum of 5).

Thank you.

Appendix D

Guiding Questions for Initial Teacher Interview

The interviews are semi-structured. The questions below are prompts to direct the conversation.

Hi, I would like to take about 45 minutes to 1 hour of your time today to ask you some questions about teaching science, particularly at year 8. I would like to talk to you about your beliefs and experiences of science and about teaching and learning science. In particular I am interested in your reasons for why and how you teach science.
There are no right or wrong answers, the information that you give me today will be confidential and after I have transcribed it, I will give you a copy to view at your convenience. You may change any of it at that time. I would like to tape record this interview for transcription later on, is that all right with you?

Teacher Background

1. I asked you to fill in a survey to give me some general information about your background in science and teaching. If we look at that now, can I just check a couple of things:
    - **a.** Did you study any science in year 12?
    - **b.** 34 years at this school or other schools?
    - **c.** What is the EPL program? What did it involve?

2. How would you describe your own science education when you were at secondary school?

3. Did you have a favourite/excellent science teacher when you were at school? What made them so good?

4. If you had to explain "inquiry in science" to another teacher, what would you say that it was?

5. What led you to becoming a science teacher? Was it your first choice of career?

6. What experiences have influenced how you teach science? The way you were taught? Your teacher education?

Additional questions, depending on the response in demographic information

Teacher Belief's

7. I see in question 8 that you [**have another role in the Science Department** or at the school] Does this effect/influence the way you teach science – particularly at
8. What do you think is the purpose of science education in year 8? Is it different to other year levels? (understand sci concepts? Sci literacy? Prepare for VCE?
9. Why do you think Science is compulsory for all students in years 7-10? Should it
10. Are you satisfied with the science curriculum for your students? [Why? /Why not?]
11. What areas or topics of science do you think you prefer to teach at year 8? Why?
12. Do you enjoy teaching science at year 8? (what's good/bad about it?)
13. How do your students learn best in year 8 science?
14. What seems to be the principle difference between a student who is successful in science and one who struggles?
15. How would you describe your role as a teacher?
16. How do you think other teachers would describe you as a science teacher?
17. You were asked to be part of this research because you've been identified as an excellent science teacher. How would you rate yourself as a science teacher? Why/why not? Strengths? Weaknesses?

Teacher Practice (relating to year 8 & 9)

18. Where do you start when planning your lessons? (by topic? Adapt to group?)
19. How do you decide what to teach and what not to teach?
20. What influences your choice of learning activities? (other teachers? School restrictions/expectations?)

21. How do you cater for student diversity in your year 8 class? (interest, ability, gender)
22. How do you maximise student learning in your classroom?

23. How do you know when learning is occurring in your class?

24. How do you know when your students understand?

25. Where does assessment fit in to your classes?

26. Do you reflect on a class afterwards? How do you do this and what happens?

27. Is there anything that you would like to add that that you think might be relevant?

Appendix E

Pre- and Post-lesson Guiding Questions

Pre-lesson questions:

1. What is the purpose of today's lesson?
2. How did you decide on these activities? What do you want your students to learn from these activities?
3. What was the process you went through in planning today's lesson?

Post lesson reflections

4. How did you feel about the lesson? [Were you happy with the sequence and the activities?]
5. What were you trying to achieve through your science activities?
6. What did you focus on?
7. How did you emphasise this?
8. What was the most difficult thing for your students today?
9. How did you solve that difficult thing?
10. Did you feel or know whether your students have improved their science learning through your science activities?
11. What is the best thing that your students improved on in their science learning? (How did the students improve their scientific knowledge?) And how did you know about their improvement?

Appendix F

Lesson Observation Sheet

Table 5 Categories for prompts

<table>
<tr><td>Teacher:</td><td>year level</td><td colspan="2">Date, time</td><td>number of students</td></tr>
<tr><td>lesson length</td><td colspan="4">diversity of class (M:F), sp.needs, EALs etc</td></tr>
<tr><td colspan="5">working title of lesson:</td></tr>
<tr><td>A.
content
explicit goals/criteria
link to previous and future learning
HOTs - none
real life contexts, relevance
knowledgeable
clarity of explanation
address misconceptions
teachable moment
contemporary science
human endeavour</td><td colspan="2">C.
resources
computer/iPad
worksheets
textbook
video
lab with worksheet
lab with no worksheet
whiteboard/
smartboard/ppoint
internet
other ICT, media</td><td colspan="2" rowspan="2">E.
personal attributes
greet students, rapport
tone of voice
reflective
accessible, approachable
confident
creative, interesting
clarity, communication
curious
rapport
punctual/organised
humorous, positive
flexible
enthusiasm, passion
respectful, genuine, caring
risk taker
high expectations
stimulate curiosity, imagination
innovative</td></tr>
<tr><td>B.
delivery
whole group
partner work
small group
independent
co-teaching
other
% of time on - admin,</td><td colspan="2">D.
level of student engagement
engaged & thinking
interested, enjoy
‘in and out’
low, disengaged
sustained</td></tr>
</table>

