UNIVERSITY OF SOUTHERN QUEENSLAND

# EFFECTIVE SECONDARY SCIENCE TEACHER PROFESSIONAL DEVELOPMENT AND GROWTH:

# A QUEENSLAND CASE STUDY

A Thesis submitted by

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# ABSTRACT

Science education remains a priority for researchers and governments, with the quality of science teaching and its impact on student learning being of central importance. Teaching quality arising from the experience, knowledge (both content and pedagogical) and skills of the teacher has a demonstrably positive influence on student achievements, particularly when teachers engage with professional development throughout their career. Underpinning the scientific knowledge of teachers is their epistemological understanding of the nature of science and scientific inquiry as the fundamental basis for scientific advancement.

The research presented here investigates secondary school science teacher professional development in Queensland, Australia, and within the framework of modern educational theory. In this thesis therefore, the aim is to gain a better understanding of Professional Development (PD) opportunities for science teachers in terms of content knowledge of the different scientific domains. This thesis combines a series of academic papers and book chapters centred on secondary science teaching.

Following a brief introduction to the context and significance of the study (Chapter 1), the thesis begins with Paper 1 (Chapter 2), a comprehensive literature review of studies related to in-service secondary science teachers' science PD, with a focus on teacher science content knowledge. The research examines relevant international and Australian educational trends and practices. Next, a quantitative enquiry was undertaken into secondary science teacher confidence teaching junior (Years 7 to 10) secondary science and their related interest for professional development (PD) (Chapter 3). The paper provides a better understanding and trends of the relationship between teacher knowledge (content knowledge (CK) and pedagogical content knowledge (PCK)) and requirements for PD within the specific focus on Australian Science curriculum.

Paper 3 (Chapter 4) presents a design for teacher industry internship for enhancing teacher understanding of the nature of science through participating in authentic, real world science, technology, engineering, and mathematics (STEM) experiences. The components and the capacity of the teacher industry internship model to create change in teacher NOS understanding and influence teacher growth is then analysed across the four change domains for teacher professional growth. Chapter 5 and 6 (Book chapters 1 and 2) provides a mechanism to support an early understanding for pre-service science teachers so they can adopt the practices of incorporating authentic, real-life contexts and concepts in their teacher development. The work thus focuses on reinforcing the concept of role NOS and maintaining currency with cutting-edge scientific developments and integrating them into their classroom instruction.

The thesis concludes with a short summary and synthesis of relevant research findings and the implications for future teacher professional development programs for enhancing science teachers' knowledge (CK and PCK), their understanding of the nature of science (NOS) concepts, and their professional growth (Chapter 7). In overall terms, the thesis provides evidence for the need for multiple complementary approaches to science teacher professional development which are guided by both pedagogical understanding and surveys of the specific teacher cohorts served.

# CERTIFICATION OF THESIS

I Kay Ann Lembo declare that the PhD Thesis entitled *Effective Secondary Science Teacher Professional Development and Growth: a Queensland case study* is not more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references, and footnotes.

This Thesis is the work of Kay Ann Lembo except where otherwise acknowledged, with the majority of the authorship of the papers presented as a Thesis by Publication undertaken by the Student. The work is original and has not previously been submitted for any other award, except where acknowledged.

[redacted]

3 December 2021

Signature of Candidate

Date

Endorsement by:

[redacted]

3 December 2021

Signature of Principal Supervisor

Date

Student and supervisors' signatures of endorsement are held at the University.

# STATEMENT OF CONTRIBUTION

## ***Journal Manuscripts under review***

Paper 1:

Lembo, K., Carter, B., & Fitzgerald, A., (2021). Strategies for effective teacher professional development involving scientific content knowledge: A review of the research. Submitted to the Journal of Studies in Science Education

Kay Lembo contributed 95% to this paper. Collectively Brad Carter and Angela Fitzgerald contributed the remainder.

Paper 2:

Lembo, K., Carter, B., & Fitzgerald, A., (2021). Investigating teachers' confidence in teaching junior science and subsequent interest in professional development. Submitted to The Australian Journal of Teacher Education

Kay Lembo contributed 95% to this paper. Collectively Brad Carter and Angela Fitzgerald contributed the remainder.

Paper 3:

Lembo, K., (2021). Content, Context and Connections: A design for teacher industry internship to enhance teacher understanding of nature of science. Submitted to the journal Professional Development

Kay Lembo contributed 100% to this paper.

## ***Published Book Chapters***

Book Chapter 1:

Lembo, K., Crough, J., & Woolcott, G. (2017). Real world science in the classroom. In G. Woolcott & R. Whannell (Eds.), Teaching Secondary Science: Theory and Practice (pp. 73-92): Cambridge University Press.

Book Chapter 2:

Lembo, K., Crough, J., & Woolcott, G. (2017). Bringing real world science into the classroom. In G. Woolcott & R. Whannell (Eds.), Teaching Secondary Science: Theory and Practice (pp. 283-299): Cambridge University Press.

Kay Lembo contributed 70% to each of these publications. Collectively Julie Crough and Geoff Woolcott contributed the remainder.

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# CHAPTER 1. INTRODUCTION

## 1.1. Thesis Overview

Science education remains a priority for researchers and governments due to the need for effective Science, Technology Engineering and Mathematics (STEM) education and major concerns over declining enrolments in the enabling sciences in secondary and tertiary education in some nations. Central to the issue is the importance of quality science teaching and its impact on student learning. Teaching quality arising from the experience, knowledge (both content and pedagogical) and skills of the teacher has a demonstrably positive influence on student achievements, particularly when teachers engage with professional development throughout their career (Guskey & Yoon, 2009; Harris & Sass, 2011). With a continuously expanding global knowledge base and advancing capabilities in science and technology however, teachers also face ever-increasing challenges to maintain their currency with expanding scientific content knowledge and improvements in pedagogical practice.

Underpinning the scientific knowledge of teachers is their epistemological understanding of the nature of science and scientific inquiry as the fundamental basis for scientific advancement. With widespread understanding of the nature of science and scientific inquiry being a vital part of scientifically literate advanced economies, it is imperative that teachers have opportunities to maintain and enhance their understanding of modern science. As a result, enabling teacher development of a conceptual understanding of science is essential in providing quality education for the next generation of professionals and a scientific literate society, and is the motivation for this research. In this thesis therefore, the aim is to gain a better understanding of Professional Development (PD) opportunities for science teachers in terms of content knowledge of the different scientific domains. The research examines relevant international and Australian educational trends and practices, and the specific case of science teachers in Queensland, Australia.

This thesis combines a series of academic papers and book chapters centred on secondary science teaching.

Following a brief introduction to the context and significance of the study (Chapter 1), the thesis begins with Paper 1 (Chapter 2), *'Strategies for effective teacher professional development involving scientific content knowledge: A review of the research'*. This paper details the systematic literature review which analysed peer-reviewed articles in research journals for studies related to in-service secondary science teachers' science PD, with a focus on teacher science content knowledge. Published studies were reviewed to identify their respective PD design features, aims and outcomes. The Clarke and Hollingsworth's Interconnected Model for Teacher Professional Growth (IMTPG) has been applied across the four domains of change (external domain, domain of practice, personal domain and domain of consequence) to analyse PDs with respect to teacher growth.

Paper 2 (Chapter 3), *'Investigating teachers' confidence in teaching junior science and subsequent interest in professional development'* details the findings of a quantitative enquiry into teacher confidence and related interest for professional development (PD) from science teachers teaching junior secondary science, which in the Australian context covers Years 7 to 10 (students aged 12 to 15). The paper forms part of a larger study exploring Queensland secondary science teachers' experiences, confidence levels, professional learning (formal and informal), and engagement with professional development (PD). The objective of the work is to better understand the relationship between teacher knowledge (content knowledge (CK) and pedagogical content knowledge (PCK)) and requirements for PD within the specific focus on Australian Science curriculum. The paper presents the trends identified regarding the range of teacher experience, knowledge background, perceived capacity to teach core junior science curriculum and interest for PD experiences to enhance their science content knowledge. In short, the focus is on what teachers know and what they need to help enhance their teaching of school science. Paper 2 presents research findings relating to high demand interest areas for PD relating to concepts in 'Advances in science and technology', 'Human influences and practice in science' and 'Data analysis and evaluation' in the Australian science curriculum. As the chosen PD support being for the 'Science as a Human Endeavour' and 'Science Inquiry Skills' strands and concepts, the provision of 'Nature of Science' (NOS) concepts in teacher PD was explored.

Paper 3 (Chapter 4), 'Content, Context and Connections: A design for teacher industry internship to enhance teacher understanding of nature of science' reviews the capacity of an integrated science teacher professional development program to enhance teachers understanding of 'Nature of Science' (NOS), encompassing both scientific knowledge and the process of acquiring scientific knowledge (scientific inquiry). The paper provides details of the developed Teacher Industry Internship (TII) program that is underpinned by a suite of integrated professional development (PD) opportunities for science teachers to participate in authentic, real-world science, technology, engineering, and mathematics (STEM) experiences. The components and the capacity of the TII program to create change in teacher NOS understanding and influence teacher growth is then analysed across the four change domains of the IMTPG framework.

Chapter 5 and 6 follows on the work of Paper 3 and provide a mechanism to support the education of pre-service science teachers so they can adopt the practices of incorporating authentic, real-life contexts and concepts in their teacher training. The expectation of developing an early understanding and adoption of industry partnership opportunities is a valuable teaching strategy can have long-term influence on teacher pedagogical practice. The work thus focuses on reinforcing the concept of role NOS and maintaining currency with cutting-edge scientific developments and integrating them into their classroom instruction.

Chapter 5, '*Real world science in the classroom*' provides pre-service teachers with information on how teachers and students may benefit from a realisation that we rely on science every day, and that along with technology, engineering, and mathematics (STEM), is part of the fabric of our lives. Through this, the importance of understanding the nature of science and the misconceptions that form the basis of much of our teaching, is explored. Furthermore, the chapter reinforces the importance of the use of real-world contexts with local contexts as a basis for developing scenario-based or problem-based teaching for the understanding of the concepts and processes of science – including enhanced scientific literacy.

Chapter 6 '*Bringing real world science into the classroom'* mirrors chapter 5 and provides examples for the practical application of learning experiences to enable students to connect scientific principles to real-world scenarios and develop an understanding of the nature of how science works. The chapter investigates activities and strategies that teachers can bring to the classroom for engaging and authentic experiences for their students, whilst ensuring that all strands of the Australian Curriculum in Science are addressed.

The thesis concludes with a short summary and synthesis of relevant research findings and the implications for future teacher professional development programs for enhancing science teachers' knowledge (CK and PCK), their understanding of the nature of science (NOS) concepts, and their professional growth (Chapter 7).

## 1.2. Framing the Research

This study seeks to establish a framework for sustainable and effective professional development for secondary science teachers in Queensland state schools. Several key factors have underpinned the formation of this research, including my personal experiences managing multiple local, state, and national STEM programs which involved supporting teachers in the provision of science professional development workshops and witnessing their desire and frustrations in accessing relevant professional learning experiences. I believe that it is through having science teachers who are up to date with their own knowledge, are passionate, and 'effective' teachers, that they can actually enhance their student's scientific literacy, content knowledge, and understanding of the nature of science. It is through equitable access to and provisions of professional development, despite their geographic location, that will greatly assist this goal.

Science education has been a focus of numerous research and government reports which stems from the recognition of the growing concerns over declining students' enrolment in the enabling science in secondary schools and higher education. (Dobson, 2006; Fensham, 2004; Lyons & Quinn, 2010; Office of the Chief Scientist, 2014; Tytler, 2007a).  Embedded within these and other research is the recognition of the impact of individual teacher quality on student learning.

Changes to the Australian Science curriculum and the escalating knowledge base of science with the ever-changing socio-political influences, has resulted in teachers facing an ever-increasing challenge to upgrade their pedagogical content knowledge and professional learning. Due to the complexity in educational learning environments, the specific requirements and the accessibility to resources, teachers often encounter challenges such as time constraints, infrastructure availability and reliability and support networks (Castro, Kelly, & Shih, 2010; Johnson, 2006; Lyons, Cooksey, Panizzon, & Pegg, 2006). These challenges are often compounded for teachers located in more rural and remote the schools.

## 1.3. Context of Study

This research is being undertaken as a personal extension to my experiences and to enhance my understanding to further support science teaching and teachers in Queensland secondary schools.

### 1.3.1. Experiential Knowledge

I entered the secondary teacher profession over 30 years ago after completing a one-year Graduate Diploma of Teaching and a Bachelor of Applied Science (Biology major and Chemistry minor).  It was through my combined love of Science and my passion in sharing my knowledge that made this a perfect career path. After graduation and consideration of my first teaching position, I applied through Education Queensland to be posted to the Darling Downs Southwest region, first preference Toowoomba. This decision was influenced by not only the fact that I undertook my Science degree there but also through my growing up in a small rural community west of Brisbane. The thought of teaching in a large urban school had no appeal to me and upon reflection, somewhat intimidating.

While my first posting was not Toowoomba, my preference for the Darling Downs Southwest region was successful. I became the sole science teacher at a P-Year10 at a small rural school a short drive from Toowoomba. It was at this school that my love of teaching science was confirmed. The role encompassed more than was expected and more than what was explained at university. Not only did I teach science for year 8, 9 and 10 students, I was also expected to provide fortnightly, interactive science displays in the schools administrative area and do 'guest lesson' in science for primary science teachers. In addition to this, came the role of all aspects of laboratory management including maintenance and ordering of science resources, preparation of chemical solution and laboratory set-up/clean-up for all class experiments. The experience was challenging yet exhilarating, as I experienced firsthand the issues that occur when in a small P-10 rural school. While other teachers in the school provided great support with respect to departmental operational procedures, and teaching pedagogical practice, I had to seek a range of external sources to enable me to undertake the science curriculum and pedagogical content knowledge as well as the laboratory management skills.

The following year saw a posting to another rural school, this time a dedicated high school for Year 8 – 12 students.  This school provided the opportunity for me to engage with other secondary science teachers and have access to experienced laboratory staff. The professional science support and dialogue was encouraging and greatly received. However, the move brought about a new challenge, as I was to become the Agricultural Science teacher for the school, an area that was outside of my curriculum knowledge. While there were synergies between areas of biological and chemical science, the teaching of topics like crop rotation, machinery operation and maintenance and general farm management was all very foreign. The school also had extensive plant propagation and hydroponics system was included in the agricultural curriculum. So again, I was required to quickly enhance my own content knowledge and seek external sources to support my teaching of this new curriculum focus. A benefit for me in this instance was the fact that I was to teach agriculture in a rural community. The local support and knowledge that existed and that was willingly shared provided the lifeline needed. This local context also proved to be a valuable tool in engaging the students in their study.

My next two, and last, school postings saw me return to Toowoomba and teach a combination of junior and senior science and mathematics subject are two large secondary schools.  With school populations over a thousand students, this was in stark contrast to my previous rural schools. The initial relocation came with a degree of trepidation, as I remember rural teaching colleagues providing me with a barrage of 'issues' that I would face at the 'big' school. Thankfully, this was not the case. While class sizes where large, the same level of professional, and social, interaction and dialogue occurred with my new science colleagues. With the larger school also came the additional benefits of access to more laboratory staff and science resources, as well as provision of greater administrative support and information and technology infrastructure.

As I perceived that I had mastered my pedagogical skills, I sought out challenges and opportunities to maintain and enhance my own pedagogical content knowledge (PCK) as well as seeking opportunities to provide support to colleague's support that I found so vital in my own teaching profession. This included engaging in the range of extra curriculum programs facilitated by Education Queensland and Queensland Study Authority (now known as

Queensland Curriculum and Assessment Authority), as well as becoming a member the district Board of Senior Secondary Studies Biological Sciences panel. This panel externally monitors and advices to state schools on program development, assessment tasks and student rank allocations. This opportunity provided a greater understanding on the depth and variety of programs that existed in our region. While this was a positive experience, it highlighted yet another area of professional support that is not available to teachers at P -10 schools, as this moderation is only required for the senior (year 11 and 12) subjects.

Whilst at my last teaching school, it was a privilege to being tasked with developing a feasibility study for a project to support accelerated pathway for science students to university. This initiative was part of an Education Queensland 'Spotlight on Science: 2003-2006' program and the established 'Toowoomba Technology, Maths and Science Centres of Excellence (TTMSCE)' which was established to support the teaching of science through partnering a state high school with a smaller primary school. Partnership activities ranged from joint science projects, sharing physical resources, and developing open communication and professional learning experiences for both primary and secondary teachers. It was at the conclusion of this initiative and at the commencement of the next state program 'Science Education Strategy: 2006-2009', that I was given the opportunity to establish the Toowoomba based, Science Centre of Innovation and Professional Practice (SCIPP). This was one of six centres across Queensland that brought together 'secondary schools, primary schools and university partners to provide quality professional development in science education' (SCIPP project plan, 2006).

As Director of the SCIPP my interest in developing and providing teacher support programs that addressed the needs of my teaching colleagues became my future focus. It was the programs priority action areas of: developing effective support the ongoing professional development needs of teachers; active engagement in science experiences for P-7 students through the Primary Connections teaching/learning model and resources; increased support for secondary teachers to effectively implement contextually based Senior Secondary Science syllabuses and improved teacher self-efficacy and increased engagement in hands-on science in middle schooling (SES, 2007), that have provide the foundation to a university based role. Between 2006 and 2010, through the TTMSCE, SCIPP and university school support programs, I was able to instigate a range of science education focussed initiatives designed to support teachers across the Darling Downs Southwest region. The initiatives incorporated a variety of delivery timing and methods, scientific contexts, and target audiences.

Since then, I have gone on to manage state and national science education programs that have continued to provide a depth of both students and teacher initiatives focused on enhancing capacity and interest across science, technology, engineering and mathematics (STEM). The first being for the expansion of the national Primary Industry Centre for Science Education (PICSE). My key role being to oversee the development, delivery and program quality of the student and teacher bioscience engagement programs delivered by science education officers at PICSE activities centres in all Australian states and territories (with the exception and the Australian Capital Territory (ACT)). The suite of integrated PICSE program activities including science class workshops, teacher professional development, teaching resources, student camps as well as student and teacher industry placement programs. These collaborative elements of the program required building strong and sustainable relationships with universities, regional primary industries, national R&D corporations, national and regional agribusinesses, regional research institutes, government authorities, local scientists, and employers in aligned primary industries. Specifically, for the teacher PD opportunities, this involved designing authentic, interactive experiences that would contribute to teachers' interest, thinking, motivation and confidence in relation to their understanding of NOS, and teaching of biosciences subjects. Thus, allowing teachers to increasingly influence students to study science in school and at university in preparation for bioscience careers.

The other was the management of the Queensland-wide program, the Queensland STEM Education Network (QSEN). The primary goals of QSEN were similar to those of PICSE with the goals of raising awareness, interest and achievement in science and mathematics among Queensland junior secondary students, as well as, engaging with parents, teachers, guidance officer and the broader community regarding the importance of STEM education and STEM related careers. Over the three years of the program's operation, each university partner was responsible for providing engaging, informal, out-of-class STEM experiences that capitalised on local relevant contexts and expertise, resources and infrastructure available at each of the universities. Through coordinating the efforts of the science education officer at each university, I was able to produce a range of collaborative teacher PD events and STEM resources designed to enhance teachers STEM content knowledge, pedagogical practices and classroom lesson planning and practice. The development of the QSEN website, www.queensland-stem.edu.au being a significant outcome of the program that is still available for teachers to access the suite of resources developed. Unfortunately, despite the positive outcomes and success of both the PICSE and QSEN programs, and as both relied on Federal and state funding grants which provided limited duration of the support, the teacher and student support initiatives had to conclude.

Throughout the last 30 years, I have sought to enhance my understanding, provide support other science teachers and 'give back' to the science teaching profession, through active involvement with national and international science teacher associations. This has involved Board member, Australian Science Teacher Association (ASTA); President, Science Teachers Association of Queensland (STAQ), Chair, International Advisory Board and Board member Rural Science Education Advisory Board, National Science Teacher Association (NSTA). These collaborations and knowledge sharing with a wide range of science educators having helped understand common challenges and opportunities to connection to enhance science teacher knowledge. So, in summary, this research has been driven by my personal passion and science education experience, in and out of the classroom, and the desire to gain a deeper understanding of how to best align the theory and understanding of effective teacher professional programs with the needs of secondary science teachers.

### 1.3.2. Purpose of Study

The goal of this research is to develop a deeper understanding of how to best align the theory and understanding of effective teacher professional programs with the needs of secondary science teachers. The initial focus of the research sought to understand the nature of science teachers' professional development opportunities in rural and remote government schools and the factors influencing or hindering it. With an initial needs analysis to provide the researcher with a comprehensive understanding of professional learning needs for science teacher in Darling Downs Southwest P –Year 10 schools. The resultant findings are to be utilised as the foundation for developing a university-supported framework to construct effective, technology enhanced professional learning experiences.  However, through the framing of research design and due to the small number of secondary science teachers in the P-10 schools, the research scope was expanded to include all Queensland state secondary schools with Year 7 to 12 student enrolments (Figure 1.1).

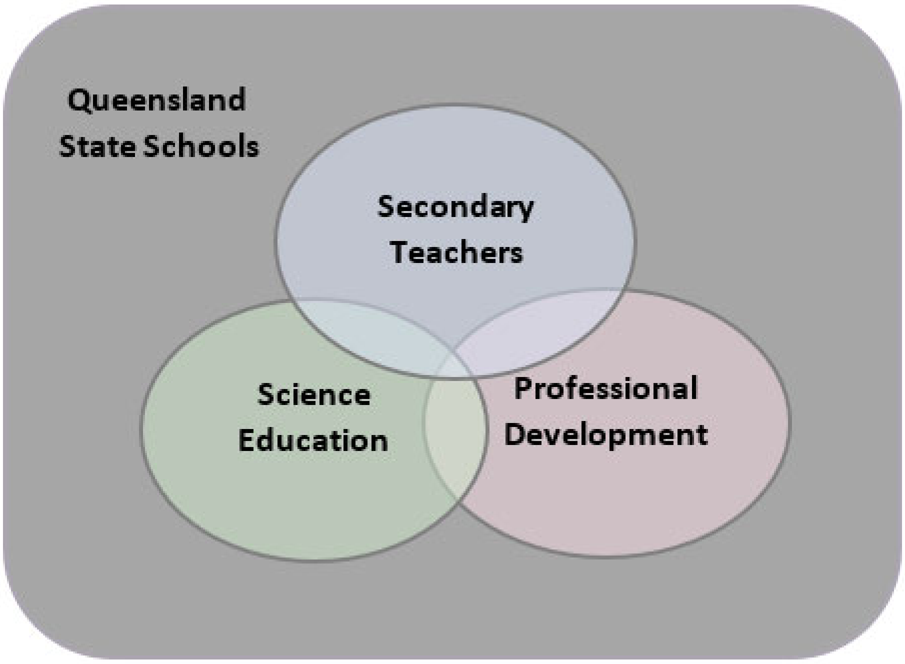


**Figure 1-1 Conceptual overview of the focus of Study**

Data collection incorporated: a systemic literature review of library databases to gather journal articles on secondary science teacher PD for detailed analysis of design features and domains of teacher professional growth; the administration of a needs analysis (fixed response and open-ended) to provide the researcher with demographic and organisational characteristics, as well as, identification of current teachers' professional learning processes and their related needs for their science-based learning.

### 1.3.3. Statement of Aims

The aim of this thesis is to provide the researcher with a comprehensive understanding of professional learning needs for secondary science teachers. The resultant findings can then be used as a foundation for developing a professional development framework to construct effective authentic professional learning experiences.

In investigate the research aim, the following research objectives provide the structure for exploring key concepts. These are:

- Explore the current nature and extent of science education professional development focused on enhancing secondary science teacher content knowledge
- Discover the level of science content knowledge confidence across all the science strands within Australian Curriculum: Science P-10.
- Provide a deeper understanding the perceived needs for science professional development in Queensland state schools
- Create a targeted science teacher professional development model for enhancing science knowledge (content and pedagogical) to improve the teaching of science in secondary schools

## 1.4. Significance of the Study

### 1.4.1. Importance of Science Education for Australia's Future

With an ever rapidly changing global economy, Australia must ensure that our next generation of young people are equipped with the skills and capabilities to be productive and competitive in the 21st century workforce (Binkley et al., 2012; Hynes & Dos Santos, 2007; Kuenzi, 2008). There is a global perception that for a country's future prosperity and growth, education systems should have considerable emphasis and engagement with STEM subjects. Recent international researchers estimate that around 75 percent of the fastest growing occupations require STEM skills and that employment requiring STEM skills are expected to grow at almost twice the pace of other occupations (Becker & Park, 2011; Craig, Thomas, Hou, & Mathur, 2011; Office of the Chief Scientist, 2014). Whilst the research indicates the growth in these areas, many countries including Australia are having concerns regarding their capacity to meet future skill demand, due partially to decline in students studying STEM subjects.

Whilst ensuring Australia's workforce capacity with STEM professions, the focus should not be lost on the capacity to for a nation with scientific literate citizens who can make informed decisions regarding emerging technologies, environmental issues, medical advancements and everyday living. It is generally accepted that the level of scientific literacy held by individuals impacts on their ability to make participate in and effective decisions in science related topics relevant to active citizenship (DeBoer, 2000; Department of Education, 2003; Tytler, 2007a). Since the 1980's, the realisation that science education should encompass wider application of scientific literacy, and not just to cater for students pursuing STEM careers (Aikenhead, 2006; Fensham, 2004). The importance of scientific literacy within education and the community has been acknowledged for many years and from broad sectors. The Department of Education, Science and Training identified that scientific and technology capabilities where required for "future growth and prosperity in a competitive global economy" (Department of Education, 2003, p. 1). This is a sentiment that is still being acknowledged by Australia's Chief Scientist in 2014, with the need for Australian education to "prepare a skilled and dynamic workforce, and lay the foundations for lifelong STEM literacy in the community" (Office of the Chief Scientist, 2014, p. 20).

Science education has been a focus of numerous research and government reports which stems from the recognition of the growing concerns over declining students enrolment in the enabling science in secondary schools and higher education (Dobson, 2006; Fensham, 2004; Lawrance & Palmer, 2003; Lyons & Quinn, 2010; Maltese & Tai, 2011; Tytler, 2007a; Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). Embedded within these and other research is the recognition of the impact of individual teacher quality on student learning (Goodrum, Druhan, & Abbs, 2011; Goodrum, Rennie, & Hackling, 2001; Hattie, 2003; OECD, 2005). A recent Grattan Institute report that a 10 percent increase in teacher effectiveness would not only Australia's lift education system into the top group of countries in the world but could also improve productivity of workers, increasing long term economic growth by $90 million by 2050.(Jensen, 2010a).

### 1.4.2. Student Interest and Participation in the Sciences

Concern has been expressed over recent years in the declining student numbers in enabling sciences (physics, chemistry and biology) in secondary and tertiary systems (Goodrum et al., 2001; Lyons, Cooksey, Panizzon, & Pegg, 2006; Lyons & Quinn, 2010; Office of Chief Scientist, 2012).  This concern can be clearly identified in Figure 1.2, which shows the decline in Year 12 student enrolment in the enabling sciences with most of the decline occurring before 2005, with numbers now remaining relatively stable (Ainley, Kos, & Nicholas, 2008). During this period, similar declines were also seen for other traditional subjects such as economics geography, history and advanced mathematics (Lyons & Quinn, 2010). These declines have been attributed to the increase in curriculum offerings that were introduced to cater for the diversity of cohorts of learners encouraged to attend school to Year 12. In the past many of these students would have left at year 10 and entered the workforce or vocational educational programs. (Lyons & Quinn, 2010; Queensland Studies Authority [QSA], 2014)

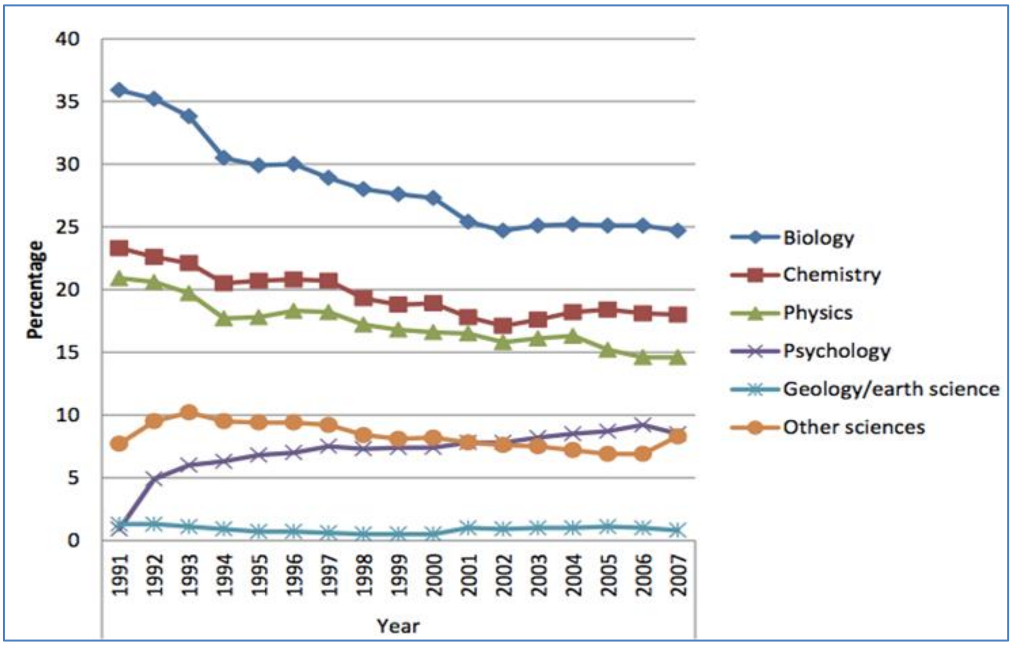


**Figure 1-2 National student enrolments in senior sciences subjects as a percentage of the Year 12 cohort in Australian schools (1991-2007)**

Source: (Ainley et al., 2008)

These overall student enrolment declines must also take into consideration that the level of students' lower achievement levels (failing students) in these subjects have also declined. In Queensland, students who would have previously been given low (LA) or very low (VLA) levels of achievement have been able to choose, or been advised, to take other suitable subjects. These students have contributed to the overall lower numbers, however the level of students achieving higher grades have shown gradual improvement. The decline in the LA and VLA students in year 12 students is shown in Figure 1.3.

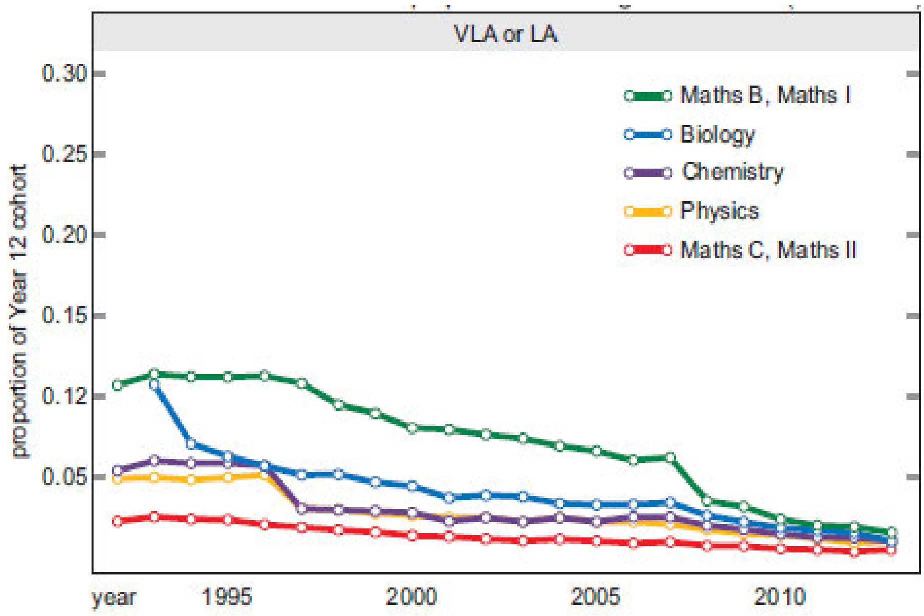


**Figure 1-3 Declining enrolments in Queensland senior mathematics and sciences subjects: Proportion of OP-eligible in bands (1992-2013) (Queensland Studies Authority 2014)**

The stabilisation in students enrolments for, and interest in, the enabling science in Queensland secondary schools has been identified by the Queensland Study Authority (Queensland Studies Authority [QSA], 2014) most popular subjects for the OP band 1 - 5 students. Among the top 5166 year 12 students, 99.7% studied English, 89.2% studied Maths B, 59.8% Chemistry, 44.5% Physics, 44.5% Biology and 39.5% Maths C. (Queensland Studies Authority [QSA], 2014). Therefore, by basing comparison of enrolments of students in the enabling sciences within the OP eligible cohort (or potentially tertiary-bound students), then Figure 1.4 reveals Queensland is starting to experience a rise in student participation with these subjects.

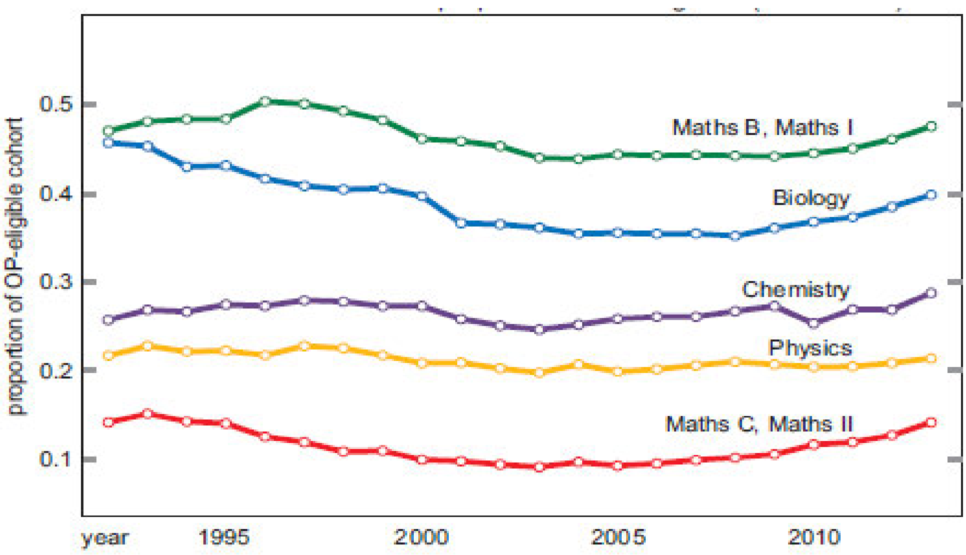


**Figure 1-4 Proportion of OP-eligible Year 12 students studying mathematics and sciences in Queensland (1992–2013) (Queensland Studies Authority, 2014)**

While the student enrolment data in Queensland is showing a promising increase, it is still to be seen if this will translate into an increase in students pursuing tertiary science and/or science education degrees. Concerns regarding the national decline have generated numerous studies to identify reasons, and pose recommendations, as to why students may be deterred from taking science subjects. (Dobson, 2006; Hackling, Goodrum, & Rennie, 2001; Lyons, Cooksey, Panizzon, & Pegg, 2006). These findings predominantly indicated that Australian students found school science to be irrelevant to their interests and everyday life and are subjects dominated by content and repetition. However, the Australian students reported positive views of science when the science is perceived as engaging, of immediate relevance, contained practical work and was provided by high-quality teaching (Lyons, 2006; Osborne & Collins, 2001; Tytler & Symington, 2006). Lyons and Quinn (2010) identified three additional contributing factors closely associated with decline in students studying science:

- students' difficulty seeing themselves as scientists,
- decrease in the utility of enabling science subjects relative to their perceived difficulty
- the failure of school science to engage the wider cohort of students

### 1.4.3. Science Education and Teacher Influence

Secondary Science teachers are the key focus of this research and with education policy and the literature emphasis the need for ongoing teacher professional learning. However, it is also essential that a detailed understanding of current professional practice, demands and accountabilities be taken into consideration (Department of Education, 2013; Education Queensland, 2011; Hattie, 2003; Meiers & Ingvarson, 2005)

Recent implementation of the Australian Science curriculum and the expanding knowledge base of science has resulted in teachers facing an ever-increasing challenge to expand their scientific content knowledge, their pedagogical practice and professional learning. Due to the complexity in educational learning environments, the specific requirements and the accessibility to resources, teachers often encounter challenges such as time constraints, infrastructure availability and reliability and support networks. These challenges are often compounded for teachers at rural and remote schools (Lock, 2008; Lonsdale & Ingvarson, 2003; Lyons, Cooksey, Panizzon, & Pegg, 2006; MCEETYA, 2011).

Irrespective of the teaching discipline taught in secondary schools, teachers are required to perform many administrative and extracurricular duties as part of their roles and responsibilities. The Australian Professional Standards for Teachers (AITSL, 2013) have outlined seven standards that identify the areas of focus of what 'effective teachers' should know and be able to do. These are articulated into three main domains: Professional Knowledge, Professional Practice and Professional Engagement. Refer appendix 1. Within each domain, the seven standards attempt to articulate the characteristics that constitute the complex process undertaken by effective teachers. These standards are;

- Know students and how they learn
- Know the content and how to teach it
- Plan or and implement effective teaching and learning

- Create and maintain supportive safe learning environments
- Assess, provide feedback and report on student learning
- Engage in professional learning
- Engage professionally with colleagues, parents/carers and the community

Whilst the standards aim to identify a range of descriptors that encompass teachers through various level of their professional journey as educators: Graduate, Proficient, Highly Accomplished and Lead, they do not address any suggested mechanisms for progression.

This research identifies specific mechanisms that can be applied to support teachers to become 'effective teachers' of science. For this report, the AITSL definition of an effective teacher is used:

> *An effective teacher is able to integrate and apply knowledge, practice and professional engagement ….to create teaching environments in which learning is valued (AITSL, 2013, p. 6)*

An effective science teacher therefore doesn't only need to have a strong understanding of learning theory, curriculum development and pedagogical practice, they must also have rich and flexible science content knowledge and pedagogical content knowledge, to promote student science learning (Borko, 2004; McDiarmid, 1989; Opfer & Pedder, 2011; Riggs & Enochs, 1990). Strong science content knowledge also helps establish higher levels of science teachers' self-efficacy, whereby effectively reducing anxiety about science teaching and promoting more positive attitudes toward science.

In the words of the Australian Chief Scientist, am inspiring teacher can be dined as follows:
'Inspiring Teachers will generally be those who are confident that they know their subjects well, and can transmit that confidence and their passion, into the classroom.' (Office of Chief Scientist, 2012, p. 7), the need to provide support and opportunities for teachers to enhance their science teaching

self-efficacy is paramount. Science teachers not only need to be confident with ‘core’ science content knowledge, but their capacity also to stay well-informed with the expanding depth of knowledge and contemporary application of new scientific knowledge is relevant.

Secondary science teachers have been identified in the literature as being an area where key teacher shortages are occurring. The shortage of speciality teachers with the STEM subjects, and the difficulty in attraction and retention of STEM teachers was found to increase proportionally with increasing distance from regional centres (Harris, Jensz, & Baldwin, 2005; Lyons, Cooksey, Panizzon, & Pegg, 2006; MCEETYA, 2001, 2011; Sharplin, O’Neill, & Chapman, 2011).

Inherent with this is the challenge in defining a ‘specialty science teacher’ as there is no standard national qualification to enter the teaching profession and accreditation is managed by either state-based organisations or even by individual schools in the case of some Catholic or independent schools (Lawrance & Palmer, 2003). This flexibility in teacher admission, and the necessity to undertake more study, has influenced the trend of fewer science teachers undertaking an undergraduate science degree.(Lawrance & Palmer, 2003; Lyons, Cooksey, Panizzon, & Pegg, 2006). In a recent Australian study ‘Who’s Teaching Science’, Heads of Department were asked to identify their preference and minimum level of science for their science teachers. 77% reported a strong preference for Science Faculty trained teachers compared to Education Faculty only trained teachers, with the main reason being related to the ‘depth of knowledge’. The remaining 23% stating the Education Faculty trained teachers had a ‘better understanding of the science required by the students’ p 12 (Harris et al., 2005). A near unanimous 98% of respondents  expressed the opinion that teachers with only science at a first year tertiary level would be ill-equipped to teach senior sciences, with 82% of these feeling that they would be unsuitable for Year 9 and 10 science teaching (Harris et al., 2005).

The consequences of a shortage of available science teachers, and the preference for highly qualified and experienced teachers, include the movement of teachers to selective schools and locations, leaving classes in other schools being taught by inexperienced teachers, often teaching 'out of field' (Berry, Loughran, Smith, & Lindsay, 2009; Lawrance & Palmer, 2003; Lyons, Cooksey, Panizzon, Parnell, & Pegg, 2006; McKenzie, Rowley, Weldon, & Murphy, 2011). The more the schools is deemed 'unfavourable' or the more remote the school the greater the chance of teacher being required to teach out of field. The detriment to student learning is highlighted by research identifying that when students are taught by teachers with science and /or maths degrees, student achievement is higher than when taught by teachers teaching 'out of field'(Clotfelter, Ladd, & Vigdor, 2007; Goldhaber & Brewer, 2000; Monk, 1994) The influence on student learning is greater in higher level sciences in which the teachers' content knowledge is presumably more critical (Goe, Bell, & Little, 2008; Monk, 1994).

Education and teaching remains a complex system and teacher qualification cannot be considered in isolation when defining teacher effectiveness. Policy and research recommendations to improve effectiveness cover the domains of improving quality of tertiary admissions requirements and training programs, ongoing in-service teacher evaluation and recognition of achievement and provision of professional development (Goe et al., 2008; Jensen, 2010a; Meiers & Ingvarson, 2005; Queensland Government, 2013; Stecher, 2011).

#### 1.4.4. Regional Challenges and Opportunities for Science Education in Queensland Schools

Whilst there is a nationwide wide shortage in speciality teachers especially in STEM, there is greater difficulty in attraction and retention of science teachers in rural and remote areas. (Harris et al., 2005; Lyons, Cooksey, Panizzon, Parnell, et al., 2006; Lyons & Quinn, 2010; McKenzie, Santiago, Sliwka, & Hiroyuki, 2005). Qualified mathematics teachers are significantly tougher to attract than science teachers, Figure 1.5 showing an increasing degree (8% – 35%) of difficulty finding science teacher the further away the school is from a metropolitan area.

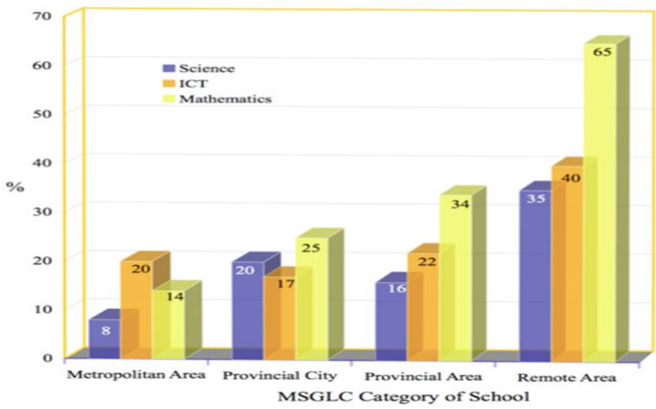


**Figure 1-5 Percentage of science, mathematics and ICT respondents in different locations that is 'very difficult' to fill teaching vacancies in their subject areas (N=1261) (Lyons, Cooksey, Panizzon, & Pegg, 2006)**

Compounding these issues is the added challenge of retaining the teacher at the more remote and regional schools, with around 58% of school administrators reporting difficulty compared to 17% in 'highly accessible' schools. (Figure 1.6). Refer appendix 2 for Education Queensland school regions and appendix 3 for Queensland area remoteness structure classifications.

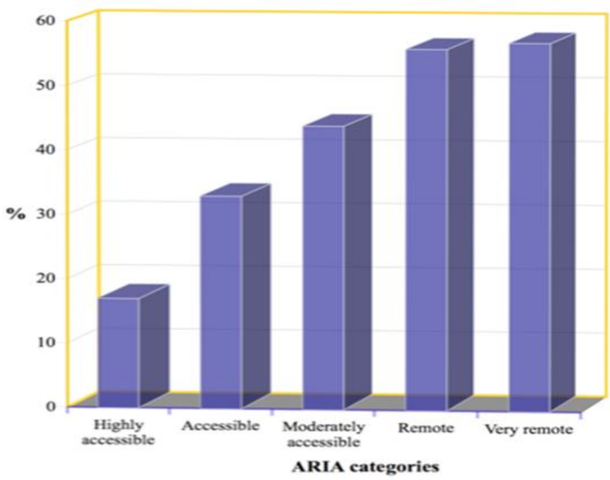


**Figure 1-6 Percentage of schools reporting difficulty in retaining science teachers, of the total number of schools responding per ARIA category (Lyons, Cooksey, Panizzon, Parnell, et al., 2006)**

Research has identified that teachers in regional areas face not only additional systemic teaching challenges including:

- multi-age classes rural classroom
- additional administrative responsibilities
- lack of access to appropriate resources (physical and social)
- lack of incentives to teach in rural and remote schools and
- lack of professional development and advancement.

As well as, depending on personal circumstances and experiences, teachers face challenges with

- Rural community dynamics and interactions
- Physical and social isolation - communication and interaction with colleagues, consultants, family and friends
- Employment opportunities for partners/family members (Black, Duff, Saggers, & Baines, 2000; Gregson, Waters, & Gruppetta, 2006; Lock, 2008; Lock et al., 2009; Lyons, Cooksey, Panizzon, Parnell, et al., 2006; Margaret & Kent, 2006; MCEETYA, 2011)

Acknowledging these challenges, pre-service teacher training programs, government and education authorities and other supporting organisations have developed specific policy and linkages to support transitions to rural and remote locations. (Chenoweth & Stehlik, 2001; Department of Education and Training, 2011; Lock, 2008; MCEETYA, 2011; Pini, Price, & McDonald, 2010; White & Kilne, 2012). Despite these policies and intent, teachers may still find teaching in rural settings too challenging and decide to leave the teaching profession.

## 1.5. Teacher Effectiveness and Professional Development

With the acknowledgment that teacher quality-experience, knowledge and skills having a positive influence on student achievements, there is also the recognition that teachers undertake ongoing professional learning through-out their career (Darling-Hammond, Chung Wei, Andree, Richardson, & Orphanos, 2009; Goodrum et al., 2001; Jensen, 2010b; OECD, 2005).

The Australian Institute for Teaching and School Leadership (AITSL) has identified 'Standard 6: Engage in professional learning' as one of the seven standards for the seven professional standards for teachers and has articulated the components of quality at each career stage (graduate, proficient, highly accomplished and lead). The areas for teacher to focus their professional learning around include:

- Identify and plan professional learning needs
- Engage in professional learning and improve practice
- Engage with colleagues and improve practice
- Apply professional learning and improve student learning. (AITSL, 2013)

Despite the value placed on professional learning, both formal and informal, numerous studies have identified that professional development can be ineffective if it does not take into account how teachers learn, how the learning is embedded in life and work environment, and the existing conditions supporting and promoting the learning. (Borko, 2004; Clarke & Hollingsworth, 2002). Therefore teacher learning must be conceptualised as a complex system involving reciprocal causation rather than events (Opfer & Pedder, 2011), where changes in any part of the system will influence the others. Simplistically the relationship is shown in Figure 1.7, where each of these key influences, each can either restrain or enable teacher learning.

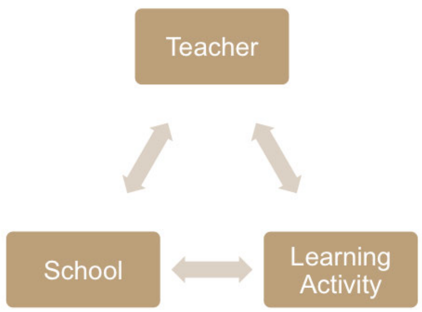


**Figure 1-7 Influencers impacting on teacher professional learning**

Research on teacher professional development concludes that teachers need time to develop, absorb, discuss and practice new knowledge and traditional; ‘one-off’ workshops are less likely to lead to teacher change. (Berry et al., 2009; Borko, 2004; Darling-Hammond et al., 2009; Hynes & Dos Santos, 2007). Professional development activities were found to be more effective if they have a contextual focus, are school-based and curriculum-integrated, teachers engage with materials of practice, are active and reflect way to teach students, entail collaborative participation and are sustained and intensive (Borko, 2004; Ingvarson, Meiers, & Beavis, 2005; Opfer & Pedder, 2011). These factors align with findings from Garet, Porter, Desimone, Birman and Yoon (2001) who identified that when professional development focusses on academic subject matter, gives opportunity for hands-on work and integrates in school life, then the teachers’ enhanced knowledge and skills are more likely to translate in changed teaching practice. School system levels involve the contexts of the organisational structure and leadership, communication and control processes, collegial interaction and shared values and beliefs and the access, support and encouragement to participate in professional learning activities (Opfer & Pedder, 2011; Sharplin et al., 2011; Tan, 2021)

While the concept that good teaching and teachers is important for student learning, researchers have not reached consensus to identify the characteristics of ‘effective’ and ‘quality’ teachers. Inherently this is due to differences in definitions combined with differences in measurement of the ‘outcomes’. In an analysis of studies of teacher quality, consolidated these into four categories of teacher qualifications, teacher characteristics, teaching practices and teacher effectiveness (Goe, 2007). Table 1.1 provides elaboration and examples encapsulated by each category (Goe & Stickler, 2008). These characteristics align with research that has identified that individual teacher learning is influenced by their personal experiences, attitudes and beliefs, their experience with school and teaching and their pedagogical content knowledge (PCK) – Subject, Pedagogy and Content knowledge (CK) and forms a complex ‘nested system’ (Opfer & Pedder, 2011)

**Table 1-1 Four categories for examining teacher quality**

| Category | Definition and example indicators |
|---|---|
| Teacher qualifications | Credentials, knowledge, and experiences that teachers bring with them when they enter the classroom, such as: Coursework, grades, subject-matter education, degrees, test scores, experience, certification(s), and evidence of participation in continued learning (e.g., internships, induction, supplemental training, and professional development) |
| Teacher characteristics | Attitudes and attributes that teachers bring with them when they enter the classroom, such as: Expectations for students, collegiality or a collaborative nature, race, and gender |
| Teacher practices | Classroom practices teachers employ—that is, the ways in which teachers interact with students and the teaching strategies they use to accomplish specific teaching tasks, such as: Aligning instruction with assessment, communicating clear learning objectives and expectations for student performance, providing intellectual challenge, allowing students to explain what they are learning, using formative assessment to understand what and the degree to which students are actually learning, offering active learning experiences, subscribing to cohesive sets of best teaching practices |
| Teacher effectiveness | A "value-added" assessment of the degree to which teachers who are already in the classroom contribute to their students' learning, as indicated by higher-than-predicted increases in student achievement scores |

## 1.6. Teacher Characteristics and Self-Efficacy

Teacher characteristics are often linked with teacher quality and effectiveness, as well as student learning. A valuable teacher characteristic that has considerable research undertaken with science education is teacher self-efficacy, which involves both a teacher's beliefs about their personal ability to influence student learning as well as the results of their specific instructional interventions (Settlage, Southerland, Smith, & Ceglie, 2009). Research has shown positive correlations between positive teacher self-efficacy and effective teaching practices, and between strong teacher self-efficacy and improved student achievement and attitude (Ross, 1992; Tschannen-Moran, Hoy, & Hoy, 1998; Wheatley, 2002).

Studies in self -efficacy are grounded in Bandura's social cognitive theory (Bandura, 1977, 1986, 1997b), where he defines self-efficacy as the "beliefs in one's capabilities to organise and execute the course of action required to produce given attainments" (Bandura, 1997b, p. 3). In an educational setting, this can be related to a teacher's beliefs about their personal ability to influence student learning and overall effectiveness with students. However, identifying the factors that influences an individual teacher self-efficacy is a complex and diverse source. Bandura assigned these influences to four inter-related categories: mastery experiences (achieved knowledge and experiential capabilities), vicarious experiences (experiences with others), social persuasions (external and verbal interactions and support) and physiological and emotional arousal (mental and physical wellbeing) (Bandura, 1997b). Mastery experiences are seen as the most powerful influences but must be weighed and processed through self-referent thought before change in self-efficacy beliefs can occur (Bandura, 1997b; Tschannen-Moran et al., 1998).

The identification of teacher self-efficacy is mainly interpreted through self-reporting surveys. Traditionally researchers measure teachers' self-efficacy in two dimensions: general teaching efficacy and personal teaching efficacy; however, these have been extended on and adapted to apply to specific teaching contexts and concepts. Commonly used self-efficacy tests for science education include STEBI (Science Teaching Efficacy Belief Instrument), two subscales STOE (Science Teacher Outcome Expectancy) and PSTE (Personal Science Teaching Efficacy belief) which utilise 5-point Likert scale to ascertain teachers self-ranking. (Henson, 2001; Ramey-Gassert, Shroyer, & Staver, 1996; Riggs & Enochs, 1990)

The challenge for the education system and policy makers is to identify and implement effective intervention programs that can assist to increase teachers' self-efficacy. Although limited, studies regarding the impact of interventions on individual teachers' efficacy, have indicated that meaningful, active interventions can have positive influence on teachers self-efficacy (Anderson, Dragsted, Evans, & Sorensen, 2004; Henson, 2001; Ross, 1992; Tschannen-Moran et al., 1998). However, Bandura (1997) suggest that more experienced teachers' efficacy is more resistant to change than early-year and pre-service teachers. Bandura (1997, p82) also emphasises that positive change can only occur through "compelling feedback that forcefully disrupts the pre-existing disbelief in one's capabilities".

While current research suggests that teacher self-efficacy is malleable, positive impact is unlikely outside of long-term, meaningful professional development opportunities that captivate a teachers critical thinking and facilitates reflection on practice (Bandura, 1997b; Henson, 2001)

## 1.7. Research Design

The research design involved three phases: Phase one involved the analysis of in-service secondary science teachers' science PD, with a focus on teacher science content knowledge. Phase two involved the development of needs analysis for science teacher current professional development engagement, their self-identified confidence teaching science content concepts and level of interest in PD opportunities against the same since content. Phase two thus established a priority of needs for professional development; Phase three involved applying the learnings from Phase one and two to address their professional development needs and develop supporting PD opportunities to enhance secondary science teacher capacity and teaching practice.

This thesis in underpinned by numerous years of predominately quantitative data collection and evaluation, with the key driver being the production of procedural, financial and annual operational reports. It has been through the desire for deeper understanding of the teacher participation motivations and achievable outcomes, thorough analysis of research design, methods and procedures, that the phenomena of science teacher learning have been sought. These insights then applied to the of university and industry partnered professional learning opportunities developed for secondary science teachers to engage authentic real-world science.