behaviour, actual T&L rewards/sanctions		
F: teaching strategy discussion lecture teacher directed Q&A hands-on giving directions modelling testing organise, re-organise, apply, analyse, synthesise, evaluate, justify predict, test, observe, question, explain feedback/assessment interdisciplinary	G: evidence of differentiation different work, special interests - encouraged to take conceptual risks work with individuals – background knowledge growth mindset promote inclusion	H: environment student work posted instructionally relevant materials posted class rules - imposed or inclusive pursue excellence physically & emotionally safe

Extended Field Notes:

A:

B:

C:

D:

E:

F:

G:

H:

Appendix G

Explanatory Statement for Parents of Students

EXPLANATORY STATEMENT

Project: Case Studies of Excellent Science Teachers' Beliefs and Practices

Investigators:

Libby Tudball
Associate Professor
Department of Education
Phone: 9905 9160
email: libby.tudball@monash.edu

Joanne Burke
PhD Student
Department of Education
Phone: 0412 898 085
email: joanne.burke@monash.edu

Permission is requested for your son/daughter ________________________ to take part in this study. Please read this Explanatory Statement in full before deciding whether or not your give consent for your child to participate. If you would like further information regarding any aspect of this project, you are encouraged to contact the researchers via the phone numbers or email addresses listed above.

Why was your child chosen for this research?
Your child is currently learning science and is a student in one of years 7-10 in a Victorian school. All students in your child's science class are being invited to participate because the study is focussed on your child's science teacher. Your child may be involved in one or all of the following data collection methods:

- Observation of their learning during several science classes by the researcher
- A small group interview with the researcher to establish your child's views on their science classes
- Collection of work samples from their science classes

What does the research involve?
The researcher spoke to the teacher and class today to explain the purpose of the research and what would be involved by the participants. The aim of this study is to investigate excellent science teachers. The study explores the beliefs of excellent science teachers and how they work in the classroom; what activities and teaching strategies they use and the reasons for their choices.

<u>The data collection involves</u>:

- Discussions between the researcher and your child's science teacher about what they believe about teaching science and how they plan their science lessons. These discussions will not involve your child.
- Observation of several science lessons for 2-3 weeks, focussing on the teaching and learning strategies that the teacher uses. The researcher will take notes during the lessons and may ask students questions about their learning during individual work but will not interfere with the teaching and learning activities.
- Individual interviews between the researcher and some students from the class. Students will be chosen by the teacher and researcher to represent a range of ability and interest levels in the class. These interviews will be about 30 minutes long, will take place either during lunchtime or after school (student's choice) at school and will be audio taped. These interviews are to find out the students' perceptions and attitudes about their science lessons and learning.
- The researcher will collect samples of students' work completed during the lessons observed. The work will be returned to the student.
- The researcher will look at the teacher's lesson plans, worksheets and activities for the lessons observed.

Consenting to participate in the project and withdrawing from the research
To give your consent, please sign and return the attached consent form to the researcher. The study will be conducted during Terms 1 and 2, 2017. Your child has a right to decide to withdraw from participation at any stage if they feel uncomfortable. There is a separate assent form for your child to also agree to their participation. The transcripts of interviews will be available for your child to review and they are welcome to make elaborations of statements they made.

Possible benefits and risks to participants
This research study will provide the researcher valuable insights into the teaching and learning of science. The collection of data will require your child's science classes to be observed and possibly a half hour interview with the researcher. Samples of work produced by your child for science classes may also be collected. There are no foreseeable risks to any participant in the study and all attempts will be made to minimise interruptions to the normal classes.

Confidentiality
Your child's identity and that of the school and teachers will be kept confidential and pseudonyms will be used. The research will be published in a doctoral thesis and may be used at conference presentations or in research articles.