# CHAPTER 2. PAPER 1 - STRATEGIES FOR EFFECTIVE TEACHER PROFESSIONAL DEVELOPMENT INVOLVING SCIENCE CONTENT KNOWLEDGE: A REVIEW OF THE RESEARCH

## 2.1. Abstract

This paper presents a systematic literature review related to in-service secondary science teachers' science professional development (PD). The research analysed peer-reviewed articles in research journals for studies with a key focus on PD involving science content knowledge published from 1990 through 2019. A total of 41 articles were identified with the majority published in the last decade. The articles were examined using a framework based on professional design features. The studies were also categorised according to their aims and outcomes using Clarke and Hollingsworth's interconnected model for teacher professional growth (IMTPG). The findings indicated that there has been increasing emphasis on supporting curriculum-focused science content knowledge and pedagogy-related content knowledge. Most studies included 'effective' PD design features identified in research and delivered intensive, long-term programs with multiple outcome evaluation methods. Inclusion of student learning consequences as part of PD outcome evaluation increased across the years, peaking in the last five years.

Keywords

Secondary science education, Professional development, Science content knowledge, Science teachers

## 2.2. Introduction

It is widely acknowledged that teacher quality, which can be conceptualised as experience, knowledge and skills, has a positive influence on student achievement, particularly when teachers engage with professional development (PD) throughout their career (Darling-Hammond et al., 2009;

Goodrum et al., 2001; Timms, Moyle, Weldon, & Mitchell, 2018). Teacher professional development programs, and subsequent professional growth, are supported by different theories and models which relate to how teachers learn and how students learn (Borko, 2004; Clarke & Hollingsworth, 2002; Darling-Hammond & Richardson, 2009; Gess-Newsome, 2015; Opfer & Pedder, 2011). Additionally, a variety of research methods has been applied to the analysis of PD based on characteristics including delivery and design, duration, intensity and context (Garet, Porter, Desimone, Birman, & Yoon, 2001; Hawley & Valli, 1999; Ingvarson et al., 2005; Knapp, 2003).

The paper reviews research that focuses on the PD of in-service secondary science teachers in relation to enhancement of their science content knowledge. With a secondary teacher, identified as per the Australian secondary education, as a teacher teaching students between years seven and twelve. Its goal is to study the changes in the design and analysis of the PD programs and builds upon the review undertaken by van Driel et al (2012) about a decade ago. van Driel et al (2012) analysed studies published between 2007 to 2012 that reported formal PD interventions for in-service science teachers which also reported on the outcomes with respect to teacher and/or student learning. This review, however, had a more focused scope on secondary science teacher content knowledge in PD programs and how these studies have changed over the last three decades.  In the context of this systematic literature review, teacher PD has been defined as activities with the intent to enhance teacher knowledge, skills and attitudes and how they apply their knowledge in practice to support student learning (Guskey, 2003).

The intention of this systematic literature review is to investigate the current state of PD in has occurred in relation to enhancing secondary science teacher science content knowledge and to reflect on changes in the methodology of integrating content knowledge enhancing goals in science PD offerings over the previous three decades.

## 2.3. Conceptual background

This section provides an overview of some of the key conceptual ideas informing this study.

### 2.3.1. Teacher Content Knowledge

Teacher knowledge is of pivotal importance in the design and conduct of teaching situations that may help students to learn science (Darling-Hammond, Hyler, & Gardner, 2017a; Goodrum et al., 2001; Hattie, 2003; OECD, 2005, 2018). Key influences which either restrain or enable teacher learning are individual in their nature and are influenced by personal experiences, attitudes and beliefs (Magnusson, Krajcik, & Borko, 1999; Wheatley, 2002); their experience within school and teaching (Kind, 2009); their pedagogical content knowledge (PCK) and their content knowledge (CK) (Gess-Newsome et al., 2019; Hashweh, 1987). Understanding the separation of CK and PCK can be described as CK being the knowledge of the subject matter taught and PCK is the knowledge needed to make the subject matter accessible to students (Shulman, 1986). Shulman (1986) further elaborates that "the teacher need not only understand that something is so, the teacher must further understand why it is so" (p.9). However the definitions, components and relationship between PCK and CK has varied since conceptualised by Shulman in 1986. Magnusson et al. (1999) proposed that PCK is the result of a "transformation of several types of knowledge for teaching (including subject matter knowledge) and it represents a unique domain of teacher knowledge" and that it consists of five core components: orientations towards teaching science; knowledge of science curricula; knowledge of instructional strategies; knowledge of student understanding of science; and knowledge of student assessment. Definitions for PCK and CK in science are usually grounded in proposed framework models for teachers generally and within specific domains (Ball, Thames, & Phelps, 2008; Carlsen, 1999a; Grossman, 1990; Veal & MaKinster, 1999b). Although, whether considered a separate domain of knowledge or included within PCK, science content knowledge is acknowledged to be a critical component and influencer of science teacher effectiveness. Figure 2.1 provides a simple conceptual overview that captures the science teacher knowledge concepts that has been developed to support this research.

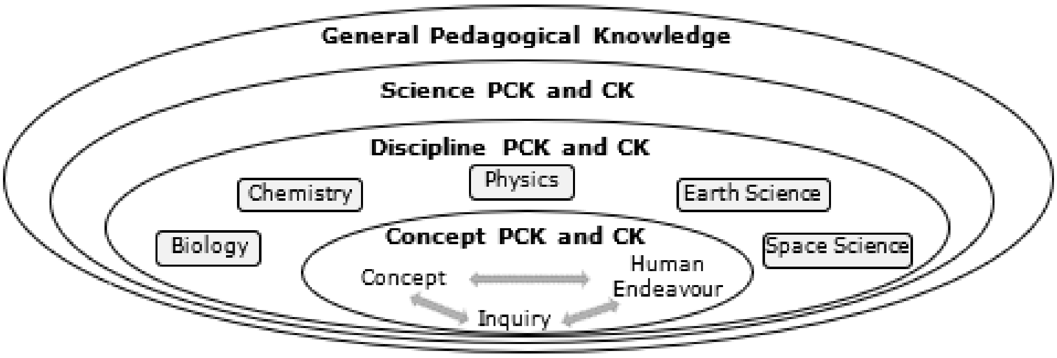


**Figure 2-1 Conceptual framework for understanding the domains of science teacher knowledge**

### 2.3.2. Teacher Science Content Knowledge and Professional Development

With the acknowledgment that teacher quality - experience, knowledge and skills - has a positive influence on student achievement, there is also recognition that teachers undertake ongoing professional development throughout their careers (Darling-Hammond et al., 2009; Department of Education, 2003; Goodrum et al., 2001; Jensen, 2010b; OECD, 2005).
An effective science teacher therefore does not only need to have a strong understanding of learning theory, curriculum development and pedagogical practice, but they must also have flexible access to rich science content knowledge (CK) and pedagogical content knowledge (PCK) to promote student science learning (Borko, 2004; Borko, Jacobs, & Koellner, 2010; McDiarmid, 1989; OECD, 2018; Opfer & Pedder, 2011; Riggs & Enochs, 1990). Strong science content knowledge also helps establish higher levels of science teacher self-efficacy, thereby effectively reducing anxiety about science teaching and promoting more positive attitudes toward science. Despite the value placed on professional learning and development, both formal and informal, numerous studies have identified that professional development can be ineffective if not taking into account how teachers learn, how the learning is embedded in life and the work environment, and how the

existing conditions support and promote learning. (Borko, 2004; Clarke & Hollingsworth, 2002).

Over many years of research into professional development and its effectiveness, the majority of studies have sought to provide lists of essential design features. These include aspects of program context, focus, duration, contact hours and type of learning (Darling-Hammond et al., 2017a; Desimone, 2009; Hawley & Valli, 1999; Kennedy, 1998b; Timperley, Wilson, Barrar, & Fung, 2008). Research on teacher professional development activities concludes that teachers need time to develop, absorb, discuss and practice new knowledge, and that traditional 'one-off' workshops are less likely to lead to teacher change. (Berry et al., 2009; Borko, 2004; Darling-Hammond et al., 2009; Hynes & Dos Santos, 2007). Professional development activities are found to be more effective if they: a) have a contextual focus; b) are school based and curriculum integrated; c) have teachers engage with materials of practice; d) are active and reflect way to teach students; e) entail collaborative participation; and f) are sustained and intensive (Borko, 2004; Borko et al., 2010; Ingvarson et al., 2005; Opfer & Pedder, 2011). However, whilst the most widely referenced requirement for PD is that it should focus on content knowledge (Blank, 2013; Blank et al., 2005; Desimone, 2009; Timperley et al., 2008), research findings vary on the extent teacher knowledge-only professional development impacts on student learning (Ingvarson et al., 2005; Kennedy, 1998a).

These factors align with findings from Garet et al (2001) who identified that when professional development focuses on academic subject matter, gives opportunity for hands-on work and is integrated into school life, then the teachers enhanced knowledge and skills are more likely to translate in changed teaching practice (Garet et al., 2001). Another acknowledged consideration for teacher PD is the teachers need to have input and control over their professional development, and that: "Teacher development is considered especially productive when teachers are in charge of the agenda and determine the focus and nature of the programming offered." (Ball, 1996, p. 502)

### 2.3.3. Teacher Professional Growth and Learning

Research on teacher professional development has changed considerably over the past three decades. It had been widely assumed when teachers are presented with PD opportunities that their knowledge and teaching practice would improve, and accordingly better student outcomes would result. However, prior to 1990, ideas about teacher change had been more focused on learning through reflection on personal teaching practice. PD programs effectiveness was generally investigated on a small scale, often using teacher self-perceived change or program satisfaction as a primary criterion of program success (Frechtling, Sharp, Carey, & Vaden-Keirnan, 1995; Hill, Beisiegel, & Jacob, 2013). In the next decade a larger body of literature emerged on in-service professional development programs, teacher learning and teacher change. The research consolidated the notions that PD could cause changes in teacher practice, which could in turn lead to changes in students' learning, and therefore could result in changes in teacher knowledge, beliefs, and attitudes. Researchers found that teacher change and growth covers a complex system of processes in which teachers are engaged in active and meaningful learning (Borko, 2004; Clarke & Hollingsworth, 2002; Desimone, Porter, Garet, Yoon, & Birman, 2002; Guskey & Yoon, 2009).

Clarke and Hollingsworth (2002) stated that teacher growth is: "…a process of construction of a variety of knowledge types (content knowledge, pedagogical knowledge, and PCK) by individual teachers in response to their participation in the experiences provided by PD program and through their participation in the classroom" (p. 955). They introduced the Interconnected Models of Teacher Professional Growth (IMTPG) to study changes in teacher knowledge when engaged with active and meaningful learning. The model builds upon the work of Guskey (1986) and other researchers which recognised the need for teacher PD to move from the ineffective 'deficit model' to teachers as active leaners with the capacity to shape their professional growth through reflective participation in PD programs and in classroom practice. The model provides the details of an empirically grounded model of professional growth that incorporates key features of contemporary learning theory and is based on the assumption that professional learning is idiosyncratic, non-linear and varies based on contextual situations. According to the authors, the model can be utilised as an analytical, predictive, and interrogatory tool and provides a framework to support the planning for professional development providers and for research analysis of teacher change or growth.

The IMTPG consists of four domains: the Personal Domain (teacher knowledge, beliefs and attitudes), the Domain of Practice (professional experimentation), the Domain of Consequence (salient outcomes such as student learning), and the External Domain (sources of information, stimulus or support). The model highlights the change in mediating processes of 'reflection' and 'enactment' as the mechanisms that induce change in domains; with the complexity of teacher learning recognised through the multiple growth connections between the domains. (Figure 2.1). The external domain is identified as occurring outside a teachers' 'person world', in contrast to the other three domains which encompass their professional practices including their actions, knowledge and beliefs. Through a teacher's mediating process of 'reflection and 'enaction' change in one domain is translated into change in another domain.

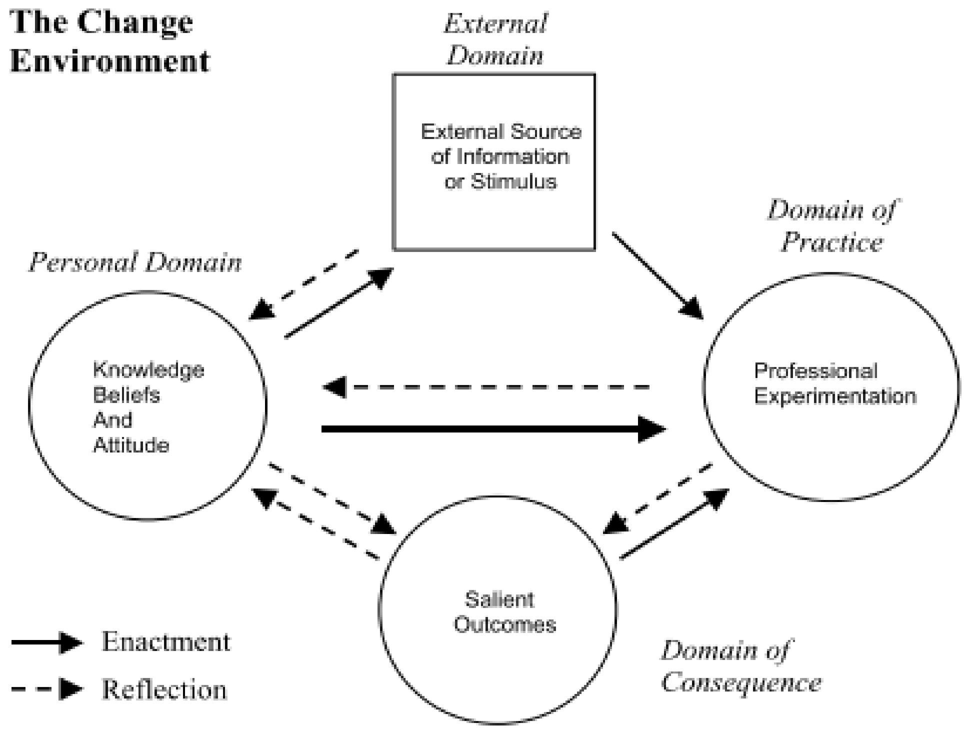


**Figure 2-2 The Interconnected Model of Teacher Professional Growth (IMTPG) (Clarke & Hollingsworth, 2002)**

## 2.4. Method

Research articles were analysed to identify trends and changes occurring in the provision of secondary science teacher PD. Initially articles were identified as part of systematic literature review of journal publications, specifically between 1990 and 2019. Identified articles were reviewed with respect to focus, context, design structure and outcome measures utilised within the individual PD's. Secondly, the change domains from the IMTPG model were used to categorise the identified research articles based on their reported PD objectives to bring about change in teacher knowledge, beliefs, attitudes, and their practice as well as changes in student learning.

### 2.4.1. Literature search method

Two well-known and respected educational databases – ERIC and A+ education were searched for this study: ERIC, as the largest educational database and A$^+$ Education, based on ACER's Australian Education Index (AEI) and being associated with the focus country. The scan of the literature was taken of peer-reviewed articles within the date range 1st January 1990 to 31st December 2019.

The inclusion criteria used were the descriptors of "professional development", "science teacher" and "content knowledge" in the title, abstract or document text, with the selection limited to scholarly journals. The search produced 63 articles in ERIC and 9 articles from A+ Education. These articles were then grouped into three decades based on year of publication; one article from 1990 to 1999, 22 from 2000 to 2009 and 49 from 2010 to 2019.

Through the scan of the abstracts, articles were excluded based on three criteria:

1. if primary or pre-service teachers were the main PD audience;
2. if the focus was on student learning rather than teacher development and learning; or
3. if PD wasn't the main focus of the article.

This reduced the number of articles to 41; the final group for analysis. The spread across the decades being: one from 1990 to 1999, 10 from 2000 to 2009 and 30 from 2010 to 2019.

### 2.4.2. Analysis strategy

The analysis of the articles utilised a model based on the Interconnected Model of Teacher Professional Growth (IMTPG) (Clarke & Hollingsworth, 2002). Whilst the IMTPG has been used as the basis for numerous contexts in educational research (Eilks & Markic, 2011; Hilton & Hilton, 2014; Justi & van Driel, 2006; Lomas, 2018; Pham & Tytler, 2021), the thematic analysis for this review utilised the IMTPG coding implemented by the van Driel and colleagues through their research relating the model to a science education context (van Driel, Meirink, van Veen, & Zwart, 2012). However, while van Driel et al (2012) analysed articles for formal PD interventions for in-service science teachers between 2007 to 2012, the criteria for literature search for this research had a more focused scope over a greater length of time.

In order to analyse the studies on secondary science teacher science content knowledge, the main aim of this paper, the IMTPG model was used to categorise the studies based on the main focus of the intervention. The following assigned classification coding is based on the relationship between the respective domains:

1. External domain and the domain of practice (i.e., leading to changes in classroom practice).
2. External domain and the personal domain (i.e., leading to changes in teacher knowledge, attitudes and/or beliefs).
3. External domain, the domain of practice and the personal domain, and
4. All domains, which implies that the domain of consequence is also included (i.e., effects on student learning or changes at school level).

The descriptions of each criteria used in analysing each of the identified studies are presented in Table 2.1. These criteria align with the previously mentioned research identified 'effective' PD design features.

**Table 2-1 Analysis categories for science education research papers**

| Category | Description | Code |
|---|---|---|
| IMTPG Domain Relationship | Main focus of the PD is to bring about changes in: | |
| | Teacher behaviour, *without* taking related changes in teacher cognition or changed student outcomes into account i.e., focus between the external domain and the domain of practice | 1 |
| | Teacher cognition, such as knowledge, beliefs and attitudes, *without* taking into account any changes in the other domains i.e., focus between the external domain and the personal domain | 2 |
| | Teacher cognition and behaviour, *without* taking any changes in student learning into account i.e., focus between the external domain, the domain of practice and the personal domain | 3 |
| | All three domains (personal, practice and consequence), and including changes in student learning | 4 |

| Category | Description | Code |
|---|---|---|
| | i.e., focus involves external domain, personal domain, domain of practice and domain of consequence | |
| Focus | The content of the PD i.e., the central topic of the intervention or knowledge area that teachers are focused on. | As shown |
| Professional Development design features | **Curriculum focus:** subject content knowledge, pedagogical content knowledge, classroom practice | 1 |
| | **Active participation:** | 2 |
| | Experimenting | 2a |
| | Observation | 2b |
| | Research/inquiry-based | 2c |
| | Analysis of student learning | 2d |
| | Reading and discussing literature | 2e |
| | Collaborative: The PD incorporates collaborative learning with colleagues (within or between schools) | 3 |
| | **Duration:** | |
| | One-off | 4a |
| | Substantial i.e., includes substantial teacher time commitment, follow-up sessions, extended vacation programs | 4b |
| Outcome measures | **Observed (actual) behaviour:** | |
| | Classroom observation | 1a |
| | Video/audio observation | 1b |
| | Fieldnotes | 1c |
| | Alternative method | 1d |
| | **Self-perceived behaviour:** | |
| | Questionnaire/survey | 2a |
| | Questionnaire/survey others (e.g., students, parents) | 2b |
| | Interview | 2c |
| | Reflective journal/learner report | 2d |
| | Alternative method | 2e |
| | **Observed knowledge:** | |
| | Achievement test | 3a |
| | Artefacts | 3b |

| Category | Description | Code |
|---|---|---|
| | Alternative method | 3c |
| | **Self-perceived knowledge:** | |
| | Questionnaire/survey | 4a |
| | Interview | 4b |
| | Reflective journal/learner report | 4c |
| | Stimulated-recall interviews | 4d |
| | Alternative method | 4e |
| | **Beliefs/conceptions:** | |
| | Questionnaire/survey | 5a |
| | Interview | 5b |
| | Reflective journal/learner report | 5c |
| | Alternative method | 5d |
| | **Attitudes/emotions (e.g. satisfaction, perceived effectiveness):** | |
| | Questionnaire/survey | 6a |
| | Interview | 6b |
| | Reflective journal/learner report | 6c |
| | Alternative method | 6d |
| | **Observed skills:** | |
| | Achievement test | 7a |
| | Interview | 7b |
| | Reflective journal/learner report | 7c |
| | Alternative method | 7d |
| | **Self-perceived skills:** | |
| | Questionnaire/survey teacher | 8a |
| | Interview | 8b |
| | Reflective journal/learner report | 8c |
| | Alternative method | 8d |

### 2.4.3. Analysis of research articles

In undertaking the examination of the 41 teacher professional development articles a framework matrix analysis was performed (Miles & Huberman, 1994). Individual articles were used as the coding unit and coding occurred in three phases. Initially the abstract and methods of each article were re-viewed to identify the focus, target audience and objective of each paper.

For the second coding phase, each paper was reread in their entirety and were coded in accordance with the IMTPG domain relationship integrated in each. The coding for this was to one of four categories as described in the first section of Table 2.1. Applying these analyses, a further seven articles were identified that could not have the IMTPG model applied and as such didn't align with objectives of the paper. One article was within the 2000 to 2009 cohort and six in the 2010 to 2019 cohort. While aligning with initial review parameters, these papers, removed from further analysis, involved literature reviews, a published thesis and curriculum reviews and evaluations. Thus leaving 34 articles for final analysis.

The third and final coding phase involved identifying the design features of the PD and the outcome measures utilised for the PD program. The design features relating to the respective PD delivered were coded into three core areas: based on whether they were curriculum focused (1), involved active participation (2), and included collaborative learning with colleagues (3). Additional coding was applied to differentiate if specific active learning was identified. These are provided in Table 2.1 and coded 2a-2e.

The assessment methods of the PD outcomes were coded across eight themes which involved the outcome themes and then the instruments utilised; main outcome themes being observed behaviour (1); self-perceived behaviour (2); observed knowledge (3); self-perceived knowledge (4); beliefs/conceptions (5); attitudes/emotions (6); observed skills (7) and self-perceived (8). Each theme relates to teacher participants and is further clarified in relevant sub-categorisation. For just under half of the identified articles (19 of 41), pre-assessment of teacher was undertaken for comparison of PD outcomes. Since the specific nature of the pre-assessment was not specified, a similar level of theme differentiation could not be applied. Articles with pre-assessment are shown by bolded author, design feature and outcome details in Tables 2.2 – 2.4.

## 2.5. Results

With the specific secondary science PD studies identified, the studies were analysed and categorised based on their main intervention objective using the IMTPG model, articles were grouped into their IMTPG domain relationships (refer to Figure 2.1). These relationships relate to the intent of the individual PD to influence teacher change and growth and are coded one to four, in accordance with the four relationships mentioned previously.

No articles were identified as having the primary focus of influencing teacher classroom behaviours (domain of practice) without taking into account other consequences or domains. Table 2.2 includes the five articles identified as relating the external domain and personal domain. The number of articles increased for the PDs imbedding external domain, domain of practice and personal domain into their teacher influence strategies (refer Table 2.3). Table 2.4 lists articles that included the domain of consequence, i.e., effects on student learning or changes at school level, in addition to all other domains.

**Table 2-2 Research relating to the External Domain and Personal Domain (Code 2)**

| Author/s | Focus | PD Design features | Outcome measures & N | Country | Teacher level |
|---|---|---|---|---|---|
| **Greene, Lubin, Slater, and Walden (2013)** | **Nine Science domains** | **1, 2, 2c, 3, 4b** | **3c, 4d, 5d. N=34 + 24** | **USA** | **Years 6-12** |
| Krall, Lott, and Wymer (2009) | Biology | 1, 2b, 4b | 3a. N=76 | USA | Elementary & middle, Yrs 4-7 |
| **McConnell, Parker, and Eberhardt (2013)** | **Problem Based Learning, Assessment of content learning** | **1, 2b, 3, 4b** | **3c. N=41** | **USA** | **Middle & high** |
| Rahman (2011) | Professional Learning Community | 1, 2b, 3, 4b | 1a, 1c, 2c, 3c, 4d, 5d, 6d, 7d, 8d. N=14 | Bangladesh | Secondary |
| Berry et al. (2009) | Science instruction | 1, 2a, 2e, 3, 4b | 2e, 4c. N=107 | Australia | Years K-12 |

[1] Bolded article indicates teacher pre-assessment was undertaken for comparison of PD outcomes

Table 2.2 provides the details of five articles describing the Science PD that focuses on influencing teacher cognition, such as knowledge, beliefs and attitudes (personal domain). The PD offered a diverse range of curriculum contexts from a focus on nine broad science curriculum domains to a focus on specific knowledge, e.g. biology or chemistry, which sometimes incorporated the application of various approaches such as professional learning communities and problem-based learning. The targeted teaching cohorts varied in composition from all year levels (kindergarten to Year 12) to solely secondary (Years 7 to 12). The number of teachers participating in the studies ranges from N=14 to 107. In relation to the design features, all PDs were curriculum focused and involved active participation (coded 2 to 2e in Table 2.1). However, three studies applied observation (code 2b) as the only active participation. Four of the five studies included teachers in various collaborative features (code 3) for the PD design. These collaborations extended from the initial PD delivery with one to three years' participation, with one article (Rahman, 2011) not articulating the specific duration of collaboration. The Rahman (2011) study was the only one that reported observing teacher behaviour (code 1a and1c) as part of understanding the outcome of the PD undertaken. The only other study including PD outcome on teacher behaviour was Berry et al. (2009) by asking teachers to report their self-perceived behaviour.

**Table 2-3 Research relating to the External Domain, Domain of Practise and Personal Domain (Code 3)**

| Author/s | Focus | PD Design features | Outcome measures & N | Country | Teacher level |
|---|---|---|---|---|---|
| Feille, Nettles, and Weinburgh (2018) | Earth and space science | 1, 2c, 3, 4b | 2a, 4a, 5a, 6a, 8a. N=29 | USA | Middle |

| Author/s | Focus | PD Design features | Outcome measures & N | Country | Teacher level |
|---|---|---|---|---|---|
| **Clary et al. (2017)** | **Chemistry, geoscience & physics** | **1, 2, 2c, 2e, 4b** | **2a, 3c, 5a, 6a, 8a. N=81** | **USA** | **Middle (Years 6-8)** |
| **Whitworth, Bell, Maeng, and Gonczi (2017)** | **Problem Based Learning, NOS, In-quiry** | **1, 2, 2c, 2e, 3, 4b** | **1a, 2a, 2b, 4a, 4b, 5a, 5b, 7b, 7d. N=47** | **USA** | **Science coordina-tors** |
| Jaipal-Jamani and Figg (2015) | Technology | 1, 2b, 2e, 3, 4b | 1a, 1b, 1c, 2c, 3b, 3c, 4b, 7d, 8b. N=3 | Canada | Middle |
| **Zhang, Parker, Koehler, and Eberhardt (2015)** | **Life science, physics and earth sci-ences** | **1, 2, 4b** | **No evalu-ation of PD. N=118** | **USA** | **K-12** |
| Holliday, Lederman, and Lederman (2014) | Life science, Museums | 1, 2, 2b, 4b | 1b, 1c, 2e, 3b, 3c, 4b, 6d. N=94 | USA | Elementary & middle |
| **Annetta et al. (2013)** | **TPACK - video games** | **1, 2, 3, 4b** | **2a, 2d, 4c, 5a, 6a, 6c, 7c, 8c. N=51** | **USA** | **Middle & high** |
| Crippen (2012) | NOS, Argu-mentation | 1, 2, 2e, 3 | 1d, 3a, 3b, 4d, 5b, 7d. N=42 | USA | High |
| Van Duzor (2012) | Chemistry | 1, 2, 2b, 3, 4b | 2d, 2e, 3a, 3b, 4b, 4c, 5c, 7b, 7c, 8c. N=17 | USA | K-Year 8 |
| **Coenders, Terlouw, Dijkstra, and Pieters (2010)** | **Chemistry** | **1, 2, 2b, 3, 4b** | **1d, 2a, 2c, 4a, 4b, 5a, 5b, 6a, 6b, 7b. N=3** | **Neth-er-lands** | **Second-ary** |

| Author/s | Focus | PD Design features | Outcome measures & N | Country | Teacher level |
|---|---|---|---|---|---|
| **Khourey-Bowers and Fenk (2009)** | **Chemistry & Biology** | **1, 2 2b, 2c, 2e,4b** | **3a, 3b, 4d, 5a, 6a. N=69** | **USA** | **Years 4-9** |
| **Monet and Etkina (2008)** | **Earth Science** | **1, 2, 2c, 4b** | **2a, 2d, 3a, 4c, 5a, 5c. N=10** | **USA** | **Middle (K-8)** |
| Jones and Eick (2007) | Inquiry-based science | 1, 2a, 2b, 3, 4b | 1b, 1c, 2b, 2d, 3b, 4b, 4c, 7d, 8b, 8c. N=6 | USA | Middle Years 6-7 |
| **Khourey-Bowers and Simonis (2004)** | **Chemistry** | **1, 2, 2b, 2c, 3, 4b** | **3a, 3c, 4b, 4d, 5a, 5b, 6a, 8d. N=135** | **USA** | **Middle Years 4-9** |
| **Hofstein, Carmeli, and Shore (2004)** | **Chemistry** | **1, 2b, 2e, 4b** | **2a, 2e, 4a, 5a, 8a, 8d. N=21** | **Israel** | **High Years 10-12** |
| Parker, Wallace, and Fraser (1993) | Multidisciplinary science and Physics | 1, 2, 2c, 3, 4b | No evaluation of PD. N=30 | Australia | Middle Senior |

1 Bolded article indicate teacher pre-assessment was undertaken for comparison of PD outcomes

Table 2.3 displays 16 articles that incorporate changes in both teacher classroom practice (domain of practice) as well as their knowledge, beliefs and attitudes (personal domain) in the focus of the reported science PD opportunities. Teacher participation in the studies ranged from small case studies of three participants up to N=135 teachers (Khourey-Bowers & Fenk, 2009) involved in a science PD that was offered over a four-year period. The teaching cohorts targeted in the PD offerings range from kindergarten to year 12, with nine articles (56%) only offering the PD up to middle school teaching levels. One science PD (Whitworth et al., 2017) was directed at science coordinators participation only. All PDs were designed with specific curriculum emphasis and related science content knowledge and pedagogical content knowledge focus (coded 1). Science concepts varied for the PD delivered, however, chemistry concepts predominated (38%). All PD's included active participation in their design features (coded 2 to 2e), with around half imbedding observation and research and inquiry. Ten of the 16 articles described the use of collaborative processes to support their PD program and teacher learning. The majority of PDs (94%) engaged with teachers over a substantial time period (from a four-week period to a four-year period), with 50% being one year or longer. It should be noted that the article by Feille et al. (2018) while examining the needs and growth of science teachers in relation to earth and space science, the PD design was not the focus of study.

**Table 2-4 Research relating to all IMTPG relationships: External Domain, Domain of Practise, Personal Domain and Domain of Consequence (Code 4)**

| Author/s | Focus | PD Design features | Outcome measures & N | Country | Teacher level |
|---|---|---|---|---|---|
| Aldahmash, Alshamrani, Alshaya, and Alsarrani (2019) | Physical science | 1, 2b, 3, 4b | 1b, 1c, 2c, 2d, 3a, 4b, 5c, 7c, 7d, 8c. N=4 | South Africa | Years 10 &11 |
| Yang, Liu, and Gardella (2018) | Science inquiry, NOS | 1, 2, 2c, 2d, 3, 4d | 1d, 2b, 3a, 3c, 4a, 5d, 6a, 7d, 8d. N=93 | USA | Elementary & middle |
| **Hestness, McGinnis, Breslyn, McDonald, and Mouza (2017)** | **Climate change, Learning progression** | **1, 2, 2e, 3, 4b** | **1c, 1d, 2c, 3a, 4b, 5b, 5d, 6b, 8b. N=27** | **USA** | **Middle & high** |
| **Cutucache et al. (2017)** | **Ecosystems Inquiry** | **1, 2, 2c, 2e, 3, 4b** | **1d, 2c, 3c, 4a, 4b, 4d, 5b, 6b, 6d, 7d, 8b. N=21** | **USA** | **K-12** |
| **Reiser et al. (2017)** | **Classroom practice, 3D learning** | **1, 2b, 2e, 3, 4b** | **1b, 2a, 4a, 4d, 5a, 6a, 8a. N=24** | **USA** | **Elementary, middle & high** |
| **Pringle, Mesa, and Hayes (2017)** | **Science curriculum** | **1, 2, 2c, 2e, 3, 4b** | **1a, 2a, 2c, 3a, 3b, 4a, 4b, 5a, 5b, 6b, 8a. N=35** | **USA** | **Middle** |
| Townsend, McKinnon, Fitzgerald, Morris, and Lummis (2017) | Astronomy, Educative curriculum | 1, 2, 2b, 2d, 4b | 1a, 1b, 1c, 3c, 4b, 5b, 6b, 7b, 7d, 8b, 8d. N=15 | Australia | Elementary & middle |

| Author/s | Focus | PD Design features | Outcome measures & N | Country | Teacher level |
|---|---|---|---|---|---|
| **Kafyulilo, Fisser, and Voogt (2015)** | **Technol-ogy, TPACK** | **1, 2, 2b, 3, 4b** | **1a, 3c, 4a, 4d, 8a, 8b, 8d. N=20** | **Tanzania** | **Years 7-12** |
| Chowdhary, Liu, Yerrick, Smith, and Grant (2014) | Interdisci-plinary Sci-ence In-quiry | 1, 2, 2b, 2d, 3, 4b | 1a, 2a, 2d, 4a, 4b, 4c, 4d, 5d, 5c, 7b, 7b, 8c. N=3 | USA | Middle & high |
| **Lotter, Rushton, and Singer (2013)** | **Inquiry, Biology, Chemistry & Physics** | **1, 2, 2b, 2c, 3, 4b** | **1a, 1b, 1c, 2e, 5b, 5c, 6b N=3(58)** | **USA** | **High** |
| **Trautmann and MaKinster (2010)** | **Geospatial Technol-ogy, TPACK** | **1, 2, 3, 4b** | **1c, 1d, 2a, 2d, 3c, 5a, 5c, 6a, 6c, 8a, 8c N=36** | **USA** | **Years 6-12** |
| **Akcay (2007)** | **Inquiry (NOS)** | **1, 2, 2b, 2c, 4b** | **1b, 2a, 2d, 4a, 5a, 5c, 6a, 7d, 8c N=1** | **USA** | **Middle** |
| Lockhart and Le Doux (2005) | Gene Ther-apy (PBL) | 2, 2c, 3, 4b | 2c, 4d, 5d, 8d N=1 | USA | High |

[1] Bolded article indicate teacher pre-assessment was undertaken

Table 2.4 provides the details for 13 articles that describe PD studies which focused on influencing teacher classroom practice (domain of practice), teacher cognition (personal domain) and the effects on student learning or changes at school level (domain of consequence). As with previous relationships, the studies in this section involved teachers from kindergarten to Year 12. However, unlike the previous relationship focus, most studies (69%) included senior secondary (high school) teachers. Teacher participation in the PD opportunities ranged from one person (a personal reflection (Lockhart & Le Doux, 2005) and a case study (Akcay, 2007)) to N=93 people (Yang et al., 2018). With the exception of Lockhart and Le Doux (2005) describing a partnership for problem-based learning, all other studies included a curriculum focus in the PD design. All PDs reported included imbedding active teacher participation in the PD design with over 50% using research and inquiry and observation being the more utilised method and 77% (n=10) incorporating collaborative processes into their PDs. The duration of these reported programs ranged from a one week intensive (with six follow-up sessions) (Hestness et al., 2017) to a longitudinal study over 5 years (Pringle et al., 2017). With the exception of Lockhart and Le Doux (2005), all studies reported evaluation of PD outcomes using both observed and self-perceived outcome measures with eight studies (62%) included pre-assessment instruments. These studies utilised multiple outcome measures with 90% (n=12) evaluating through classroom observation (coded 1a to 1d), self-perceived knowledge (coded 4a to 4d), beliefs and conceptions (coded 5a to 5d), and self-perceived skills (coded 8a to 8d).

### 2.5.1. Country

The articles were predominately (74%) about professional development occurring in the United States of America (n=25). The remaining articles were from Australia (n=3) and Bangladesh, Canada, Israel, Netherlands and South Africa (n=1 per country).

### 2.5.2. Teacher participation

Whist the target focus for this review was for secondary teachers and the search filters applied as such, all articles included teachers across a range of teaching levels with participants from primary (elementary), middle and high (senior) teachers. Articles that specified the specific year level, have been included in Tables 2.2 to 2.4. Eleven of the selected articles (32%) involved elementary teachers participating in PD with middle and high school teachers. Middle years teachers represented the highest target cohort for PD with 77% of articles indicating their involvement (n=26). High or senior school teachers were reported to be involved in 53% of the PD articles (n=18).

Across the selected PD programs, the number of participants varied from one to N=135 teachers (Mean=41, Median = 29). Two articles (Akcay, 2007; Lockhart & Le Doux, 2005) discussed the PD from one teacher's perspective however Akcay's (2007) participants was part of a larger cohort of which size was not identified and the Lockhart and Le Doux (2005) study was a personal reflection of a problem-based learning experience. Three articles reported about PD programs with over 100 teacher participants (Berry et al., 2009; Khourey-Bowers & Simonis, 2004; Zhang et al., 2015).

### 2.5.3. Context Focus

The focus of the PD program in each study is reported in Tables 2.2 to 2.4 respective to each study. The scope of the focus varied across three key contexts to include a specific science discipline base (i.e., chemistry, astronomy, earth science), a pedagogical approach (i.e., problem-based learning, argumentation) and broader scientific approaches (i.e., NOS, Science Inquiry). Many PD programs integrated more than one key context focus to the PD delivered, involving a curriculum focus, pedagogy and/or scientific approach.

### 2.5.4. Professional Development Design Features

Most of the PD programs (97%) aligned the learning focus with their country's state or national curriculum, with only one article not providing explicit mention to the school curriculum. This one article reported in the 2000-2009 decade. The same number (n=33) of articles referred to a sustained PD delivery design feature and follow-up support. These were mainly delivered in school vacation periods, with follow-up support (individually or as a cohort) across an extended period. Only one article describing the delivered program as being 'one-off'.

The 'effectiveness' of the PD being enhanced through the inclusion of collaborative practice in the design feature was reported in 71% (n=24) of the articles. The same proportion of articles (71%) involved teachers through active participation. The remaining 29% (n=10) of articles did not involve active participation but enhanced their delivery with teacher participation through observation (n=8), experimentation (n=2), research/inquiry-based (n=1) and reading literature (n=4). When looking across all the articles, the incorporation of these design features saw 53% engaging in observation (n=18), 6% experimentation (n=2), 41% with research/inquiry-based aspects (n=14) and 32% reading literature (n=11). Two PD programs (6%) also integrated the analysis of student learning into the delivery design.

### 2.5.5. Outcome Measures

All articles analysed the PD outcomes utilising more than one method with 56% of these (n=19) undertaking pre-participation assessment methods for later comparison. A similar proportion (55%) of articles from the decades 2010-2019 and 2000-2009 reported pre-assessment. Outcomes evaluation for the one paper reported in 1990-1999 did not include the outcome evaluation in the article stating these were provided in a later government-funded report. However, due to the limited nature of the explicit format of these pre-assessment tools, only the post outcomes analysis tools are reviewed in the present research.

The outcome measures applied across the reported PDs were categorised into eight overarching themes, broadly considered to be from observed outcomes (observed behaviour, observed knowledge and observed skills) and self-perceived outcomes (self-perceived behaviour, self-perceived knowledge, self-perceived skills, beliefs/ conceptions and attitudes/ emotions). Whether observed or self-perceived, the overarching intention of the PD outcomes, teacher knowledge and teacher behaviour, equally dominated the outcome focus in the articles (29% respectively) with teacher skills measured by 19% of outcome measures. Fewer articles reported on using outcome measures of teacher beliefs and conceptions (14%) and attitudes and emotions (9%).

The focus of each of the broad outcome measures was associated with various measurement instruments, such as a survey/questionnaire, test, interview, reflective journal, field notes or a range of alternative records. The application of self-perceived instruments significantly outweighed the use of observed measures (70% to 30% respectively). The most common outcomes measurement instrument was surveys and questionnaires (34%), followed by interviews (29%) and reflective journals (21%). Specific measures were utilised for observed outcomes being classroom observation (13%), video and audio recordings (10%), fieldnotes (11%) and tests (12%). Significant change was seen between decades 2000-2009 and 2010-2019 with to regards the focus of outcomes being measured. The greatest change was a three-fold increase in the utilisation of observed behaviour techniques embedded into the PD evaluation design, with 75% (n=18) in 2010-2019 compared to 22% in 2000-2009 (n=2). The assessment of teacher attitudes and emotions as well as through observing teacher skills also increased over the same period; this being from 33% (n=3) to 54% (n=13) of articles which included using instruments to assess changes in teacher attitudes and emotions and from 22% (n=2) to 50% (n=12) for evaluation through observed skills of teachers. Only minor variations in application were noted for all other outcome measurement instruments.

### 2.5.6. Overall

The IMTPG framework was utilised to categorise the 34 articles as indicated in Tables 2.2 to 2.4. The distribution of the articles in relation to the domain and year of publication are shown in Table 2.5.

**Table 2-5 Distribution of science PD articles published in relation to program IMTPG domain relationships from 1990 to 2019**

| | 1990 to 1999 | 2000 to 2009 | 2010 to 2019 |
|---|---|---|---|
| External Domain and Domain of Practice (Code 1) | - | - | - |
| External Domain and Personal Domain (Code 2) | - | 2 | 3 |
| External Domain, Domain of Practice and Personal Domain (Code 3) | 1 | 5 | 10 |

| | 1990 to 1999 | 2000 to 2009 | 2010 to 2019 |
|---|---|---|---|
| External Domain, Domain of Practice, Personal Domain and Domain of Consequence (Code 4) | - | 2 | 11 |

Sixteen articles (47%) reported on Science PD that supported teacher growth in both the personal domain (changes in teacher knowledge, attitudes and/or beliefs) and domain of practice (changes in classroom practice) (refer Table 2.3). Thirteen articles (38%) reported supporting a focus on all relationships, which includes the personal domain, domain of practice and domain of consequence (effects on student learning or changes at school level) (refer Table 2.4). Five studies (15%) reported the aim to change in only the personal domain (teacher cognition, such as knowledge, beliefs and attitudes), without accounting for any changes in the other domains (refer Table 2.2). No studies reported focusing on changes in teacher behaviour (domain of practice), without taking into account changes in teacher cognition or student outcomes. In summary, Table 2.5 shows an increasing trend for research regarding science teacher PD for secondary teachers over the last three decades. Embedded with this increase in research output, is the shift toward a more holistic teacher growth (and learning) approach to the PD design, goals and outcome measurement.

#### 2.5.6.1. Exemplar study focusing on the relation between the external domain and the personal domain (Code 2)

The article by Greene et al. (2013) provides a good example of a study that focused on the influence of the external domain (PD) and the personal domain (teacher cognition) (refer Table 2.2). The study reported on the two-week component of a year-long PD program, which included scientific research with university scientists, delivered to two cohorts of Year 6 to 12 teachers (N= 34 and N= 24). The influence on the teacher knowledge gain (coded 3c and 4d) was identified through pre- and post-concept maps in one of nine science content areas. The PD applied a multi-faceted approach aimed at increasing teacher content knowledge, the use of inquiry instruction, and to establish a science learning community. The initial phase was a two-week workshop working with a university research scientist on an authentic research question, followed by hands-on inquiry activities and discussions focused on enhancing teacher understanding of inquiry pedagogy through their individual experiences, science classroom activities, and technology. Concept maps were used to capture teacher knowledge during respective research sessions and were scored quantitatively across six criteria to evaluate both content and process accuracy. Overall PD influence on teachers was assessed using both quantitative and qualitative evaluations of the teachers pre- and post-maps constructed.

The inclusion of the study by Krall et al. (2009) provides marginal influence on this review. Whilst the article presented findings of a PD with curriculum focus teachers' knowledge of photosynthesis and respiration conceptions delivered to 76 elementary and middle schools (years 4 to 7) teachers, the limited number of middle schools' teachers and no differentiation of findings, there is limited relevance with the teaching level focus of this report.

#### 2.5.6.2. Exemplar study focusing on the relations between the external domain, the domain of practice and the personal domain (Code 3)

The article by Coenders et al. (2010) (refer Table 2.3) provides a good illustration of a PD which imbedded these relationship goals. The study follows three experienced chemistry teachers from the process of undertaking PD, developing and writing new module implementations, through to class enactments of the contextualised student learning material. The focus of the PD was first year chemistry course modules delivered in secondary school (students around 15 years of age). The PD process occurred over one year. A collaborative network was established which included teachers from different schools, 'Teacher-developers', with a university trainer and author of chemistry textbooks, 'Coach'. Teacher growth during the process was collected via pre and post questionnaires and interviews. The study describes the teachers' initial perceived goal of chemistry education for students through to changes in their perception after they delivered their newly developed learning materials to their students. During the process teachers changed with respect to the goals of chemistry education and with respect to teaching methodology and learning material. The study found that while all of the teachers were initially hesitant about the potential of the new approaches, their practical knowledge and especially their knowledge in all five PCK domains (Magnusson et al., 1999) increased during the cycle of development of learning material and its use in class.

#### 2.5.6.3. Exemplar study focusing on all relationships, including the domain of consequence (Code 4)

The article by Chowdhary et al. (2014) is an illustration of a PD program that incorporates all relationship influences on teachers as defined in the IMTPG framework (refer Table 2.4). The study examines the effect of university-based research experiences, ongoing PD, and in-school support on teacher development of Interdisciplinary Science Inquiry (ISI) pedagogical knowledge and practices. The article presents a case study analysis of three teachers who were part of a 58 in-service teacher PD program. Participating teachers represented 12 public middle or high schools in north eastern USA. Teachers undertook summer research experiences along with a variety of PD experiences; the aims being to increase their knowledge, understanding, and practice of ISI as well as providing support to help translate their research experiences into their classroom practice; one aspect being to support teachers designing their own ISI-related classroom activities as well as creating rubrics for assessing ISI in their lessons. The study utilises multiple data sources to evaluate the PD outcome measure. These include written pre and post questionnaires from teachers focusing on their preconceptions of ISI, research observations, reflective log sheets, research posters, and classroom observations. Semi-structured interviews were also conducted with teachers and students. However, the article reported solely on data gathered from teachers. The overall finding of the study stated that teachers interacted with the partnership in different ways, therefore developing varied levels of ISI understanding and experiences. Teachers also exhibited varying levels of growth in both content and pedagogy. Consequently, teachers also varied in their application of ISI within their classrooms as evidenced by their choices of instructional practices. The authors identified that to increase understanding and application of ISI, teacher PD needs to continually contribute to teacher growth in knowledge of both science content and pedagogy. PD must also take into consideration contextual and cultural factors of the schools and teachers within which it aims to create change.

## 2.6. Discussion

Overall, this analysis identified that there has been a substantial increase in the reporting of PD opportunities for enhancing secondary science teacher science content knowledge over the last three decades. The greatest emphasis focussed on supporting science curriculum-related content. Analysis of articles utilised a framework based upon the established design features of effective PD (Borko, 2004; Borko et al., 2010; Desimone, 2009; Hawley & Valli, 1999) as well as the IMTPG model (Clarke & Hollingsworth, 2002). Approximately three quarters of all articles (31 out of 41) identified from research journals highlighting the themes 'professional development', 'science teacher' and 'content knowledge' were published in the years since 2010. In comparison, only one study was published in the decade 1990 to 1999 and five within 2000 to 2009 period. Seven articles reported on studies that could not have the IMTPG model applied and as such didn't align with objectives of the paper.  One article was within the 2000 to 2009 cohort and six from 2010 to 2019 cohort. During this period there was an increasing emphasis on curriculum-related science content knowledge and pedagogical-related content knowledge. This trend correlated with increased acknowledgment of the impact and importance of scientific literacy and science, technology, engineering and mathematics (STEM) skills for local and global economic growth. (Becker & Park, 2011; Office of the Chief Scientist, 2014; Teo & Choy, 2021; Tytler, 2007b)

Similar to the findings of van Driel et al. (2012), most science PD articles continued to show strong congruence between the PD goals, applied design features and the outcome measures that were used. Most studies included 'effective' PD design features identified in research and delivered intensive, long-term programs with multiple outcome evaluation methods. The greatest consistency in design features across the majority of PD programs was curriculum-focused and substantial sustained program delivery. Both features were reported being integrated in 97% of all articles (33 out of 34). Teachers were provided with sustained time to absorb, discuss and practice their learning from a two-week period to three years with numerous PDs being delivered across weeks and months to allow the material to be revisited. Many of these consisted of an initial intensive block program followed by interval support periods. The 'effectiveness' of the PD was also enhanced through the inclusion of collaborative practice, and active participation in the design feature was reported equally in 71% (24 of 34) of the articles. The most commonly applied active participation method was 'observation' and 'teacher engaged research and inquiry' in the respective science curriculum context. These design features are found in the PD reported in all three decades however no significant inference can be made with reference to this due to the low number of articles published in the first two decades. The increase in the science PD research in the last decade (2010-2019) with the 'effective' design feature as acknowledged through research for enhancing teaching practice and knowledge provide a positive outlook to the future for both teacher and student learning. These findings of an increase in science teacher PD research indicates a positive move from earlier research on science PD undertaken by research leaders such as Borko (2004) and Dede (2006), and has identified that there was a limited number of studies examining changes in teacher knowledge or skills, and even fewer evaluating the impact on student learning. Also identified is that there is a need for more well-designed empirical research studies.

Regarding the PD evaluation outcome measures, the majority of studies in both the 2000 to 2009 and 2010 to 2019 decades, utilised teacher self-perceived knowledge reporting (8 out of 9 and 21 out of 24 respectively). Similar proportions across these time frames also incorporated pre-assessment measures to their PD design, mostly through questionnaires/surveys, in conjunction with their post-PD outcomes measures (5 out of 9 and 14 out of 24). Teachers' self-reporting of the influence of the PD on their attitudes, behaviour and skills were frequently used across the studies, however teachers perceived skills were the lesser assessed. In the most recent decade (2010 to 2019) there was a considerable increase in the use of researcher observation to evaluate the PD influence on teacher behaviour and knowledge and again to a lesser extent on teacher skills. Primarily this was collected through direct classroom observation and /or video and audio recordings, however test instruments and a range of other additional strategies were used.

Whilst a range of articles reporting on science PD included a focus on influencing the effects on student learning (Table 2.4), very few studies collected information from students. The most comprehensive of the articles reviewed is the  article by Yang et al. (2018)  which investigated the influence PD had in changing teacher knowledge and practice and how these changes influenced student understanding. The researchers analysed data from interdisciplinary science tests of 509 Grade 4 to 8 students, and administrating student surveys to review the students' opinions about science, their respective teacher's classroom actions, the student classroom activities, and at home parental support. The study provided evidence on the influence and effectiveness of PD coherence and duration as well as how PD can benefit student learning outcomes.

With the acknowledgement of the increased time and often financial implication associated with undertaking both direct observation of the PD on teachers' attributes and engaging student contribution on PD influences, it is through implementation of these PD outcome evaluation measures, that richer evaluation of PD objectives and impact can be ascertained.

Findings concerning the goals of the science PD delivered, the classification the IMTPG model categories of Clarke and Hollingsworth (2002) showed just under half of the programs (16 of 34) refer to the relationships between the external domain, the domain of practice and the personal domain (code 3). In addition, a substantial number of studies (13 of 34) also integrated student learning outcomes as a result of the science teacher's PD (code 4). A smaller proportion of studies (5 of 34) had a goal focused on the relationship between the external domain and the personal domain, (i.e., leading to changes in teacher knowledge, attitudes and/or beliefs) (code 2). No studies were found to have the sole goal of the relationship between the external domain and the domain of practice (i.e., leading to changes in classroom practice). The distribution across the three decades showed articles from 2010 to 2019 represented the greatest proportion in all increasing goal groupings, again influenced by the largest representation of articles in that decade. However, it is the (code 3) studies with goals focused on relationships between the external domain, the domain of practice and the personal domain that had the greatest distribution of all three decades. Of the 16 articles, ten were published between 2010 to 2019, five between 1999 to 2009 and the sole paper published between 1990 to 1999.

## 2.7. Conclusion

This review examines the research across 30 years regarding in-service secondary teachers' experiences of science professional development (PD), particularly in relation to the enhancement of their content knowledge. On the surface, there have been significant changes over this time span around the PD frameworks, models and approaches used to enhance teacher science content knowledge, including significant growth in the area of science pedagogical content knowledge. As a means to guide this review and developed a more nuanced understanding of the impact of PD on teachers, the Interconnected Models of Teacher Professional Growth (IMTPG) (Clarke & Hollingsworth, 2002) was adopted as a framework for the analysis of the 34 papers that ultimately formed the basis of this paper. The IMTPG was specifically developed to study changes in teacher knowledge as a result of active engagement with meaningful learning, which identified it as a useful model for sense making for this particular study.

As a starting point, this review captures a significant growth in articles published on science PD for secondary school teachers over the three decades. This trend may be recognised as symbolising a shift toward a more holistic understanding of the importance behind researching teacher growth and development. More specifically, this growing research profile identified changes over time in the way that PD was designed, the goals it sought to obtain and the ways in which outcomes were measured. Particularly noteworthy is the increased complexity evident in the PD with the focus not on shifting teacher practice, but making sustained changes to teachers' knowledge, attitudes and/or beliefs as well as raising awareness around effecting change on student learning or at a school level. This finding highlights the significant role PD can have on enacting change on a larger scale and over a longer period of time. This growth in research also highlights that in the secondary school context that the development of teacher content knowledge in science remains of critical importance and is necessary for sustained, quality teaching practices.

This systematic literature review points to some key learnings and future considerations for PD providers, schools and other science education researchers. Foremost, there is a need for science teachers and PD providers to further investigate the features of emerging PD programs, frameworks and models whilst taking into consideration already known features of currently effective PD programs to ensure they are contemporary in nature and meeting the needs of 21st century learners. More specifically, PD providers should be considering the integration of multiple evaluation methods into their programming, including pre-assessment of teacher knowledge and allowing for long-term tracking of the impact of the PD, to ensure a holistic understanding of impact is garnered. This research highlights that ongoing efforts should be made to provide PD initiatives for science teachers, which imbed explicit student learning consequences into PD design and goals as a way of aligning with the critical shift in focus from teacher to learner. Finally, learnings from this study suggest that longitudinal studies are required into the PD science teachers undertake across the different stages of their careers to acknowledge and allow for increased ‘fit’ with teacher experience, teacher science content knowledge, professional interests and growth stages.

## 2.8. Implications

In considering the implications of this systematic literature review, it is important for all teachers that we reflect on the past. In doing so, we can on draw our relevant learnings into the future to ensure engagement in meaningful PD opportunities and increased capacity to influence student learning. This research uncovers considerations around the range and format of PDs alongside the outcomes achieved, which we have the potential to inform an improvement process. Through accessing studies like this one, we can identify practices and processes that do and do not work, and therefore deepening our understandings of the interrelationships underpinning teacher professional growth and learning, in this case, particularly in relation to science content knowledge.

## 2.9. Limitations of the study

A limiting factor in this research study was whilst the analysis of the research articles reviewed concentrated on PD design features, outcome measures and goals, it did not consider the influence and impact of differences in curriculum and cultural contexts across the various countries. This is largely due to the biased reflection of changes in or development of PD programs due to the inclusion of only English language, scholarly, peer-reviewed articles. Expanding the search parameters to include reports and conference papers may have provided a richer and more diverse understanding of PD programs delivered globally.