Storage of data
Data will be stored in a password-protected folder on the researcher's personal computer, and only the researchers will have access to the data.

Results

The transcripts of interviews and observations of lessons will be available to participants within a month of collection of data. This will allow your child to make comments on what was observed, and these can be included in the research findings. The participants will be informed when the full thesis is completed, and access will be made available upon request.

Complaints

Should you have any concerns or complaints about the conduct of the project, you should contact the Executive Officer, Monash University Human Research Ethics (MUHREC) and cite Project: Number: CF14/3873 – 2014002018.

Executive Officer
Monash University Human Research Ethics Committee (MUHREC)
Room 111, Building 3e
Research Office
Monash University VIC 3800

Tel: +61 3 9905 2052 Email: muhrec@monash.edu Fax: +61 3 9905 3831

Thank you,

Chief Investigator's signature

Dr Libby Tudball Ms Joanne Burke

Appendix H

Student and Parent Assent/Consent Form

CONSENT FORM

(Parent of Student)

Project: Case Studies of Excellent Science Teachers' Beliefs and Practices

Chief Investigator:

Libby Tudball
Associate Professor
Faculty of Education
Phone: 9905 9160
email: libby.tudball@monash.edu

Joanne Burke
PhD Student
Faculty of Education
Phone: 0412 898 085
email: joanne.burke@monash.edu

I have been asked if my child ______(insert name)______________________may take part in the Monash University research project specified above. I have read and understood the Explanatory Statement and I hereby consent for him/her to participate in this project.

I consent to the following:	Yes	No
• My child to be interviewed in a group of 4-5 students with the researcher	☐	☐
• Audio recording during the interview with the researcher	☐	☐
• Observation of science classes	☐	☐
• Access to my child's work produced for science classes	☐	☐

Name of Student________________________________

Parent/Guardian Signature____Date______________

ASSENT FORM

(Student)

I, [Student name]_________________, have been asked to take part in a research study called, *Case Studies of Excellent Science Teachers' Beliefs and Practices*. The researcher, Joanne Burke, a PhD student at Monash University, explained what is involved in the study to the class and me.

I understand that I will be observed during several science classes and possibly be asked to participate in a group interview with other students and the researcher about learning science. The interview would take about 30 minutes and would take place at school, either at lunchtime or after school. I could also be asked to show the researcher some of my work produced for science classes.

I will face no known risks by taking part in the study. My participation is voluntary, and I can change my mind at any time without any penalty. All students in my science class will be observed during science lessons and 5 students will take part in the group interview.
The researcher will not reveal my name to anyone, and my name will not appear in any reports on this study.

I was also informed that if I have questions, I can call, Joanne Burke at Monash University on 0412 898 085. If I have questions about my rights, I can call the Monash University Human Research Ethics Committee (MUHREC) on 9905 2052 or email them at muhrec@monash.edu. The project number is CF14/3873 – 2014002018.

After I sign this form, I will receive a copy of it.

I am willing to do the following:	Yes	No
• Be interviewed by the researcher	☐	☐
• Have my voice audio recorded during an interview with the researcher	☐	☐
• Be observed during some science classes	☐	☐
• Show the researcher some of my work produced for science classes	☐	☐

Student signature:_______________________ Date: _____________

Appendix I
Guiding Questions for Student Focus Group

The interviews are semi-structured. The questions below are prompts to direct the conversation.

Hi, thank you for meeting with me. This discussion will take about 30 minutes of your time today. I'm going to ask you some questions about learning science at school. I would like to talk to you about what you like and don't like about your science classes and what helps you to learn.
There are no right or wrong answers. The information that you give me today will be confidential. I would like to tape record this interview so I can transcribe it later on, is that all right with you?

Student beliefs/opinions

1. Do you like science? (has this always been the case? Why/why not?)

2. Why do you think science is compulsory until the end of year 10? How do you feel about this?

3. What do you like about the way your science teacher teaches you science? (relationships, knowledge, communication, expectations, enthusiasm, choice of activities, feedback, organisation)

4. What don't you like about the way your science teacher teaches you science? (relationships, knowledge, communication, expectations, enthusiasm, choice of activities, feedback, organisation)

5. Have the lessons over the past week been typical of science lessons this year? (activities, level of concept, teacher expectation)

6. What makes a teacher a good teacher (in science)?

7. Is what you learn in science applicable to other classes? Or real life?

8. Here are some cards with the names of possible class activities (see next page)
   - **a.** Choose the top 5 that help you to learn.
   - **b.** Choose 5 that you do most often in science?