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# CHAPTER 3. PAPER 2 - INVESTIGATING TEACHERS' CONFIDENCE IN TEACHING JUNIOR SCIENCE AND CORRESPONDING INTEREST IN PROFESSIONAL DEVELOPMENT

## 3.1. Abstract

Science teachers confidence in understanding the depth of subject content knowledge has the capacity to have a positive impact on their student learning outcomes. With higher levels of science content knowledge found to have positive influence science teachers' self-efficacy, reduces anxiety, and promotes more positive attitudes toward science. With this understanding, this paper shares findings of science teachers' confidence and interest in professional development of science content knowledge within the Australian Sciences Years 7 - 10 curriculum. Results were obtained from 89 respondents to an online survey of Years 7 to 12 science teachers from 77 Queensland State schools. Initially teachers reported near unanimous (97%) confidence in teaching secondary Junior Science. However, when presented with specific junior science concepts, teacher confidence levels declined significantly. Confidence levels for individual science concepts dropping to 69%. Irrespective of teachers' confidence levels for specific scientific concepts, discrepancies were found in their desire for professional development on identical concepts. Findings reinforce the imperative of teachers developing detailed individual learning plans with attention directed to their subject content knowledge base.

Keywords

Secondary science education, Teacher confidence, Professional development, Science content knowledge, Science teachers, Self-efficacy

## 3.2. Introduction

Science education has been a focus of numerous research and government reports stemming from growing concerns over declining student enrolment in the enabling science subjects in secondary schools and higher education. (Dobson, 2006; Fensham, 2004; Lyons & Quinn, 2010; Maltese & Tai, 2011; Tytler, 2007a). Central to the importance of this and other research is the recognition of the impact of individual teacher quality on student learning (Goodrum et al., 2011; Goodrum et al., 2001; Hattie, 2003; OECD, 2005).

With recent changes to the Australian Science curriculum (ACARA, 2017), the expanding knowledge base of science has resulted in teachers facing ever-increasing challenges to expanding their scientific content knowledge, their pedagogical practice and professional learning. An 'effective science teacher' not only needs to have a strong understanding of learning theory, curriculum development and pedagogical practice, they must also have rich and flexible science content knowledge and pedagogical content knowledge to promote student learning in science (Borko, 2004; McDiarmid, 1989; Opfer & Pedder, 2011; Riggs & Enochs, 1990).

This paper is part of a larger study exploring Queensland secondary science teachers' experiences, confidence levels, professional learning (formal and informal), and engagement with professional development (PD). This paper presents the trends identified regarding the range of teacher experience, knowledge background, perceived capacity to teach core junior science curriculum and interest for PD experiences to enhance their science content knowledge. In short, the focus is on what they know and what they need to help enhance their teaching of school science.

To better understand the relationship between teacher content knowledge and requirements for PD, the following research questions were posed:

1. What are the perceptions of teachers' confidence to teach topics in the junior high science curriculum?
2. What are science teacher's interest in PD for science content knowledge within the Australian Sciences Years 7 - 10 curriculum?

For this study, teaching confidence is used as it is a simple and intuitive term for inclusivity and brevity and may refer to beliefs of their ability and capability to teach junior science concepts. Figure 3.1 provides a simple conceptual overview that captures the concepts of interest that has been developed to support this research, where teacher confidence incorporates multiple factors of an individual teachers' self-concept, self-efficacy, and domains of knowledge. Included in this conceptual model is the acknowledgement that these factors can also be influenced by dynamics on individual classes taught and the specific school environment.

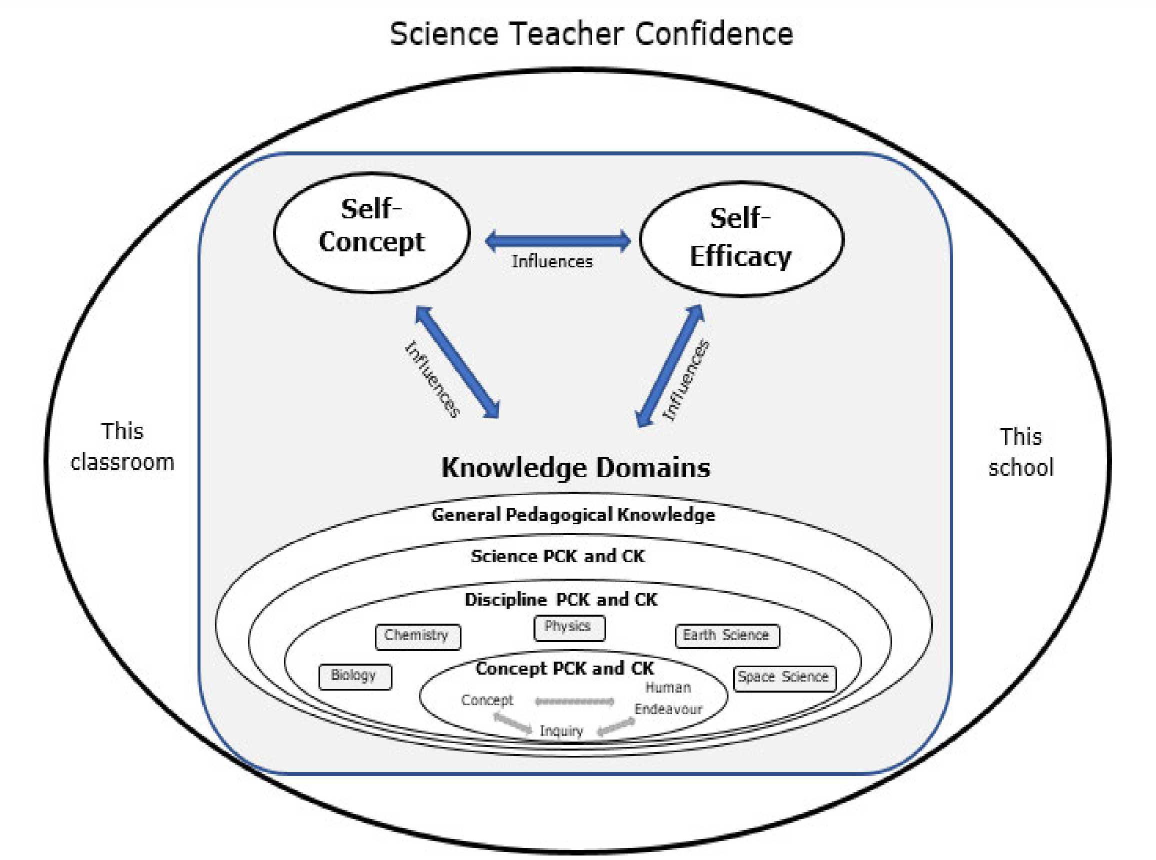


**Figure 3-1 Conceptual framework for teacher confidence**

### 3.2.1. Teacher Content Knowledge and Professional Development

It is widely acknowledged that teacher quality, which can be conceptualised as experience, knowledge and skills, has a positive influence on student achievements, particularly when teachers engage with professional development throughout their career (Darling-Hammond et al., 2009; Department of Education, 2003; Goodrum et al., 2001; Jensen, 2010b; OECD, 2005). The importance of career-long PD has been recognised as one of seven Australian professional standards for teachers, which is the context of this study. In particular, Standard 6, which focuses on professional engagement, refers to 'Engage[ment] in professional learning' though the identification, planning and engaging in professional learning to improve practice (AITSL, 2013). These standards also recognise the importance of teacher subject content knowledge in professional practice. This is articulated in Standard 2, which states "know the content and how to teach it" (AITSL, 2013). More specifically, the National Professional Standards for Teachers of Science reflects the complexity of knowledge and pedagogical reasoning that underpins excellence in science teaching (Australian Science Teachers Association, 2002). These standards articulate the strong relationship between pedagogy and science knowledge and that the depth of subject matter knowledge has profound effects on the pedagogical choices utilised by teachers. An additional outcome from these standards is informing and improving effectiveness of PD within the areas deemed important for continuing professional learning across the profession.

Despite the value placed on teacher professional learning, both formal and informal, numerous studies have identified that professional learning opportunities (PD) can be ineffective if the following factors are not taken into account: how teachers learn, how the learning is embedded in life and the work environment, and the existing conditions supporting and promoting learning. (Borko, 2004; Clarke & Hollingsworth, 2002). Therefore teacher learning must be conceptualised as a complex system involving reciprocal causation and influences rather than event (Opfer & Pedder, 2011), where changes in any part of the system will influence the others. When examining these key influences, each can either restrain or enable teacher learning. For example, individual teacher learning can be influenced by personal experiences, attitudes and beliefs, experiences with school and teaching and level of pedagogical content knowledge (PCK) as well as content knowledge (CK).

Whilst research has shown that teachers PCK and CK influence teaching practice and student learning (Carlsen, 1991; Hashweh, 1987; Magnusson, 1992; Nespor, 1987; Rollnick & Mavhunga, 2016), the definitions, components and relationship between PCK and CK has varied since conceptualised by Shulman in 1986. Despite these variations, comparisons between models of PCK has three most predominant characteristics are knowledge of students, knowledge of content and knowledge of instructional characteristics (pedagogy). (Ball et al., 2008; Carlsen, 1999b; Grossman, Wilson, & Shulman, 1989; Magnusson et al., 1999; Shulman, 1987; Shulman, 1986). For science teaching, teachers' PCK is seen to include their knowledge of students' thinking about science, science curriculum, science-specific instructional strategies, student assessment of science learning, and orientations to teaching science (Magnusson et al., 1999). Definitions for PCK in science are usually grounded in proposed framework models for teachers generally and within specific domains. For example, the domains of teaching model (shown graphically in Figure 3.2) reformulated PCK of teacher knowledge to incorporate five general knowledge domains: general education context, specific education context, general pedagogical knowledge, subject matter knowledge and PCK (Carlsen, 1999b). Although, whether considered a separate domain of knowledge or included within PCK, subject matter knowledge (furthermore referred to as CK) is acknowledged to be a critical component and influencer of teacher effectiveness. With specific relation to science teaching, to develop PCK science teachers need an understanding of science, general pedagogy, and the context (school and students) where the teaching occurs. However, inferences cannot be made that content knowledge can solely develop teachers' PCK (Magnusson et al., 1999). Research that have stemmed since the introduction of PCK have proposed various representations and models for PCK for in-service and pre-service teachers. The General taxonomies of PCK conceptualised by Veal and Makinster (1999) which provided further categorisation of the distinctions within and between the knowledge bases of science subjects, science disciplines and science concepts, align with the emphasis of this study (Smith, 2020; Veal & Makinster, 1999a). This utilises a hierarchical arrangement from the broader conceptions of PCK to the most specific concepts to represent a process by which secondary science teachers obtain different knowledge bases that contribute to their PCK development.

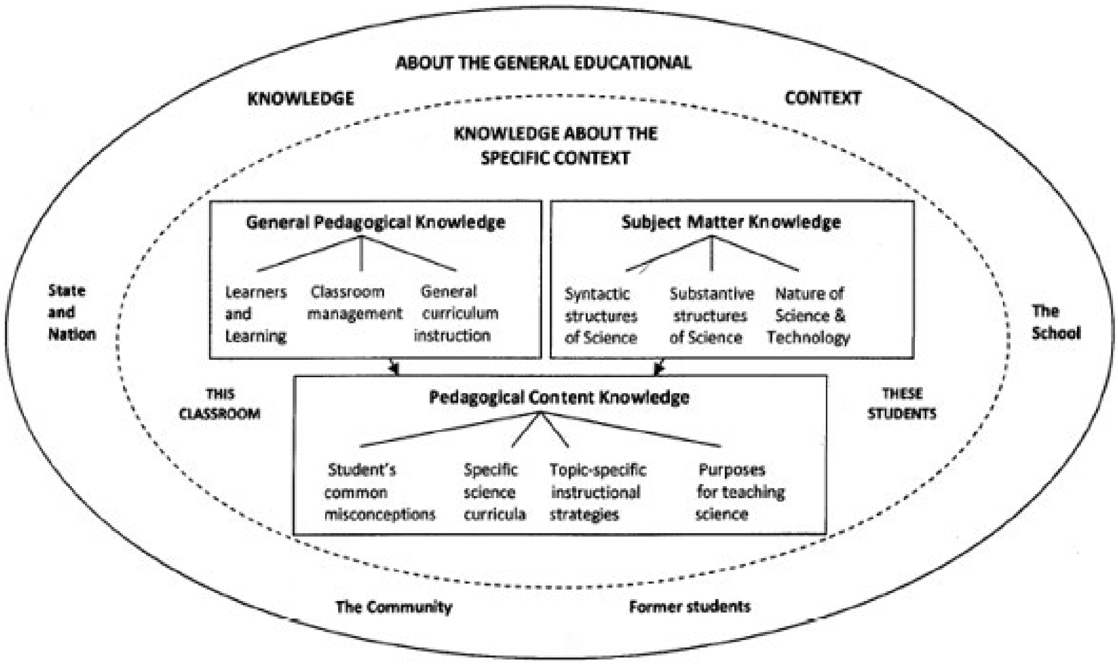


**Figure 3-2 Domains of teacher knowledge (Carlsen, 1999)**

### 3.2.2. Teacher Confidence and Self-Efficacy

Teacher characteristics are often linked with teacher quality and effectiveness as well as student learning. Additionally, a valuable teacher characteristic that has been widely researched in science education is teacher self-efficacy, which involves both a teacher's beliefs about their personal ability to influence student learning as well as the results of their specific instructional interventions (Settlage et al., 2009).

Studies in self-efficacy are grounded in Bandura's social cognitive theory (Bandura, 1977, 1986, 1997a), where he defines self-efficacy as the "beliefs in one's capabilities to organise and execute the course of action required to produce given attainments" (p. 3). In an educational setting, this can be related to a teacher's beliefs about their personal ability to influence student learning and their overall effectiveness as an educator. However, identifying the factors that influence an individual teacher's self-efficacy is complex and diverse. Bandura assigned these influences to four inter-related categories: mastery experiences (achieved knowledge and experiential capabilities), vicarious experiences (experiences with others), social persuasions (external and verbal interactions and support) and physiological and emotional arousal (mental and physical wellbeing) (Bandura, 1997a). Mastery experiences are seen as the most powerful influences but must be weighed up against and processed through self-referent thought before change in self-efficacy beliefs can occur (Bandura, 1997a; Tschannen-Moran et al., 1998).

Research has shown positive correlations between positive teaching confidence and effective teaching practices, and between strong teacher self-efficacy and improved student achievement and attitude (Ross, 1992; Tschannen-Moran et al., 1998; Wheatley, 2002). However, the distinction should be made that self-efficacy is related to self-perception of competence rather than the actual level of competence, as overestimation or underestimation in one's own confidence and actual ability may influence an individual's view of the skills they possess (Tschannen-Moran et al., 1998). Within educational research, self-confidence has often been conceptualised as self-concept and self-efficacy beliefs and is often focused on specific academic subject disciplines (Bong & Clark, 1999; Bong & Skaalvik, 2003; Marsh, Walker, & Debus, 1991) Due to the varying or unclear definitions, the use of these terms may be inadvertently be used interchangeably (Archer et al., 2010; Marsh et al., 2019).

### 3.2.3. Teacher Professional Development Interventions

The challenge for the education system and policy makers is to identify and implement effective intervention programs that can assist in increasing teachers' confidence and ultimately their self-efficacy. Although research is limited, studies regarding the impact of interventions on individual teachers' self-efficacy, confidence in teachers need to take a series of behaviours in specific situations, structured teaching and active interventions to have a positive influence (Lakshmanan, Heath, Perlmutter, & Elder, 2011; Tschannen-Moran et al., 1998; Tschannen-Moran & McMaster, 2009) . While current research suggests that teacher self-efficacy is malleable, positive impact is unlikely outside of long-term, meaningful PD opportunities that captivate a teacher's critical thinking and facilitates reflection on practice (Bandura, 1997a; Henson, 2001).

Research on teacher professional development activities concludes that teachers need time to develop, absorb, discuss and practise new knowledge; and traditional 'one-off' workshops are less likely to lead to teacher change. (Berry et al., 2009; Borko, 2004; Darling-Hammond et al., 2009; Hynes & Dos Santos, 2007). Professional development activities are found to be more effective if they have a contextual focus, are school based and curriculum integrated, teachers engage with materials of practice, are active and reflect the way to teach students, entail collaborative participation and are sustained and intensive (Borko, 2004; Ingvarson et al., 2005; Opfer & Pedder, 2011). These factors align with findings from Garet, Porter, Desimone, Birman and Yoon (2001) who identified that when PD focuses on academic subject matter, gives opportunity for hand on work and is integrated in school life, then the teachers enhanced knowledge and skills are more likely to translate in changed teaching practice (Garet et al., 2001).

## 3.3. Method

This study utilised a survey research design to understand teacher self-perceived confidence and related interest for PD from science teachers teaching junior secondary science, which in the Australian context covers Years 7 to 10 (students aged 12 to 15). Survey methods have been used widely in teacher focused research (Adler, Ball, Krainer, Lin, & Novotna, 2005; Goodrum et al., 2011; Lyons, Cooksey, Panizzon, Parnell, et al., 2006), with research signifying that self-reporting surveys provide generally low cost, wide geographic coverage and relatively accurate quality of account of teacher beliefs and practices (Owens, 2002; Ross, McDougall, Hogaboam-Gray, & LeSage, 2003). The survey for this study was primarily conducted in an online interactive format and distributed via numerous Queensland regional and state science discussion lists and through the Science Teachers' association newsletters. Optional hardcopy surveys were provided when technology issues where encountered. An eight-week time frame was available for teacher completion of the survey.

### 3.3.1. Data collection

The data were collected using a comprehensive online survey of some 141 questions, which focused on science teachers' background and professional development experiences regarding teaching of the Australian Curriculum: Science Year 7 - 10) (ACARA, 2017).

The survey builds upon the *'Science, ICT and mathematics education in rural and regional Australia: the SiMERR National Survey'* (Lyons, Cooksey, Panizzon, & Pegg, 2006) and utilises the collection of respondent information relating to profile and demographics, and views on and engagement with recent PD opportunities. Additional investigation included questions relating to teacher confidence (self-efficacy) in teaching specific junior science content, as well as interest to undertake content related PD in the same content.

The junior science curriculum content was expressed as 48 individual scientific concepts that underpin the disciplines of Biological Sciences, Chemical Sciences, Physical Sciences, Earth and Space Sciences, and Science Inquiry Skills and Science as a Human Endeavour. The survey contained both closed response and open-ended questions to identify current teachers' science teaching experience, format and content of PD undertaken, formal and informal learning accessed, and interest for PD in each of the 48 specific science knowledge concepts.

A five-point Likert scale was used for the content-specific perceived self-efficacy and expressed interest in curriculum content professional learning. The individual strands from Australian Curriculum: Science F-10 (ACARA, 2017) was the source for the identified science content concepts.

The ethics approval for this study was granted as indicated in appendix 4, and with the full survey shown in appendix 5.

### 3.3.2. Participants

The study focused on secondary science teachers in Queensland government schools. Results were collated from 89 respondents teaching across 77 individual Queensland State government schools with teacher representation received from all seven education geographical regions across the state. Their associated school enrolment cohorts varied from 11 small schools with fewer than 500 hundred students, 24 schools from 500 – 1000 students, 48 schools with 1000 – 2000 students, to five larger schools with 2000 plus students.

### 3.3.3. Data analysis

The data were analysed using SPSS to investigate associations between perceived confidence to teach scientific content knowledge and interest for more PD in science curriculum content across different junior science discipline strands. Patterns and trends were predominately displayed using a frequency table or cross-tabulation table. In cross-tabulation tables, data was reported as cell count and percentage in row. Individual scientific content components were compared for confidence and PD interest, as well as for collective thematic principal subject strands.

## 3.4. Results

The survey results provided a depth of information with individual teacher responses uncovering considerable variation in teaching confidence and interest in PD. The following results relate solely to the Australian Junior secondary science curriculum content in one of Australia's eight states and territories.

### 3.4.1. Confidence teaching explicit Junior Secondary Science content

Prior to responding to specific topics within each strand of the Australian Curriculum- Science (F-10), teachers were asked to identify their confidence teaching Junior secondary science subjects. Nearly all of the teachers stated they were confident to teach Junior Science (Years 7 to 10) with 100 % of males and 94% of females reporting they were confident teaching the general secondary junior science subject. However, despite the initial confidence expressed in the teaching of junior secondary science, teachers expressed noticeably less confidence when asked about specific science curriculum knowledge (Table 3.1).

When the level of confidence for teaching individual science concepts was summarised for each discipline strands, the proportion of teachers expressing high or very high teaching confidence was lowest for the Biological Science concepts (69.2% expressing high or very high teaching confidence). The proportion of teachers expressing high or very high confidence in teaching a specific junior science discipline was highest for Chemical Sciences, closely followed by Science Inquiry Skills and Science as a Human Endeavour (78.3% and 76.1% respectively). This finding is interesting to note as it does not align with other research reporting that the teaching of physics and chemistry are deemed more difficult, and thus teachers are less confident to teach this content and are in greater demand. (Harris et al., 2005; Lyons, Cooksey, Panizzon, & Pegg, 2006; Office of Chief Scientist, 2012)

**Table 3-1 Mean percentage and standard deviation of expressed confidence for teaching Junior Science curriculum discipline areas**

| Junior Science Curriculum | Confidence to Teach | | |
|---|---|---|---|
| | None/Little | Moderate | High/V.High |
| Biological sciences | 7.7 % +/- 4.9 | 23.1 % +/- 5.1 | 69.2 % +/- 8.2 |
| Chemical sciences | 5.1 % +/- 3.6 | 15.8 % +/- 4.8 | 78.3 % +/- 7.8 |
| Earth & Space sciences | 6.9 % +/- 3.4 | 18.4 % +/- 6.0 | 74.8 % +/- 9.3 |

| Junior Science Curriculum | Confidence to Teach | | |
|---|---|---|---|
| | None/Little | Moderate | High/V.High |
| Physical sciences | 6.7 % +/- 1.9 | 20.5 % +/- 4.1 | 72.7 % +/- 5.3 |
| Science inquiry skills and Human endeavour | 4.6 % +/- 3.5 | 17.7 % +/- 7.2 | 76.1 % +/- 9.0 |

In contrast to the above, when the analysis is applied to the content elaborations for each science discipline strand, greater variation in teaching confidence was observed and is shown in Table 3.2. When averaging across all the identified junior science concepts, 74.3% of teachers responded with high or very high levels of confidence teaching junior science. This is in contrast to the initial 97% confidence in teaching the junior science subject as stated at the commencement of the survey.

Upon examination of individual science concepts within each discipline area, the Chemical Sciences concepts of 'States of Matter' (91%) and 'Atomic Structure' (87.6%) had the highest proportions of high/very high teaching confidence by respondents. This was closely followed by 'Water Cycle' (Earth and Space Sciences) with 86.5 %, and 'Elements, Compounds and Mixtures' (Chemical Sciences), 'Data Analysis and Evaluation' and 'Planning and Conducting Investigations' (Science Inquiry Skills), all with 85.4% of respondents selecting high or very high teacher confidence.

**Table 3-2 Percentage of teaching confidence and professional development interest for elaborations of junior science disciplines**[1]

| Junior Science Curriculum | Confidence to Teach (%) | | | Interest for PD (%) | | |
|---|---|---|---|---|---|---|
| **Biological sciences** | none/ little | moderate | high/ v.high | none/ little | moderate | high/ v.high |
| Classification system | 6.7 | 30.3 | 62.9 | 33.7 | 40.4 | **25.9*** |
| Plants, animals and micro-organisms | 6.7 | 24.7 | 68.5 | 32.6 | 38.2 | 29.2 |
| Food chains and webs | 4.5 | 16.9 | **78.7** | 34.8 | 33.7 | 31.5 |
| Cell structure and function | 5.6 | 28.1 | 66.3 | 29.2 | 38.2 | 32.6 |
| Organs and systems | **3.4*** | 16.9 | **79.8** | 32.6 | 36 | 31.5 |
| Enzymes | **20.3** | 29.2 | 50.6 | 34.9 | 33.7 | 31.5 |
| Reproduction | **2.2*** | 19.1 | **78.6** | 31.5 | 37.1 | 31.5 |

| Junior Science Curriculum | Confidence to Teach (%) | | | Interest for PD (%) | | |
|---|---|---|---|---|---|---|
| Multicellular organisms and homeostasis | 11.2 | 20.2 | 68.6 | 32.6 | 37.1 | 30.4 |
| Disease | 12.3 | 21.3 | 66.2 | 27.0 | 34.8 | 38.2 |
| Ecosystems and communities | 7.9 | 16.9 | 75.2 | 25.9 | 38.2 | 35.9 |
| Heredity, genetics and DNA | 5.6 | 27 | 67.5 | **14.6*** | 37.1 | **48.3** |
| Evolution and natural selection | 5.6 | 27 | 67.4 | 20.2 | 41.6 | 38.2 |
| **Chemical sciences** | **none/ little** | **moderate** | **high/ v.high** | **none/ little** | **moderate** | **high/ v.high** |
| Mixtures and Solutions | 5.6 | 13.5 | 80.9 | 38.2 | 30.3 | 31.5 |
| States of matter | **0.0*** | 9 | **91** | 41.6 | 29.2 | **29.2*** |
| Elements, compounds and mixtures | **2.2*** | 12.4 | 85.4 | 40.5 | 31.5 | **28.1*** |
| Chemical changes | 3.3 | 14.6 | 82.1 | 32.5 | 32.6 | 34.8 |
| Atomic structure | 3.4 | 9 | 87.6 | 38.2 | 28.1 | 33.7 |
| Law of Conservation | 5.6 | 13.5 | 80.9 | 34.9 | 32.6 | 32.6 |
| Chemical reactions | 9.0 | 19.1 | 71.9 | 31.4 | 25.8 | **42.7** |
| Combustion | 9.0 | 21.3 | 69.6 | 32.5 | 29.2 | 38.2 |
| Acid and Bases | 6.7 | 24.7 | 68.5 | 34.7 | 30.3 | 34.9 |
| Energy transfer: wave and particle model | **12.4** | 20.2 | 67.4 | 30.3 | 32.6 | 37.1 |
| Periodic table | 3.3 | 16.9 | 79.7 | 36.0 | 30.3 | 33.8 |
| Rates of reaction | 9.0 | 16.9 | 74.2 | 34.8 | 27 | 38.2 |
| **Earth & Space sciences** | **none/ little** | **moderate** | **high/ v.high** | **none/ little** | **moderate** | **high/ v.high** |
| Earth and Seasons | 4.5 | 16.9 | 78.7 | 33.7 | 32.6 | 33.7 |
| Renewable and Non-renewable resources | **3.4*** | 12.4 | 84.2 | 29.2 | 32.6 | 38.2 |
| Water cycle | **3.4*** | 10.1 | 86.5 | 37.0 | 33.7 | 29.2 |
| Rock types and identification | **13.5** | 28.1 | **58.4*** | 33.7 | 32.6 | 33.8 |
| Rock cycle | 6.7 | 16.9 | 76.4 | **40.4** | 34.8 | 24.8 |
| Plate tectonics | 4.5 | 15.7 | 79.8 | 35.9 | 33.7 | 30.4 |
| Astronomy and Origin of Universe | **10.1** | 27 | 62.9 | 26.9 | 29.2 | **43.8** |
| Earth systems and cycles | 6.7 | 19.1 | 74.1 | 30.4 | 33.7 | 35.9 |
| Solar system | 9.0 | 19.1 | 71.9 | 30.4 | 25.8 | **43.8** |
| **Physical sciences** | **none/ little** | **moderate** | **high/ v.high** | **none/ little** | **moderate** | **high/ v.high** |
| Force and motion | 6.7 | 22.5 | 70.8 | 31.5 | 33.7 | 34.8 |
| Gravity | 6.7 | 28.1 | 65.1 | 29.2 | 38.2 | 32.5 |
| Types of Energy ie kinetic, potential, heat, | **4.5*** | 15.7 | 79.7 | 33.8 | 38.2 | 28.1 |
| Sources of Energy | **4.5*** | 15.7 | 79.8 | 31.4 | 34.8 | 33.7 |

| Junior Science Curriculum | Confidence to Teach (%) | | | Interest for PD (%) | | |
|---|---|---|---|---|---|---|
| Energy transfers and transformations | 5.6 | 19.1 | 75.3 | 31.5 | 37.1 | 31.5 |
| Energy conservation | 7.9 | 21.3 | 70.8 | 33.7 | 34.8 | 31.5 |
| Motion and Energy | **10.1** | 22.5 | 67.4 | 30.3 | 33.7 | 36.9 |
| Alternative way of obtaining energy | 7.9 | 19.1 | 73 | 24.8 | 36 | 39.3 |
| **Science Inquiry and Human Endeavour** | **none/ little** | **moderate** | **high/ v.high** | **none/ little** | **moderate** | **high/ v.high** |
| Human influences and practice in science | 4.5 | 28.1 | 67.4 | 17.9 | 38.2 | 43.8 |
| Scientific models and theory | 9.0 | 16.9 | 74.1 | 23.6 | 41.6 | 34.8 |
| Advances in Science and Technology | 9.0 | 27 | 64 | **11.2*** | 29.20 | **59.6** |
| Scientific methodology | 5.6 | 10.1 | **84.3** | 22.5 | 46.10 | 31.5 |
| Planning and conducting investigations | **2.2*** | 12.4 | **85.4** | 24.7 | 36.00 | 39.4 |
| Data analysis and evaluation | **2.2*** | 12.4 | **85.4** | 19.1 | 32.60 | 48.3 |
| Science communication and writing | **0.0*** | 19.1 | **80.9** | 23.6 | 34.80 | 41.6 |

Note [1]. Bold- highest and * lowest percentages of respondents expressing their confidence and desire

Whilst there are identified areas of strong confidence in the teaching of the concepts in the various junior science disciplines, it is the areas in which there is low teaching confidence that need particular attention. It is these concepts that teachers should be supported with greater urgency.