9. Is there anything that you would like to add that that you think might be relevant?

Appendix J
Explanatory Letter for Principals

Dear [Principal's name]

Project: Case Studies of Excellent Science Teachers' Beliefs and Practices
(Project: Number: CF14/3873 – 2014002018)

Investigators:

Libby Tudball
Associate Professor
Faculty of Education
Phone: 9905 9160
email: libby.tudball@monash.edu

Joanne Burke
PhD Student
Faculty of Education
Phone: 0412 898 085
email: joanne.burke@monash.edu

Your staff member [teacher name] has expressed interest in being a participant in this study. I invited him to participate based on a recommendation from a science teacher educator at Monash University who has worked with her previously. A request was made to teacher educators to identify excellent science teachers who currently teach years 7-10 Science.

What does the research involve?
The aim of this study is to investigate the factors involved in [teacher name]'s journey to becoming an excellent science teacher, his beliefs about what is important in teaching science in years 7-10 and his practice in the classroom. The study will explore his background education and qualifications, his teaching and learning approaches in the classroom: what activities and teaching strategies he uses and the reasons for these choices.

The data collection involves:
- A pre-interview demographic questionnaire for [teacher name]to complete. This will take about 15 minutes.
- An interview with [teacher name] about his beliefs about teaching secondary school science.
- A pre-lesson interview with [teacher name] about his teaching and learning intentions – 5-10 minutes before each lesson.
- Observation of [teacher name] in a year 10 science class over a 2-3 week period. The researcher will take notes on the teaching and learning activities that occur during the lessons.

- Follow up interviews with [teacher name] about the different learning activities he chose for the observed lessons; the reasons for including them and his reflections on students' engagement in the learning – 15-20 minutes after each lesson.
- Interviews between the researcher and about 5 students from these classes to establish their perceptions and attitudes about their science classes and learning. The students will be chosen by the researcher in consultation with [teacher name] to reflect a range of ability and interest levels and separate explanatory statements and consent forms will be provided to the students and their parents
- Analysis of [teacher's] lesson plans and the teaching resources he selected to use during the observed classes.
- Analysis of work samples from the students who are interviewed.

Permission for this research to be conducted in your school

If you are willing to give your permission, please sign and return the attached permission letter to Joanne Burke at the email address at the top of this letter. The study will be conducted during Terms 1 and 2, 2017. [Teacher] has the right to withdraw from participation at any stage. I have gained approval from the DET and have attached the details to this email.

Confidentiality

The identity of the school, teacher and students will be kept confidential and pseudonyms will be used. The research will be published in a doctoral thesis and may be used at conference presentations or in research articles.

Storage of data

Data will be stored in a password-protected folder on the researcher's personal computer, and only the researchers will have access to the data.

Complaints

Should you have any concerns or complaints about the conduct of the project, you are welcome to contact the Executive Officer, Monash University Human Research Ethics (MUHREC), citing the project number CF14/3873 – 2014002018.

Executive Officer
Monash University Human Research Ethics Committee (MUHREC)
Room 111, Building 3e
Research Office
Monash University VIC 3800

Tel: +61 3 9905 2052 Email: muhrec@monash.edu Fax: +61 3 9905 3831

Thank you

Chief Investigators' signatures

Associate Professor Libby Tudball Ms Joanne Burke

Appendix K Principal Consent Template

(Insert letterhead of the organization giving permission)

Project: Case Studies of Excellent Science Teachers' Beliefs and Practices

Date

Libby Tudball
Associate Professor
Faculty of Education
Monash University
Wellington Rd, Clayton 3161
Phone: 990 59160
email: libby.tudball@monash.edu

Joanne Burke
PhD Student
Faculty of Education
Monash University
Wellington Rd, Clayton 3161
Phone: 0412 898 085
email: joanne.burke@monash.edu

Dear Libby and Joanne,

Thank you for your request to recruit participants from (organization) for the above-named research.

I have read and understood the Explanatory Statement regarding the research project and hereby give permission for this research to be conducted.

Yours sincerely

(Signature of person granting permission)

(Name of person granting permission)

(Position of person granting permission)