Though an average of 6.5% of respondents expressed little or no confidence in teaching the various curriculum areas, two areas had no teachers indicating any lack of confidence (0%), these being 'States of Matter' (Chemical Sciences) and 'Science Communication and Writing' (Science Inquiry Skills). The scientific concept where the highest proportion of respondents expressed a low level of confidence was 'Enzymes' (Biological Sciences), with 20.3% expressing no or little confidence. This was followed by 'Rock Types and Identification' (Earth and Space Sciences, 13.5%), 'Energy Transfer: wave and particle model' (Chemical Sciences, 12.4%), 'Disease' (Biological Sciences, 12.3%), 'Multicellular organisms and homeostasis' (Biological

Sciences, 11.2%), and 'Astronomy and Origin of Universe' (Earth and Space Sciences) and 'Motion and Energy' (Physical Sciences), both with 10.1%.

In overall terms, respondents expressed the lowest teaching confidence across the biology content for the junior science curriculum (see Table 3.2). The biological concepts of 'Enzymes', 'Disease' and 'Multicellular Organisms and Homeostasis' were where the greater proportion of teachers expressed little or no teaching confidence (20.3%, 12.3% and 11.2% respectively). In comparison to all other disciplines, teaching chemistry content across junior science had the highest proportion of teachers expressing confidence with only 5.1% of teachers citing no or little confidence (see Table 3.2). The chemistry concept with the highest proportion of respondents with little or no teaching confidence was 'Energy Transfer: Wave and Particle model' (12.4%). 'Rates of Reaction' 'Combustion' and 'Chemical Reactions' were next with equal proportions of respondents with low levels of teaching confidence (9%).

Confidence in the teaching of Earth and Space Sciences rated strongly, with the mean confidence across the earth and space concepts slightly higher than those for the chemical sciences. The highest proportion of respondents expressing the lowest teaching confidence was for 'Rock Types and Identification' (13.5%), closely followed by low teaching confidence for 'Astronomy and Origins of the Universe' and 'Solar System' (10.1% and 9%, see Table 3.2). The Physical Sciences Discipline had the greatest consistency of teaching confidence across concepts. The proportion of respondents expressing no or little teaching confidence for physical sciences ranged from 10.1% for 'Motion and Energy' to 4.5% for 'Sources of Energy' and 'Types of Energy' (see Table 3.2).

The concepts within the Science Inquiry Skills and Human Endeavour disciplines had the highest proportion of respondents expressing the high and very high teaching confidence with only 4.6% of teachers, on average, reporting no or little confidence in teaching the concepts across these disciplines. For each of the concepts 'Planning and Conducting Investigations' and 'Data Analysis and Evaluations' only 2.2% reported little or no teaching confidence (see Table 3.2).

### 3.4.2. Interest in junior science content professional development

After responding to their confidence to teach specific junior science concepts, teachers were then asked to indicate their desire for PD, formal or informal, to enhance their knowledge/understanding in the specific concept area. Table 3.3 summarises the responses for desire for PD for the junior science curriculum strands. As previously mentioned, the highest proportion of teachers expressing high or very high confidence to teach was for Chemical Sciences closely followed by Science Inquiry Skills and Science as a Human Endeavour.

**Table 3-3 Mean percentage and standard deviation of teacher interest for professional development for Junior Science curriculum discipline areas**

| Junior Science Curriculum | Desire for PD (%) | | |
|---|---|---|---|
| | None/Little | Moderate | High/V.High |
| Biological sciences | 29.1% +/- 6.3 | 37.2% +/- 2.4 | 33.7% +/- 5.8 |
| Chemical sciences | 35.5% +/- 3.6 | 30.0% +/- 2.2 | 34.6% +/- 4.1 |
| Earth & Space sciences | 33.1% +/- 4.3 | 32.1% +/- 2.8 | 34.8% +/- 6.4 |
| Physical sciences | 30.8% +/- 2.9 | 35.8% +/- 1.9 | 33.5% +/- 3.5 |
| Science inquiry skills and Human endeavour | 20.4% +/- 4.8 | 36.9% +/- 5.6 | 42.7% +/- 9.3 |

However, this pattern does not align with either the desire or lack of desire for PD in the concepts. This indicates that teachers' confidence, or lack thereof, cannot be used as an indicator for prioritising the provision of PD.

The discipline of greatest overall PD interest was for the Science Inquiry Skills and Science as a Human Endeavour. Not only did this discipline area have the highest proportion of teachers expressing a high or very high desire for PD (42.7%), but it also had the lowest proportion for no or little PD interest (20.4%). Whilst the Chemical Sciences discipline had the highest proportion of teachers expressing no or little interest (35.5%) in PD, a similar proportion of teachers expressed high levels of PD interest (34.6%). For Earth & Space Sciences, the proportion of respondents' PD interest across all three desire levels was relatively consistent. The 'pattern' of interest in PD for the Biological Sciences and Physical sciences indicated a higher portion of teachers with moderate interest rather than high/very high or no/little interest (see Table 3.2).

Whilst there was variation in level of interest in PD across the discipline areas, the variation was significantly less than in the levels of confidence to teach the concept (see Table 3.2). The individual scientific concepts with the greatest proportion of teachers expressing of a high level of interest for PD within each discipline were: 'Heredity, Genetics and DNA' (Biological Sciences); 'Chemical Reactions' (Chemical Sciences); 'Solar Systems' and 'Astronomy and Origin of the Universe' (Earth and Space Science); 'Alternative ways of Obtaining Energy' (Physical Sciences) and 'Advances in Science and Technology' (Science Inquiry Skills and Human Endeavour). Overall, the greatest number of respondents expressed interest in undertaking PD in scientific skills, advances and applications within the Science Inquiry Skills and Human Endeavour in the junior science curriculum area.

### 3.4.3. Teacher confidence versus desire for professional learning

With the larger variation in the expressed teachers' confidence to teach the junior science concepts, than for the desire for professional development in the same area, the interest turned to examining the relationship between these. Are the teachers with the lowest confidence expressing the greatest interest in undertaking professional learning to increase their understandings? Table 3.4 provides the comparison of individual teacher responses for confidence to teacher and interest in professional development for the five junior science individual discipline areas. The number of individual concepts within each discipline varied, with Biological and Chemical Sciences (12 concepts), Earth & Space Science (9 concepts), Physical Science (8 concepts) and Science Inquiry and Human Endeavour (7 concepts). These concept numbers combined with the respondent number (89) resulted in the different n values (n=number of concepts x number of respondents).

**Table 3-4 Individual respondents' relationship between confidence teaching science concepts and interest for PD involving the same science concept for science curriculum discipline strands (percentage and count)**

| Science Content | Biological Sciences (n=1068) | Chemical Sciences (n=1068) | Earth & Space Sciences (n=801) | Physical Sciences (n=712) | Science Inquiry Skills & Human Endeavour (n=623) |
|---|---|---|---|---|---|
| little/no confidence AND little/no interest | 3% (37) | 3% (30) | 3% (24) | 3% (19) | 1% (7) |
| little/no confidence AND moderate interest | 3% (37) | 1% (15) | 3% (25) | 3% (18) | 2% (15) |
| little/no confidence AND high/v.high interest | 1% (8) | 2% (17) | 1% (6) | 2% (11) | 1% (7) |
| moderate confidence AND little/no interest | 4% (44) | 5% (49) | 4% (30) | 5% (35) | 3% (17) |
| moderate confidence AND moderate interest | 12% (131) | 7% (74) | 9% (76) | 10% (72) | 8% (52) |
| moderate confidence AND high/v.high interest | 7% (72) | 4% (47) | 5% (41) | 5% (39) | 7% (43) |
| high/v.high confidence AND little/no interest | 22% (230) | 28% (300) | 26% (211) | 23% (165) | 17% (103) |
| high/v.high confidence AND moderate interest | 21% (229) | 22% (231) | 19% (156) | 23% (165) | 26% (163) |
| high/v.high confidence AND high/v.high interest | 26% (280) | 29% (305) | 29% (232) | 26% (188) | 35% (216) |

For teachers expressing high and very high confidence in teaching, the relationship to their level of interest in PD varied across the discipline areas. Only for the Science Inquiry Skills and Human Endeavour discipline was there a noticeably higher proportion of respondents expressing a high/very high interest in PD (35%) and a correspondingly lower proportion of respondents expressing little/no interest in PD (17%). Similarly, although at much lower proportions, for teachers expressing moderate confidence in teaching, the relationship to their level of interest in PD varied little across the discipline areas. Only for the Biological Sciences was there a noticeably higher proportion of respondents expressing moderate interest in PD (12%) (see Table 3.4).

With the disconcerting proportion of teachers expressing little/no confidence and little/no interest in PD, responses were drilled down to identify individual teacher responses across the of the 48 junior science concepts. Forty-four of the concepts had at least one least one teacher expressing little/no confidence and little/no interest in PD, with the exception of the concepts of ‘States of matter’, ‘Human influences and practice in science’, Planning and conducting investigations ‘and ‘Science communication and writing. Whilst 26% (n=23) of teachers indicated little/no confidence and little/no confidence in at least one science concept, only two teachers’ interest did not express any high/very high level of confidence and high/very high levels of PD interest of which 78 percent of teachers expressed high/very high levels of confidence with corresponding high/very high level of confidence in one or more of the 48 scientific concepts.

## 3.5. Discussion

This study identified the disparity between teacher’s overall confidence level in teaching junior science at a board science understanding level and the significantly lower proportion of teaching self-confidence across the individual scientific disciplines. Science teachers’ perceptions of their confidence for teaching the individual concepts within each of the disciplines showed even greater variations. The initial assumption was that teachers who had low teaching confidence for a specific discipline or concept would have the desire to improve through professional learning opportunities. However, the trends in teaching confidence were not replicated in teachers’ desire for PD in the specific scientific disciplines or concepts. The anticipated higher proportion of teachers expressing moderate confidence levels or moderate desire for PD was also not identified by the results of this study.

Despite initial anecdotal understandings that teachers with the least confidence in teaching particular concepts would have high related interest for PD, this was not the case. The overall lowest responses being received in the 'little/no confidence AND high/very high interest' for all discipline areas with a slight difference in the Chemical Sciences. Surprisingly the highest response rate for teachers with 'no or little' teacher confidence was for 'little or no' interest in undertaking PD in this area. This is a little disconcerting given the professional expectations of knowledge sharing and development of students. The relationships for teachers expressing 'moderate' confidence levels across the junior science disciplines was only slightly better than those with 'no or little' confidence.

Analysis of the results initially raised concerns in the number of teachers expressing no or low confidence to teach a scientific concept yet having no or little interest to engage with PD opportunities regarding that concept. Contemporary research (Goodrum et al., 2011; Goodrum et al., 2001; Opfer & Pedder, 2011; van Driel, Berry, & Meirink, 2014) indicates that teachers play an integral role in the content knowledge and skill development in their students, which suggests that their individual knowledge level should be high enough to enhance student understandings and questioning appropriate to the student cohort. The influence and impact of teachers' science content knowledge on a range of teaching and student learning outcomes is an area of considerable research (Gess-Newsome et al., 2019; Hattie, 2003; OECD, 2005). As mentioned earlier, research has identified that teachers who lack 'robust' subject knowledge are less likely to anticipate student difficulties within specific content areas (Halim & Meerah, 2002) These teachers are also less likely to use flexible and complex representations, or utilise constructivist teaching practices. Other researchers has also shown a positive relationship between teachers' subject matter knowledge and teachers pedagogical content knowledge (Darling-Hammond & Bransford, 2007; Gess-Newsome et al., 2019; Kaya, 2009). Researchers have also examined the lack of subject matter knowledge (SMK) on teacher's capacity and PCK (Rollnick & Mavhunga, 2016). Despite the initial concerns, the analysis also showed encouraging and positive levels of interest for more PD opportunities for concepts in which teachers had moderate to very high levels of confidence teaching. Thus, indicating a substantial number of teachers are motivated to continually learn and enhance their science knowledge through undertaking formal PD.

The results showed that individual teaching confidence across the disciplines and concepts of junior science is fragmented and inconsistent. Due to the complex cognitive nature of teaching, irrespective of teaching discipline, teachers must be able to apply knowledge across multiple domains. (Leinhardt & Greeno, 1986; Resnick, 1987; Wilson, 1987). Research has shown that teachers with differentiated and integrated knowledge will have greater ability than those with limited and fragmented knowledge, to plan and deliver lessons that support students to develop deeper and integrated understandings (Magnusson et al., 1999). There is also a body of research supporting the concepts that science teachers' knowledge and beliefs have a profound effect on all aspects of their teaching (Carlsen, 1993; Hashweh, 1987; Nespor, 1987; Smith & Neale, 1991). However, it must be noted that the due to variation of teacher definition as to what defines 'professional development', teachers lack of expressed interest may not necessarily indicate lack of undertaking 'up-skilling' or professional learning opportunities. Other opportunities such as academic and journal readings, formal academic courses and online scientific enrichment /learnings (i.e., MOOCs, Khan Academy, etc.) may be identified by some as professional learning and not PD (Labone & Long, 2016; Scherff, 2018).

## 3.6. Implications and Conclusions

To conclude, this study highlights the range of perception held by science teachers about the science content knowledge presented in the Australian junior (Year 7-10) science curriculum. Whilst initial high teaching confidence were expressed for the teaching of the Junior Science subject, drilling down into individual science content greater range of confidence levels were expressed. The study also indicates teachers' interest in science PD is not determined by their confidence to teach science content. This finding supports the need for teachers to identify their individual needs and for these to be supported by school administration. Personalised learning is the most suitable approach to delivering science teacher professional learning (AITSL, 2013). In addition to consideration of teacher confidence level, it is advised that administrators and PD providers "be considerate of teachers' backgrounds and existing knowledge and beliefs" (Hochberg & Desimone, 2010, p. 100). It is also suggested that annual reviews for teacher efficacy in regard to detailed subject-related concepts (content knowledge) be undertaken to assist schools to maximise the PD opportunities for staff. Furthermore, providers and presenters of PD opportunities need to provide explicit details of scientific content embedded within the expected learning outcomes for any programs. The provision of a general description of the learning opportunity does not allow the individual teacher to make an informed evaluation of the extent of knowledge alignment to their personal needs. It is also strongly suggested that prior to PD delivery, the implementation of a pre-learning efficacy survey be undertaken. Not only will this further articulate to teachers the specific content and nature of the professional opportunity, but also allow developer/presenters to provide value-added learning experiences. Through clearer articulation of the explicit content knowledge concepts will allow teachers greater capacity to align engage in PD best suited their personal contexts and needs.

Identified in the study was a range of scientific content areas of increased teacher interest for professional development. These concept areas and individual topics allow for greater strategic development of learning support initiatives (PD), providing developers with higher levels of teacher engagement. Increased teacher engagement with scientific content knowledge can produce significantly higher positive impact on their teaching and subsequent student learnings. The implementation of pre- and post-evaluations to gauge the PD 'learning' impact on enhancing content knowledge can provide opportunities for individual teacher reflections. Through reflection on the science content and teaching confidence levels, PD can provide opportunities to develop higher levels of science teachers' self-efficacy (Ross & Bruce, 2007; Tschannen-Moran & McMaster, 2009). Schools need to create an environment where teachers are encouraged to engage in continual learning in terms of both their currency of content knowledge and pedagogical practice. Through establishing a culture that supports PD, both formal and informal learning activities, this will provide the vehicle for enhancing teaching practices and student learning within the school (Goodrum et al., 2011; Opfer & Pedder, 2011; Sharplin et al., 2011)

An interesting finding of the study is the degree of variation and capacity of the science teachers' confidence across the scientific concepts underpinning the junior science curriculum and is an area for further study. In particular, given that teachers initially reported near unanimous confidence to teach junior science, it was not until teachers were provided the opportunity to reflect on the individual scientific concepts did they indicate their actual confidence levels with the content. This study highlights that there is a need within schools to develop strategies to raise teachers' confidence levels across junior science discipline areas and concepts. Implementing regular needs analysis and self-efficacy surveys on the content knowledge concepts of science curriculum would help identify areas of professional development most needed and desired by teachers. This would ensure that any PD provided is not disconnected from their teaching practice and supports the knowledge concepts and skills they want to develop. (Darling-Hammond, Hyler, & Gardner, 2017b). While the research supports the value of teacher content knowledge (Darling-Hammond & Bransford, 2007; Gess-Newsome et al., 2019), the best format, timing and delivery method for teachers to develop and enhance their content knowledge skills is still debated (Adler & Davis, 2006).

Further research is required to identify what are the strategies and pedagogical practice that teachers with no or low confidence use to develop and deliver their lessons.  Teacher knowledge is acknowledged as a key aspect for the teaching a subject (Shulman, 1986). Reinforcing the importance of competence and confidence with science content knowledge is required by teachers to teach for effective student learning in science.

## 3.7. Limitations of the study

Survey methods, including self-reported questionnaires, as used in this research, and the quality of data received, depends upon the respondent for the data reliability. The time required to complete the survey, along with the detailed scientific concepts may have led to survey fatigue. This may have negatively impacted on the response rate of the survey with teacher's abonnement mid-survey and failure to submit, or if completed, on the accuracy of responses the provided.  Individual views and experiences of teachers with the science concepts, along with personal understandings of teacher confidence and professional development are all potential limiting factors on accuracy of data.

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# CHAPTER 4. PAPER 3 - CONTENT, CONTEXT AND CONNECTIONS: A DESIGN FOR TEACHER INDUSTRY INTERNSHIP TO ENHANCE TEACHER UNDERSTANDING OF NATURE OF SCIENCE

## 4.1. Abstract

This paper reviews the capacity of an integrated science teacher professional development program to enhance teachers understanding of 'Nature of Science' (NOS), encompassing both scientific knowledge and the process of acquiring scientific knowledge (scientific inquiry). The key component of the proposed model is to provide opportunities for teacher to undertake an industry internship. The Teacher Industry Internship (TII) model builds upon the teacher professional development opportunities established by the Primary Industry Centre for Science Education (PICSE). Both programs focused on opportunities that provided immersive and interactive learning experiences that allowed teachers to gain relevant industry experience, aiding classroom lesson plans and instruction that resembles what is current in the real-world. The strength and capacity of the TII model to create change and growth in teacher practice and pedagogy is reviewed using the lens of the Integrated Model of Teacher Professional Growth (IMTPG).

## 4.2. Introduction

There is general agreement within the contemporary science education literature that having detailed understanding of nature of science (NOS) and scientific inquiry is vital to the development of scientifically literate citizens. (Aikenhead & Orpwood, 2010; Bybee, 2013; DeBoer, 2000). Consequently, "…without a proper understanding of NOS one cannot truly understand the process of science, make well-informed decisions about socio-scientific issues, or fully appreciate the importance science has in our contemporary culture" (McCain, 2016, p. 4). However, the low level of confidence about teaching science, understanding of science and science concepts has been well established by research conducted in many countries. Such research highlights teacher lack of confidence and understanding being associated with classroom activities that demonstrate little engagement of students in the real-world applications of science and thus inhibiting creativity and questioning (Harlen, 1999; Lam, Alviar-Martin, Adler, & Sim, 2013).

The development of scientific literacy is fostered by integrating explicit, reflective instruction about the Nature of Science together with scientific literacy in traditional science content  (Lederman, Lederman, & Antink, 2013). Essentially, if teachers create a range of opportunities for their students to practise doing science and reflect on what they are doing, their science learning experiences will be richer and more authentic and meaningful.

Taking a broader view of the role of teachers in a knowledge society, Hargreaves (2001) suggests that knowledge evolves within the context of its application within the real world. The knowledge for science classrooms should be applied, contextual and related to the real world. Currently, authentic real-world science can be presented as a relationship within and between science, technology, engineering, and mathematics (STEM).

This paper supports this view, as have many education authorities worldwide. The USA has developed The Next Generation Science Standards (NGSS) and use the dimensions of crosscutting concepts, science and engineering practices and disciplinary core ideas to bring authentic real-world science to their classrooms. Crosscutting concepts connect four domains of science (Disciplinary Core Ideas (DCIs)): Physical Science, Life Science, Earth and Space Science, and Engineering Design through concepts such as 'Cause and Effect' to make explicit a coherent and scientifically based view of the world around them. Science and Engineering Practices are combined to explain inquiry as investigating, designing, and building systems in the natural world (National Research Council, 2012). The NGSS Science Curriculum Innovation has brought together science, technology, engineering, and mathematics to the classroom - in essence STEM.

The UK, Singapore and many other countries, including Australia have in their science curriculum documents maintained the 'classic' curriculum organisation by using science, mathematics, and technology as standalone discipline areas. These are referred to as STEM subjects. Yet, there is an emphasis on improving the quality of science education through a STEM organisation that aims to present science as connected learning based on real-world applications.

The question, therefore, is what activities or professional development (PD) opportunities can teachers participate in to bring authentic, real-world science, technology, engineering, and mathematics (STEM) experiences into their classroom?

One Australian program that provided such PD opportunities through extensive collaborations between universities, regional primary industries, research and development corporations, national and regional agribusiness, regional research institutes, government authorities, local community organisations and schools was the Primary Industry Centre for Science Education (PICSE). PICSE was a national program between 2007 and 2015. The PICSE program delivered a suite of integrated activities including science class workshops, teacher professional development, teaching resources, student camps as well as student and teacher industry placement programs. These collaborative elements of the program also built strong and sustainable relationships between local scientists and employers in aligned primary industries, and with students, teachers, and universities.

The PICSE teacher PD opportunities were designed to effectively contribute to teachers' interest, thinking, motivation and confidence in relation to their understanding of NOS; teaching of biosciences subjects and encouragement of students in this area; thus allowing teachers to increasingly influence students to study science in school and at university in preparation for bioscience careers. The three key teacher-focussed PICSE initiatives involved:

(1) **A two-day program of teacher professional development for teachers**, to illustrate the contextualisation of the Australian science curriculum and the science used locally in primary industries, businesses and Research and Development organisations.
(2) **Production of science teaching resources** that integrated pre-tertiary science curricula and use practical primary industry science (bio-science) examples. Each year topical national themes were selected, relating to different science subjects and linked to industry applications.
(3) **One-week Internships** for **secondary science teachers** (in vacation periods) with scientists in specific local industries or research organisations. At the conclusion of the placement, teachers produced a written report and/or resource to demonstrate its value and relevance.

Across the nine-year program 1,562 middle and secondary school teachers from 199 schools participated with the PICSE teacher two-day PD program and/or teacher industry internships. Feedback indicated that the program achieved its aims of equipping teachers better in the classroom (average 88%) and encouraging students towards future science studies (average 82%). Most teachers (94%) indicated they would participate in future, similar PD opportunities. Teachers reported positively on the value and impact of the internship both personally and professionally. Participant feedback on the program elicited comment towards influence on their:

Classroom teaching with enhanced outcomes for their students:

> "… has helped me gain a better understanding of the skills, knowledge and attitude that we teachers need to encourage and develop in our students to help them succeed in industry" (Tasmania)

> "Opened my eyes to the complexity and importance of genetics behind wheat production. He raised some ideas that I will be able to implement in the classroom" (South Australia)

> “The internship allowed me to build valuable networks and has enabled me to apply my learning to my pre-tertiary classes, but especially to Environmental Science, Biology and Chemistry.” (Tasmania)

Understanding of interdisciplinary /STEM knowledge:

> “I was impressed by the broad application of science to solving problems in agriculture and the potential for spin-offs in other areas of society. This certainly changed my view of agricultural science today. I now see it as a very real option for bright students who enjoy hands-on cross disciplinary science.” (Queensland)

> “My reasons for undertaking the internship were to gain insights into the horticulture industry, to understand the career options available now and into the future and to gain knowledge and skills to be able to teach and lead a new project” (Victoria)

Personal reflection:

> “The internship program reminded me that I still love science and that this is why I chose science teaching as a profession. The experience has shown me that the staff at the university are very willing to work with local schools.” (Queensland)

> “…it was interesting to reflect back and realise my understanding of agricultural practices were limited. I was able to develop an appreciation for the importance of water management, sustainable farming and reduction in pesticide use.” (South Australia)

The focus, format and outcomes of the PICSE PD opportunities for teachers in connecting and establishing partnerships with industry continue to align with current NOS and STEM research and report supporting the provision of avenues for teachers to ‘maintain contemporary STEM knowledge and practices that energise teaching and learning in STEM’ (Education Services Australia, 2018). Giving teachers an opportunity to gain knowledge of how industry utilises different processes to solve technological problems as part of an industry internship program, allows them to bring authentic scientific knowledge back to their classrooms. Furthermore, when teachers are able to relate scientific concepts taught in their class by showing the relevance to the students' everyday lives and wider society problems it makes science more attractive to them – and teaching and learning more effective (Teo & Choy, 2021; Vincent-Lancrin, Jacotin, Urgel, Kar, & González-Sancho, 2017).

The underpinning goal of this research is to develop an enhanced teacher industry engagement professional development program for the Australian Science Teachers' Association, intended for middle and high school teachers. The development of the Teacher Industry Internship (TII) program encompasses the following the objectives:

- utilise lessons learnt from the delivery of PICSE teacher PD and industry internships.
- identify intervention components of the proposed TII program to enhance teacher understanding of NOS conceptions.
- enhance 'effectiveness' of teacher professional development opportunities; and
- analyse TII program delivery design and capacity to enhance NOS though the reflective lens of the Interconnected Model of Teacher Professional Growth (IMTPG) for an understanding of the interventions to create teacher change and growth.

## 4.3. Teacher industry internship model

The goal of teacher industry internship (TII) intervention is to immerse teachers in an authentic science setting and encourage them to spend time reflecting on the processes and knowledge generated by scientists. The provision of authentic, integrated engagement opportunities for science teachers to develop detailed understanding of NOS will enhance the context relevance to the curriculum as well as helping to facilitate rich conversations with their students.

Providing such PD opportunities for teachers to undertake industry internships is a concept strengthened through a recent report by Education Services Australia (2018). The report encouraged education authorities to engage with and promote identified best practice approaches for industry partnership models. These include designing for scale, integrating teacher professional learning into the programs, and alignment with the curriculum. These approaches and deliverables are core aspects of the TII model as shown in program logic overview in Figure 4.1. The TII program logic was established to depict the implementation and deliverables aspects of the program as well as to identify the anticipated impact on teachers, students, and industry.

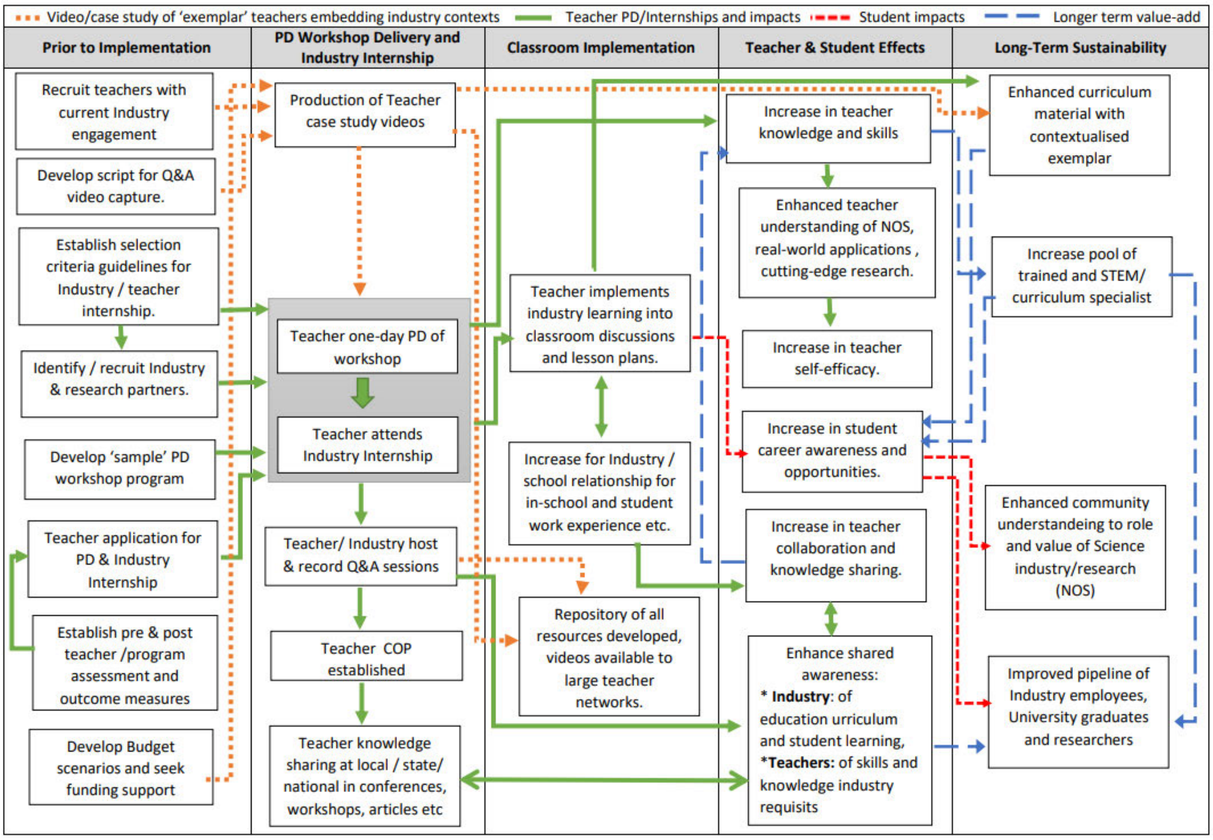


**Figure 4-1 Program Logic of Teacher Industry Internship (TII) model showing the integral PD com-ponents and expected outcomes and effect on teachers, their classroom, and students.**

Research on teacher PD activities indicates that PD interventions are more 'effective' when they: a) have a contextual focus; b) have teachers engage with materials of practice; c) are active and reflect ways to teach students;

d) entail collaborative participation; and e) are sustained and intensive (Borko, 2004; Borko et al., 2010; Ingvarson et al., 2005; Opfer & Pedder, 2011). Therefore, the TII embedded a suite of interventions to support the teacher growth process, including substantial teacher time commitment, follow-up sessions and vacation programs.  These aspects align with research that concludes that teachers need time to develop, absorb, discuss and practise new knowledge, and that traditional 'one-off' workshops are less likely to lead to teacher change. (Berry et al., 2009; Borko, 2004; Darling-Hammond et al., 2009; Hynes & Dos Santos, 2007).

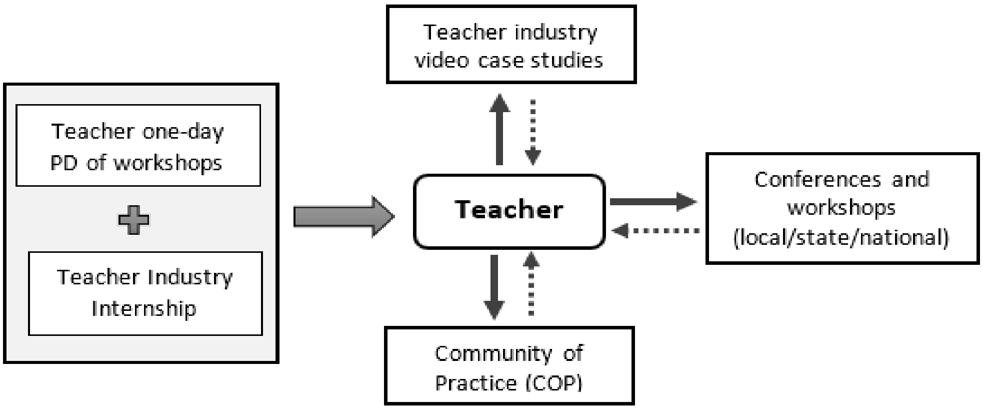


**Figure 4-2 Teacher Industry Internship (TII) integrated engagement opportunities**

The initial PD opportunities (teacher case study videos, one day intensive PD and one-to-four-week industry internship) are of a short duration, the additional external change features of the Community of Practice (COP), conference/workshop presentations, reflective articles and recording of individual case studies, extending the teacher engagement and support over two or more years. As indicated in Figure 4.2, the science teachers themselves become active external influencers upon other teachers, through both their reflective learning experiences and the continued TII program annual roll-out to new teacher cohorts.

## 4.4. Conceptual background

### 4.4.1. Scientific Literacy and Nature of Science

It is widely accepted that the knowledge gained from the sciences has made an enormous impact on every aspect of our lives - continued enhancement of food and agriculture, technology, communication, transport, health and medicine. The acknowledgement of this importance of scientific knowledge and the value to our local and global economy, underpins our need to develop citizenry to function in society with acquired scientific literacy.

A scientifically literate person can be described as action-oriented (Rennie, 2006) and should be competent to understand STEM-related local, national and global issues (Bybee, 2013). According to Lembo, Crough, and Woolcott (2017) scientifically literate individuals should:

- be interested in and understand the world around them
- engage in discussions about and of science, identify questions, investigate, and draw evidence-based conclusions
- be sceptical and question claims made about scientific matters
- make informed decisions about their own health and wellbeing and environment.

The development of students' scientific knowledge and reasoning ability through their school education sets up the potential for lifelong participation in and learning of science-related issues. To this end, the purpose of teaching of science in school is not only the teaching of science content knowledge, but also the enhancing of scientific literacy. However behind science education and curriculum development are the discussions of a) what science content, among many possibilities, to select and teach in the limited amount of time available, b) how students can be made to internalise or construct specific scientific concepts, and c) how to make students transfer science to out-of-school situations (Roth & Lee, 2004).

Students are encouraged to study the sciences to understand the extent and depth of scientific knowledge already available as well as to help contribute to developing new scientific knowledge (Office of the Chief Scientist, 2014). However, it is widely held that merely studying the content within the various science curricula is not enough by itself to achieve these goals (Holbrook & Rannikmae, 2007). Most nations regard the development of students' scientific literacy and understanding of NOS as a primary objective of science education (ACARA, 2017; Eurydice Network, 2011; Ministry of Education, 2020; NGSS Lead States, 2013; Ofsted, 2021).

#### 4.4.2. Teaching NOS in the Curriculum

While there is no one list defining the NOS (McCain, 2016), a 'consensus view' of aspects of NOS that are relevant and accessible to K-12 students has been agreed upon by science teacher educators (Lederman, 2013; Lederman et al., 2013; Smith, Lederman, Bell, McComas, & Clough, 1997). For this paper the term 'Nature of Science' (NOS) is taken to encompass both scientific knowledge and the process of acquiring scientific knowledge (scientific inquiry).

The common aspects of NOS are the following:

- empirically based
- tentative, yet durable.
- subjective and theory laden.
- product of human imagination and creativity.
- theories and laws as distinct types of knowledge.
- society and culture affect scientific knowledge and difference between observations and inferences.

The processes for acquiring scientific knowledge (scientific inquiry) are based upon the premises that:

- scientific investigations begin with and are guided by scientific questions.
- no single method or sequence of steps in a scientific investigation.
- data are not the same as evidence; scientific explanations are developed using evidence and known information; conclusions must be consistent with data.
- scientists work in a community of practice.

These processes and aspects are "uncontroversial and have clear implications for school science teaching" (Clough, 2006, p. 463) and have been included in school science curriculum documents for decades (ACARA, 2017; BSSSS, 1995; Ministry of Education, 2013; National Research Council [NRC], 1996; NGSS Lead States, 2013; QCAA, 2019; QSA, 2004). Similar to many nations, the Australian curriculum aims to provide "opportunities for students to develop an understanding of important science concepts and processes, the practices used to develop scientific knowledge, of science's contribution to our culture and society, and its applications" (ACARA, 2017, p. 4).

To achieve this goal, the national curriculum has been provided across three interrelated strands: science understanding, science as a human endeavour and science inquiry skills. However, to fully address key aspects of "a scientific view of the world and bridge knowledge and understanding across all the disciplines of science" (ACARA, 2017, p. 5), all strands must be integrated and be reflected in the K-12 science teaching / learning for students. Although despite the real-world and integrated focus within the Australian curriculum, many Australian students, particularly secondary students, perceive school science to lack relevance (Goodrum & Rennie, 2007; Tytler, 2007a).

Through this integration, students can be informed of the understandings of contemporary issues, with their importance to societal emphasised through critical analysis, evaluation, and communication. However, should one or more of these strands be removed, a serious deficit in understanding the NOS will occur. Figure 4.3 provides a three-dimensional model to depict the interrelated nature of the three strands to the overarching NOS concept. Within each circle, the curriculum strands are described with detailed learning focus. Where the circles overlap, the description provides an understanding of the value of the two joined strands, along with the deficit of not having the benefit of the third. These illustrate the misgivings that would occur should an insufficient number of strands be combined.

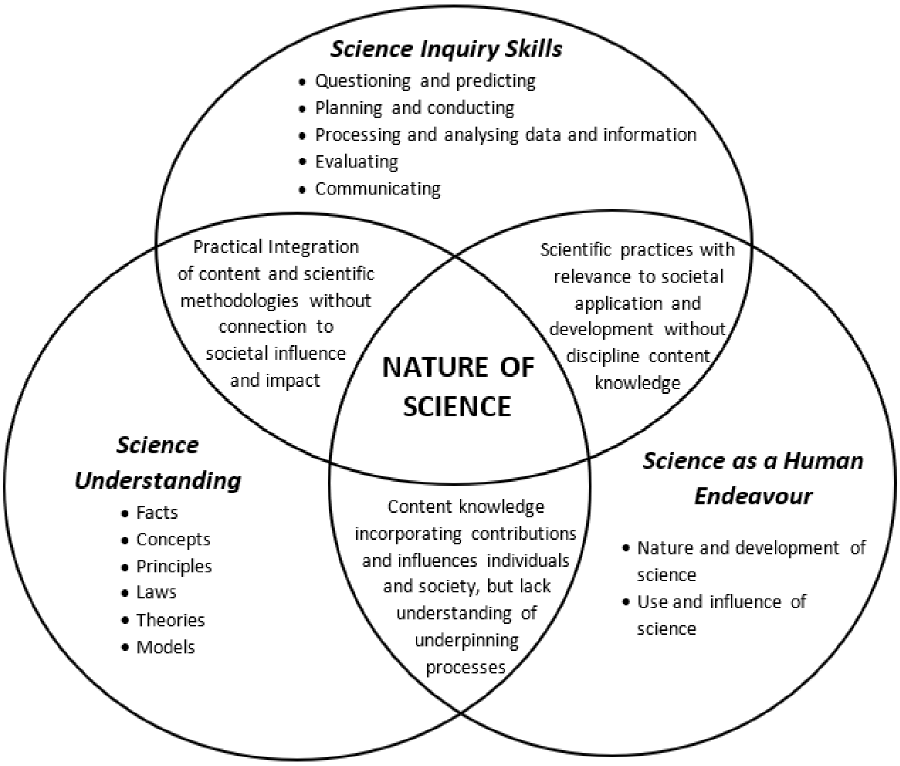


**Figure 4-3 Three dimensions model of the Nature of Science (NOS) and the Australian Curriculum: Science strands and learning focus**

However, teachers knowing what to teach and actually teaching it are not the same. Research suggests that teaching NOS effectively does not come easily for most teachers who may have limited depth of NOS understanding and may hold similar misconceptions as their students (Abd-El-Khalick, Bell,

& Lederman, 1998; Bell, Lederman, & Abd-El-Khalick, 2000; Lederman, 2013). Therefore, unless teachers have a clear understanding of NOS and its place in science education, 'it is unlikely they can fulfill the demands of society in implementing the education intended' (Holbrook & Rannikmae, 2007, p. 17). This raises the question of how to best support teachers to enhance their understanding of NOS and stay current with rapidly increasing developments in STEM knowledge and technologies?

Even though teachers and students cite preferences for hands-on, practical activities with real-world examples and student-guided research in the classroom (Office of Chief Scientist, 2012), in reality time and resource constraints hamper teachers ability to implement these in the science classroom. Coupled with this are the broader problems facing science education including: the often overcrowded curricula, which is mostly filled with traditional science content that does not resonate with many current students; the abstract nature of many science concepts; and the quality of science teaching, which is often largely confined to knowledge transfer (Van Driel, Beijaard, & Verloop, 2001).

In response, many interventions through teacher professional development opportunities have been suggested, including approaches such as inquiry-based science, context-based science, and problem-based learning. These approaches usually advocate different emphases in science teaching, such as focusing on the nature of science (NOS) or aiming at scientific literacy.

One way to answer the above limitations is to provide science teacher with authentic PD opportunities to engage with and create partnerships with scientific industry and research facilities. Research states that such opportunities should include explicit focus on curriculum relevance, classroom practice, teacher's prior knowledge and beliefs and engage teachers in active, collaborative learning (Borko et al., 2010; Desimone, 2009; Magnusson et al., 1999). It is only through such an integrated approach that teachers transfer their learning to create changes in their classroom practice.

As previously mentioned, the value of industry-school partnerships was espoused as a way to have the greatest impact on the engagement and aspirations of young people in STEM curriculum areas. The report identified three major reasons why education authorities should partner with scientific industries which would in turn enhance STEM capacity and inspire future generations, notably:

- Career awareness and understanding of the opportunities for real world problems to be solved through STEM careers
- Teacher professional learning to increase discipline specific knowledge and linkage to real world problems
- Increase understanding of the outcomes and impact of STEM partnerships through data and evidence.

This chapter, along with those of other researchers, further highlights the role that business and industry can play in building teachers' and students' enthusiasm with examples of real-world problems as well as contribute to the content and context for developing contemporary curriculum resources (Berwanger, Biando, Hunt, Tomer, & Washcock, 2021; Office of the Chief Scientist, 2014; Tytler, Williams, Hobbs, & Anderson, 2019; Yeo & Tan, 2021).  Whilst the chapter highlights a range of current school-industry partnership models it found those that focussed on teacher professional learning were more effective when led by educators and supported by industry (Education Services Australia, 2018). Providing real-world practice to curriculum content, while engaging in experiences first-hand with how STEM skills are applied in the workplace, would further strengthen teachers' understanding of NOS, in particular the aspect of what the specific scientific knowledge is, how it works, how scientists operate and acquire information, the epistemological and ontological foundations of science, and how society itself both influences and reacts to scientific endeavours (Clough, 2006).

## 4.5. Evaluating framework

The Interconnected Model of Teacher Professional Growth (IMTPG) (Clarke & Hollingsworth, 2002) model for teacher professional growth (Figure 4.4), was utilised to analyse the design features and potential outcomes of the teacher industry internship (TII) program delivery model and to enhance NOS understanding. The IMTPG framework consists of four domains vital to the professional development of teachers and how changes in one domain can contribute as a change mechanism in teacher professional growth. According to Clarke and Hollingsworth (2002) teacher growth is: '…a process of construction of a variety of knowledge types (content knowledge, pedagogical knowledge, and PCK) by individual teachers in response to their participation in the experiences provided by a PD program and through their participation in the classroom" (p. 955).

The IMTPG was chosen predominately due to being widely utilised and supported by science education researchers as it incorporates internal and external factors, their influence, and interactions which can bring about changes in teachers' pedagogical practices (Justi & van Driel, 2006; Parrish, 2017; Pham & Tytler, 2021; Van Driel et al., 2001). Also, according to Clarke and Hollingsworth (2002), the model can be utilised as an analytical, predictive, and interrogatory tool and provides a framework to support the planning for professional development providers and for research analysis of teacher change or growth. They reported "considerable success" when using the IMTPG to categorise teacher change data into each of the four domains and identify the processes by which the changes occurred (Clarke & Hollingsworth, 2002, p. 957). The model's key strength which emphasises teachers as active learners who enact and reflect during their teaching, along with the visual representation and multi-directional reflective interactions between the change domains, makes this framework ideal to examine the TII NOS interventions that are designed to be reflective in nature.

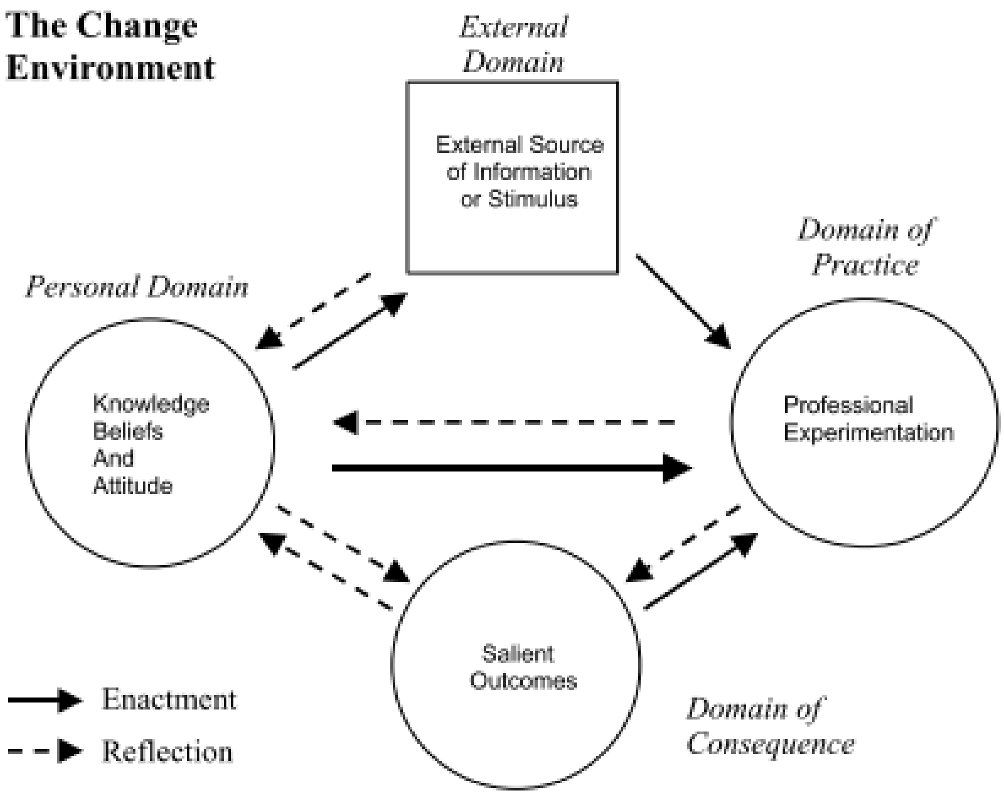


**Figure 4-4 The Interconnected Model of Teacher Professional Growth**

The four domains of the IMTPG are: the personal domain (teacher knowledge, beliefs and attitudes), the domain of practice (professional experimentation), the domain of consequence (salient outcomes such as student learning), and the external domain (sources of information, stimulus or support). The model highlights the change in mediating processes of 'reflection' and 'enactment' as the mechanisms that induce change in domains; with the complexity of teacher learning recognised through the multiple growth connections between the domains (Figure 4.4). The external domain is identified as occurring outside a teacher's 'personal world', in contrast to the other three domains which encompass their professional practices including their actions, knowledge and beliefs. Clarke and Hollingsworth (2002) identified that through a teacher's mediating process of 'reflection and 'enactment', change in one domain is translated into change in another domain.

To this end, Parrish (2017) utilised the IMTPG to analyse identified common intervention components and research methodologies employed in evidence-based explicit-reflective interventions designed to improve teachers' NOS since 2000. The analysis found that regardless of the PD context or pedagogical approach, teachers' knowledge of NOS improved when the participating teachers engaged in explicit and reflective NOS instruction.

However, other researchers have suggested that developing teachers' knowledge of NOS was difficult and varied across interventions due to possible underlying mediating factors (Abd-El-Khalick & Akerson, 2004; Lederman, Schwartz, Abd-El-Khalick, & Bell, 2001). Such mediating factors can include conceptual, affective, and motivational as well as individual social and cultural values. Wahbeh and Abd-El-Khalick (2014) identified that it is likely that teachers require a deep conceptual understanding of science content knowledge to integrate newly acquired NOS conceptions into their existing knowledge structure. These factors influence their personal domains and their domain of practice. However, it must be emphasised that each is a change domain, i.e., change in: external stimuli, practice, knowledge and /or beliefs, and salient outcomes that constitutes each domain, not information, practice, outcomes, or knowledge per se (Clarke & Hollingsworth, 2002).

## 4.6. Teacher Industry Internship and teacher growth

The PD design features, objectives and outcomes of the TII model initiatives are aligned within the four IMTPG domains and along with the NOS specific factors identified through the teacher PD analysis by Parrish (2017). Figure 4.5 depicts the salient features and NOS outcomes of the proposed TII teacher PD program. These build upon the interventions components identified from the Parrish (2017) review of the numerous interventions aimed at enhancing NOS (which for the focus of this program model includes science inquiry), along with the author's prior development and facilitation of the industry internship program implemented as part of PICSE. The contextual and localised teacher PD professional development opportunity focused on connecting secondary science educators with a broad range of primary industries (agricultural) to gain first-hand experience of the research and expertise required to support Australian food and fibre production.

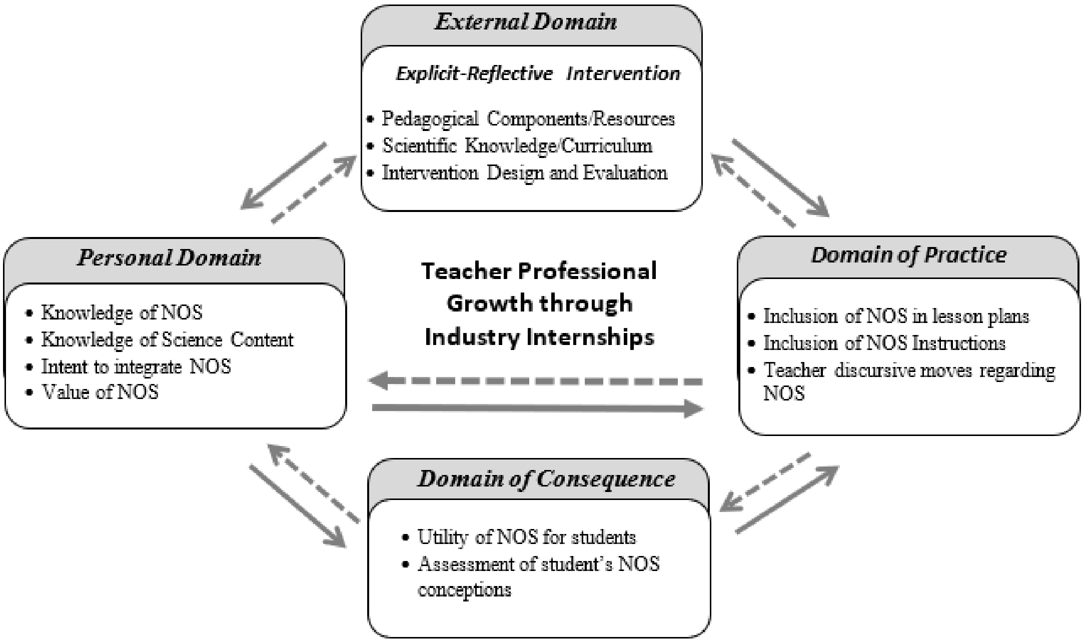


**Figure 4-5 The Interconnected Model of Teacher Professional Growth with PD features and NOS outcomes that emerge from teacher industry internships (adapted from Parrish, 2017)**

The components of the TII model build on identified important factors for promoting teacher growth and change, notably, teacher content knowledge, pedagogical content knowledge, beliefs and attitude and classroom practice. The proposed TII model was initially focused on enhancing professional growth within teachers' personal domain. Research literature identifies two important factors necessary for teacher professional growth for NOS falling into this domain (Parrish, 2017). These were identified as the teacher has sufficient knowledge of NOS, as well as their intentions to integrate NOS into pedagogical practice and curriculum delivery. With these in mind, as well as the integral role reflection plays in teacher professional growth, the proposed teacher industry internship professional development opportunity which focuses on providing authentic NOS experiences and reflection through collaborative sharing, and hence, providing changes in the personal domain. The identified features are to be analysed and aligned with the IMTPG domains.

### 4.6.1. External Domain

The external domain includes any external information stimulus, or support outside the classroom that influence actions and processes occurring within the classroom. The TII model utilises multiple external environmental change features: short course teacher PD; industry internships, conference participation and presentation, Community of Practice (COP) and audio-visual case studies (Figure 4.2). The multiple touch points are designed to provide greater opportunity for continued reflection on both NOS and PCK knowledge (personal domain) and classroom instruction and practice (domain of practice).

Through strengthening both domains and providing reflection opportunities, it would be anticipated that teacher capacity would grow within salient student-related features (domain of consequence). As indicated in Figure 4.2, teachers who have participated in TII go on to become active external domain influencers to new incoming teacher cohorts. Participating teachers, through their reflective learning experiences, classroom practice and influence sharing continue to add depth to the external domain TII program features.

### 4.6.2. Personal Domain

The personal domain includes any teacher characteristics that they bring with them into their classroom practice, such as knowledge, personal attitudes, beliefs, and values. Change in this domain leads to increases in value that a teacher attaches to new teaching strategies that is represented in new pedagogical knowledge for that teacher (Clarke & Hollingsworth, 2002). Changes within this domain may have direct relationship to the TII or may occur through the reflection and enactment of classroom practices, individual student cohorts or through interaction with colleagues. The interconnected nature of the IMTPG accounts for the occurrence of teacher professional growth, independent of participation in in-service activities. Teachers constantly engage in professional experimentation in all aspects of their teaching which includes reflecting on and modifying their practices (adaptive practice). Some adaptations may lead to long-term modifications, others only temporary changes in their practice, thereby influencing their professional growth.

The four personal characteristics thought to be related to enhancing developing teachers understanding of NOS conceptions from research (Figure 4.3) are: knowledge of NOS; knowledge of science content; intentions to integrate NOS in classroom practice; and the value teachers place on NOS as curriculum and educational outcomes. A brief description of how the TII attempts to address these personal characteristics are described below.

The TII programs initial one-day workshop and previous teacher industry-related case studies are designed to provide insight into the concept and capacity for industry engagement and partnerships. Participants are explicitly being taught currently accepted conceptions of NOS through modelled hands-on activities that incorporated varied degrees of contexts. It is through this process teachers are provided fundamental NOS understandings regarding the inclusion of both scientific knowledge and the process of acquiring scientific knowledge (scientific inquiry). Teachers pre-and-post views of NOS being assessed using pre TII questionnaires of VNOS-C (View of Nature of Science, version C) and Intent to Integrate NOS provides empirical evidence regarding impact on teachers' conceptual understanding of NOS (Akyol, Oztekin, Sungur, & Abd-El-Khalick, 2016; Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). The questionnaire has been widely used with excellent reliability and validity (Abd-El-Khalick, 2014; Lederman et al., 2002). Refer appendix 6 and 7 for detailed questionnaires.

The utilisation of pre-and-post teacher NOS understanding and intention assessment was not a component previously included in the PICSE teacher internship model, thereby missing an in-depth, quantifiable measurement of the program impact in respect to NOS conceptual development. The limitation identified in the PICSE teacher PD model has been addressed in the TII model with the inclusion of pre and post NOS questionaries.

Participants identified scientific areas of interest as well as local context that impact on them, their community, and students. Based on these factors, teacher internships are established to accommodate both industry/research institutes and teacher preferences and requirements. Each TII is designed as an interactive and collaborative program to allow teachers to undertake independent and hands-on work. Based on the specific science involved and teacher prior knowledge, initial 'shadowing' of the industry professionals may be required before the teacher performs independent work. A shadowing period at the beginning of the program allows teachers to identify any deficit in content knowledge underpinning the industry scientific context and are encouraged to undertake additional reading and knowledge accumulation on their chosen field of science. The second aspect that TII focusses on is the teacher's intent to integrate NOS into their classroom instruction - a key factor in the IMTPG personal domain. Research suggest that this intention mediates the translation of NOS understanding and knowledge to teaching practice (Bell, Mulvey, & Maeng, 2016; Lederman et al., 2001) .

With a national delivery approach of the TII, an on-line COP is established to enable ongoing reflective discussions and collaboration, where the COP is "… groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly" (Wenger, 2011, p. 1). This allows for intentional learning regarding industry collaborations as well as incidental learning and relationships. The COP thus enables facilitation of explicit and reflective discussions. Such discussions are key to conceptual change, helping teachers confront their initial conceptions and modify them as needed. Participating teachers not only need to commit to an ongoing COP participation, but also they are required to develop curriculum materials and share these and their experience through local, state, and national workshops. Similar to other school, teacher and scientific community collaborations, the scale and scope of ongoing, post TII collaborations can vary. Research suggests that collaborations, whether large or small, can provide benefit for both teachers and students (Clark, Tytler, & Symington, 2014; Tytler, Symington, & Clark, 2017).

Engaging across the diverse interventions, provides teachers with repeated opportunity for reflection. This includes reflection on the TII experience within the industry experience but also on the specific NOS concepts involved in the development and processing of new knowledge for their specific industry context. Such deliverables provide a source of external influences for the next round of teacher undertaking their TII (as shown in Figure 4.5). These repeated touchpoints for reflection, coupled with the intentions to integrate these NOS concepts and scientific contexts into their future classroom practice, provides multiple opportunities for influencing positive teacher growth, identified as an integral part of IMTPG and the personal domain.

The TII provides teachers and industry scientists and researchers the opportunity to establish ongoing collaborations. Such collaborations provide enhanced shared awareness of both education and scientific industry sectors with teachers gaining understanding of the relevance to the science curriculum in contemporary contexts that are interesting to their students. Scientists and researchers gain knowledge of school curricula and student learning outcomes and deliverables. The national delivery approach of TII and the broad range of geographical locations and scientific industry /researcher availability relevant to teachers' interests provide a diversity of scientific contexts.

### 4.6.3. Domain of Practice

Another key objective is to influence teachers' professional experimentation, that is, translation of NOS conceptional knowledge into their pedagogical decisions and classroom practice (domain of practice). Through active participation and first-hand experiences with the activities that are critical to success within a specific scientific industry and its broader industry sector, teachers gain enhanced perspectives on the relevance of curriculum content and contexts they need to provide for their students. This, in turn, influences teachers to increase the frequency of NOS dialogue and the incorporation of 21st century learning and STEM-based practices into their classroom practices (Basalari, de Seriere, Hawkins, & Miller, 2017; Bowen, 2014; Bowen & Shume, 2020; Yeo & Tan, 2021)

However, research has identified that teachers may encounter difficulties effectively integrating NOS into their science classroom instruction and practice (Abd-El-Khalick & Lederman, 2000). The review of NOS PD interventions by Parrish (2017) found 56% (22 of 39) examined factors situated within the domain of practice, with only 26% (10 of 39) examining the attempts of teachers to include NOS classroom instruction.. The TII model provides situational opportunities that encourage and support teachers to embed NOS learning and contexts into their classroom.

A conditional aspect of the TII requires participating teachers to participate in knowledge sharing activities. The development of classroom resources, production of a reflective TII case study, sharing of embedded classroom practice and lessons plans through workshop presentations or journal reports are initiatives integrated into this model. Whilst it is not essential that participants deliver on all outcome artefacts, the expectation is to undertake multiple external sharing activities, the assumption is that these deliverable outputs will elicit insight into their teaching practice and be indicative of the teachers' inclusion of NOS in their classroom lessons. Hence, teachers have the opportunity to reflect not only on the 'what' of their teaching practice but also on the 'how' and 'why'.  Prior understanding of individual participants' capacity and intent to integrate NOS into their classroom, and by extension participate in post TII knowledge sharing, should be identified via the pre-assessment questionnaires. However, accurate judgements can only be made through pre-and-post-assessment scores, indicating any changes in teacher participants intentions to integrate NOS instructions.

Domain of Consequence

The final IMTPG domain for influencing teacher growth is in relation to the domain of consequence. The domain of consequence involves salient outcomes such as student learning, teacher control and student motivation. Clarke and Hollingsworth (2002) noted that changes in domain is linked to a teacher's existing value system and inferences they draw from practices in the classroom. For example, one teacher may consider an increase in student-student talk as a positive outcome to a new teaching strategy, while another may see the same behaviour as a sign of a loss of control and thus a failure of the same new strategy. However, on reflection, and growing acceptance of the value of student-student interaction, the value placed on the new teaching strategy may ultimately be viewed more positively and thus lead to the adoption of the new strategy enhancing their pedagogical practices.

From the initial one-day intensive PD to the internship and through undertaking the suite of interconnected initiatives across the TII program, teachers are engaged thinking about NOS from their student's perspective and the consideration of how they could include NOS concepts and contexts into their classroom practice and instruction. Through explicit discussion of the interaction between the science curriculum strands, the learning focus and NOS (as highlighted in Figure 4.3) which aimed to emphasis the value of teachers embedding NOS into their lesson plans and pedagogical practices. The intersections of strands in Figure 4.3 highlights the misgivings that would occur should an insufficient number of strands be combined.

Whilst the PD design feature and outcome of 'assessment of student NOS conceptions' identified by Parrish (2017) within the domain of consequence is a feature not explicitly included within the TII model, this is not seen as an impediment for the model aligning with the IMTPG framework. Research on teacher industry internships (occasionally referred to as externships) has demonstrated that these type of PD opportunities have positive impact on both teacher and student salient outcome features. Findings from research indicate that teacher industry internships have led to: increased use of design-based classroom activities (Bowen, 2014); increases in student achievements in science (Houseal, Abd-El-Khalick, & Destefano, 2014; Silverstein, Dubner, Miller, Glied, & Loike, 2009); redesign of K-12 learning environments to engage students in authentic learning applications (Basalari et al., 2017; Bowen & Shume, 2018; Tytler, 2007a); and significant positive shifts in teachers' attitudes regarding science and scientists along with shifts in their pedagogical choices (Houseal et al., 2014). The value the influence of the previously mentioned salient outcomes feature are further supported through Australian government reports (Education Services Australia, 2018; Office of the Chief Scientist, 2014) that espoused the value of school and scientific industry partnerships and the critical value that the provision of authentic, contemporary learning experiences have on providing our future workforce.

## 4.7. Conclusion and implications

This review suggests that the teacher industry internship (TII) program can significantly influence teacher professional growth and conceptual understanding of NOS along with their teaching practices in their classroom. The TII model provides an opportunity to embed multiple interconnected teacher-focused initiatives, according to the program logic design (Figure 4.1), for personalised science teacher PD opportunity. With research suggesting that teachers must possess adequate understanding NOS conceptions and scientific content knowledge to effectively transfer this knowledge into their classroom practices, the TII model provides an opportunity to have a positive influence on both.

The TII model developed and enhanced the previous used PICSE teacher primary industry internship model provides a more sustained engagement duration and support, hence becomes a more 'effective' PD opportunity. Additionally, the overarching objective for the inclusion of all four IMTPG change domain guiding principles within the TTI model program design and outcomes will provide positive impact on teacher professional growth. The

TII model also provides teachers with up-to-date cutting-edge professional learning experiences to not only enhance their conceptional understanding of NOS, content knowledge and scientific contexts but also have positive impact on their pedagogical practice and classroom lesson plans. This study provides evidence from research and the author's professional experience in the provision of teacher PD that teacher internships are an effective professional development activity that contributes to teacher professional growth, NOS understanding, and $21^{st}$ century STEM skills.

Whilst this model is designed for practising teachers, it is recommended that similar contextual, real-world scientific industry experiences be embedded within pre-service education. The early understanding and adoption of the industry partnership opportunities as a valuable teaching strategy can have long-term influence on their pedagogical practice. Thus, ensuring teachers strengthen their conceptual role of NOS and maintain currency with the cutting-edge science developments and the integration into their classroom instruction as being a vital pedagogical practice. More research is also needed in this area.

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# CHAPTER 5. BOOK CHAPTER 1 - REAL WORLD SCIENCE IN THE CLASSROOM

## 5.1. Introduction

This chapter outlines the view that science tells us about ourselves and our lives by helping us to understand our relationships with other people and the world. Although the big ideas of science are reflected in curricula, such as in 'know the content and how to teach it' (NSWIT, 2013, pp. 6-7) this chapter shows how teachers and students may benefit from a realisation that science is embedded in our industrialised culture and is everywhere in the modern world for all to see – we rely on it every day. Science, along with technology, engineering and mathematics (STEM), is part of the fabric of our lives (Chubb, Findlay, Du, Burmester, & Kusa, 2012; Office of the Chief Scientist, 2014).

The chapter develops the important consideration that the use of real world community contexts in regional locations as a basis for developing scenario-based or problem-based teaching is crucial for a deep understanding of the concepts and processes of science – including enhanced scientific literacy through understanding how scientists go about their work (Chubb et al., 2012). This should allow both the pre-service teachers and the school students to transfer the context of a scenario while retaining the material to be learned (in a curriculum) as it applies to the new context (Barab & Plucker, 2002).

Recent publications have reinforced real-world application, for example, through the view that proficiency should emphasise using and applying scientific knowledge within a discipline (Harris, Krajcik, Pellegrino, & McElhaney, 2016). This should allow for engagement of students in sense making and problem solving in contexts that reflect real world science, thereby deepening their conceptual understanding of both content and authentic practice. The use of technology is also a consideration since scientists continually engage with and use technology. Technology, such as computer simulations, (see Chapter 1.8 and Chapter 2.8, Woolcott and Whannell (2017) ) can be an important consideration in making real world science part of the classroom, particularly in inquiry-based science education and problem-based learning (Renken, Peffer, Otrel-Cass, Girault, & Chiocarriello, 2016).

An important issue developed here relates to the Nature of Science – a poorly understood concept (Lederman, 1992; Wolpert, 1994). The chapter will focus on developments based on exploration of the Nature of Science (McComas, 1998) and the misconceptions that form the basis of much of our teaching. For example, the emphasis on scientific method as the basis of scientific practice may be underplaying the strength of science, where in fact such issues as the tentativeness of science and its reliance on subjective judgement, as well as validation by peers, may also be relevant. The critical issue of evidence will be explored, including the view that the evidence-based approach of science is a natural way of thinking for children (Gopnick, 2012). Teaching needs to build on evidence-based approaches using children's knowledge skills and experiences and to exploit this successful scientific feature, a feature being employed in other areas because of its success. A recent article discussed why business leaders should think like scientists (Gast, 2012).

An additional issue developed here will be how science helps us to identify and consider specific intrinsic and learned emotional states (Panksepp & Biven, 2012) in order to assess our own real world emotions and motivations, and to ensure that the emotional and motivational climate of the classroom is supportive (Willis, 2006). This chapter will expand protocols to assess your attitudes and interests (Rothman et al., 2012) by drawing on scientific approaches to education in relation to motivation and emotion (Yeigh et al., 2016).

### 5.1.1. Opening Vignette

Watch the video *Can you solve this?* available:
www.yowutube.com/watch?v=vKA4w2O61Xo

Questions

- After watching 'Can you solve this?' reflect on the responses provided in the video and the capacity of people involved to alter their original way of thinking.

Write a brief statement in response to the following questions that may relate to your teaching:

1. Explain the notion of the problem-solving issue identified.
2. Consider how this aspect of problem solving is reflected in your experience with classroom teaching?
3. What strategies could you apply in the classroom to ensure similar approaches?
4. Why would it be important to encourage you students to challenge their problem solving?
5. What implication do you see when relating this to real world scientific problem solving?

## 5.2. What is the Nature of Science?

The understanding and application of science, technology, engineering and mathematics (STEM) is vital in our lives. Advances in science and technology are having an impact on our food, medicine, living and environmental conditions. As our global population increases along with the demand for science and technology to supply solutions and products, understanding the role of science in society becomes increasingly important. It is critical that we have a scientifically literate society. This must begin with students developing a better understanding of scientific concepts and principles as well as ways of thinking. By using real life, authentic learning contexts, students gain an understanding of the dynamic processes, skills and attitudes that underpin an understanding of the natural world and its impact on society – the Nature of Science.

The Nature of Science is a commonly used term by science educators to specify the ideas about science and how science functions (McComas, Clough, & Almazroa, 1998). These ideas can include: what is and isn't science, how scientists work, as well as how science, technology and society (STS) are interrelated and impact on each other. The Nature of Science is 'a fertile hybrid arena which blends aspects of various social studies of science including the history, sociology, and philosophy of science combined with research from the cognitive sciences such as psychology into a rich description of what science is, how it works, how scientists operate as a social group and how society itself both directs and reacts to scientific endeavours' (McComas et al., 1998, p. 4).

## 5.3. Why is an understanding of the Nature of Science essential in science education?

The Nature of Science has always had an implicit role in science curricula. Recently, in science curricula across the world, teaching and learning about the Nature of Science has become far more explicit (Ratcliffe, 2008). The Australian Curriculum: Science (ACARA, 2017, p. 3) describes science as a: dynamic, collaborative and creative human endeavour arising from our desire to make sense of our world through exploring the unknown, investigating universal mysteries, making predictions and solving problems. Science aims to understand a large number of observations in terms of a much smaller number of broad principles. Science knowledge is contestable and is revised, refined and extended as new evidence arises.

However, there are many teachers who do not have a clear understanding of the Nature of Science and how scientists work scientifically (Lederman & Lederman, 2004; McComas, 2000). There are many misconceptions (or alternative conceptions) of science such as: hypotheses become theories that in turn become laws, there is a universal scientific method that scientists use, scientists are particularly objective and scientific models represent reality (McComas, 2000).

It is vital that we enable students to understand the complexities underpinning the work of scientists and expose them to the critical thinking they apply to problem solving. Further, it is important that school students understand that science is not merely a collection of facts and concepts. A study by Ryan and Aikenhead (1992) found that students confused science and technology and had little awareness of the concepts of science and the effect that values have on scientific knowledge.

Understanding the Nature of Science can enhance an individual's understanding of science through comparing current understandings and the limitations that exist within the realms of scientific knowledge. The description and incorporation of the Nature of Science within many school textbooks is often a simplification with the aim of introducing Nature of Science to students, as 'a more complex understanding of science, not a total or even very complex understanding' (Matthews, 1998, p. 168). A more complex understanding of what is currently in textbooks can be achieved through providing students practical real-life examples that apply to local contexts. Students should be given the opportunity to comprehend the changing Nature of Science concepts and to be able to analyse scientific literature from both an individual and a societal perspective. This enables students to analyse a context and therefore make an informed, value judgement.

#### 5.3.1.1. Critical thinking questions

The capacity for individuals to make informed decisions based on the Nature of Science application adds value to not only the significance of the context but also to possible consequences if misconceptions occur. For example, discussing the decision to vaccinate children versus the possible consequences of an outbreak of disease, can only be useful when both positive and negative aspects are understood and the research behind decisions is considered:

1. What is the reason that we are asked to vaccinate our children? Give some scientific reasons why vaccination can be considered as positive.
2. Why are some people opposed to this? Give some scientific reasons why this opposition may be considered as negative.

## 5.4. Key tenets of the Nature of Science

A good starting point for understanding the Nature of Science is to consider the key underlying principles:

1. Scientific knowledge is tentative. This is a concept where scientific knowledge can be changed as new data are acquired or understandings are developed. This alters the prior thinking or laws that have previously existed. Examples include changing views from the flat earth and circular orbits to current models of our Solar system.
2. Scientists have developed scientific knowledge based on observations, experimentation and inferences, in an attempt to explain natural phenomena. Scientific knowledge has been built on scientists making inferences derived from observations and experimentation that has been used to validate understanding. However, not every scientific discipline enables scientists to conduct experiments (such as in astronomy) and not all scientific knowledge can be based on the results of an experiment (such as in evolution – see Lombrozo, Thanukos, and Weisberg (2008)).
3. There is no universal, one way or step-by-step scientific method. There are several common scientific processes such as forming a hypothesis making observations, experimentation, interpretation and hypothesis testing; however, these processes do not need to follow a specified order.
4. Scientific ideas are affected by social and cultural factors. Factors such as politics, economy and moral values sometimes influence what and how science and research are conducted. The way that scientific knowledge is presented and analysed is also subject to social contexts and organisational imperatives.

5. Scientific knowledge must be clearly reported, replicable and based on accurate records and data. Scientific knowledge is built on the review and discussion of results and findings from scientific investigations, observations and theoretical models proposed by other scientists. Accuracy and replicability allows confirmation, rejection or modification of ideas and allows the building of new knowledge.
6. Science and technology impact on each other but are not the same thing. Science and technology differ with respect to the purpose and methods. The purpose of science is to explain the natural world, whereas the purpose of technology is to seek solutions to problems through design (Demirdöğen, Hanuscin, Uzuntiryaki-Kondakci, & Köseoğlu, 2016).

### 5.4.1. Science Reflection

Take a few moments to consider the following three statements then complete the suggested tasks as they apply to classroom teaching:

- Science affects society, but society also affects science.
- Technology is a term that describes how we as humans manipulate the world around us.
- There is no scientific method, just methods that science uses.

Suggested tasks:

1. Describe a scientific finding that has affected your role in society.
2. Describe a view of society that has affected science.
3. Describe a technology that is not used in science.
4. Describe a scientific discovery that was not developed using the scientific method. What method was used in this discovery?

## 5.5. Scientific inquiry in a science education context

Inquiry is central to real world science and how it works. This is the application of real-life science scenarios and the work of scientists and it is the interest, understanding and learning of science content that allows these aspects of the Nature of Science to become more relevant and provides linkages for students. Recent research by Shope and McComas (2015) demonstrated how creating optimal conditions for science education by using inquiry as a science process is one of the most important elements in the practice of science. Inquiry processes help model how scientists work in the real world. Scientists apply inference and other scientific inquiry methods to construct science conceptions as theories, models and conceptual maps that are derived from logical and figural thinking processes.

In science education, understanding the Nature of Science and scientific inquiry provides a context for scientific knowledge (Lederman et al., 2013). As a science teacher, creating a context ensures that scientific knowledge is meaningful for students. However, development of students' understandings takes place within each person's frame of reference. Each student's worldview is shaped by their value judgements, beliefs, perceptions and experiences and plays a role in science education, and this needs to be considered in classroom teaching (Liu & Lederman, 2007).

## 5.6. The ED$^3$U Science Model: teaching science for conceptual change

As Shope and McComas (2015, p. 222) assert, 'the most authentic models of science instruction integrate inquiry with an understanding that knowledge growth in students proceeds from a foundation of conceptual change'. With this in mind, we will explore a very useful model that teachers can adopt to facilitate scientific inquiry with conceptual change as a central process. The ED$^3$U Science Model (pronounced 'ed-you') is an instructional model that emphasises multiple entryways into the iterative and interactive aspects of scientific inquiry. As summarised below, the model places the focus on students by starting with their inquiring questions and supporting them through the Explore, Diagnose, Design, Discuss and Use phases.

With this ED$^3$U Model in mind, as a science teacher, how might you approach your science class? A good starting point is to think about your students and how you can scaffold and facilitate the scientific inquiry process for your students. Let's consider how you could scaffold each phase:

- Explore – *Why?* What type of stimulus or challenge (video, experience, observation) might you provide to your students that engages them to think about an explanation for a phenomenon?
- Diagnose – *How?* How will you identify students' alternative conceptions as plausible? How will you bring misconceptions to student awareness and then guide them to search for more accurate explanations?
- Design – *How?* How will you support students to develop approaches and ways to conduct investigations to test personally relevant questions?
- Discuss – *Why?* The phase is very important in order to generate ideas, ask questions, propose alternate explanations, make knowledge claims, interpret results, reflect on implications and essentially 'participate in the discourse of science' (Shope & McComas, 2015, p. 228)
- Use – *Where and When?* This phase enables students to apply and/or communicate their findings. This might involve applying newly produced scientific knowledge to generate new explanations.

### 5.6.1. Strategies: student goals

Well-respected Canadian science educator, Aikenhead (2006) asserts that 'humanistic' science education that is relevant for students in everyday life should have five interrelated outcomes for students:

- to make the human aspects of western science more accessible and relevant
- to improve critical thinking, creative problem-solving and decision making in their everyday lives in relation to Western science and technology

- to increase capability to communicate with scientific and technological communities, irrespective of their cultural background
- to augment commitment to social responsibility (citizenship)
- to increase interest and achievement in learning 'canonical' science found in the traditional curriculum or other contexts.

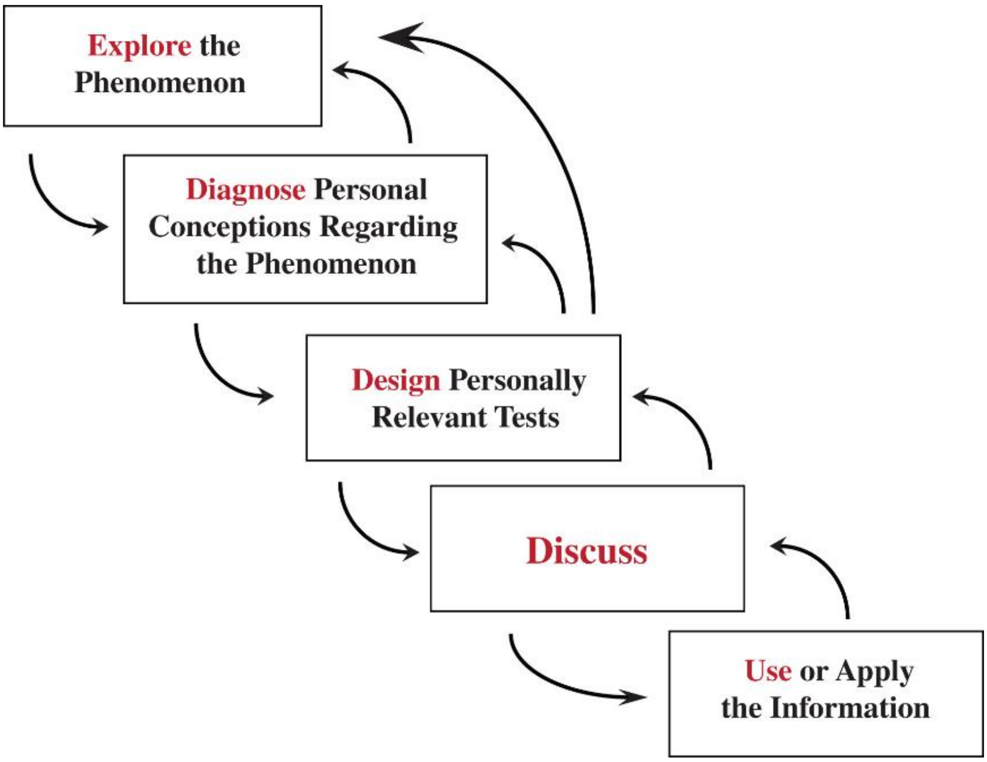


**Figure 5-1** **The ED$^3$U model of conceptual change**
Source: Shope and McComas (2015)

#### 5.6.1.1. Critical Thinking Questions

As a science teacher, an important consideration is to ask yourself what you would like to see your students doing as a result of your science teaching and instruction. Such questioning can help you shape the goals you would like your students to achieve which also reflect an understanding of the Nature of Science. Table 5.1 presents a typical list of student goals. What further goals would you like to include that are relevant to you and your students?

**Table 5-1 Student goals aligned with Nature of Science understandings, science inquiry and Education**

| | **Students will:** |
|---|---|
| **1** | think critically; question critically |
| **2** | convey an understanding of the Nature(s) of Science (i.e. social studies of science) |
| **3** | identify and solve problems effectively |
| **4** | communicate and cooperate effectively |
| **5** | work toward solutions for local, national and global problems |
| **6** | demonstrate creativity and curiosity |
| **7** | set goals, make decisions, self-evaluate and reflect |
| **8** | convey a positive attitude about science |
| **9** | access, retrieve and use the existing body of scientific knowledge in the process of investigating phenomena |
| **10** | demonstrate deep robust understandings of science concepts rather than mastery of numerous isolated facts |
| **11** | show an awareness of the importance of science in everyday life and careers |
| **12** | connect scientific theories with practical applications and students' everyday lives |
| **13** | integrate and synthesise real world issues across disciplines. |

Source: Adapted from (Clough, 1998, p. 198)

#### 5.6.1.2. Scenario - Teachers' use of Language

As a science teacher, your use of language with your students is important as it influences their view of the Nature of Science. It is important for students to be able to reflect on their own understanding of concepts (and misunderstandings too). Questioning strategies are very valuable in guiding students through the inquiry process. Therefore, teachers can adopt strategies to facilitate desired student reflection and response.

These strategies include:

- using extended answer-questions that build on students' earlier conceptions, questioning that requires students to elaborate on their ideas
- applying wait-time for students to think and rethink questions

- responding behaviours that accept and encourage rather than judge students' ideas
- ongoing listening and observing (Clough, 2006)

Reflect on one of the phases in the Explore, Diagnose, Design, Discuss and Use Model (Figure 5.1). Write down the types of strategies (e.g., questioning) that you might adopt to scaffold and instruct students in this phase.

See 'The ED$^3$U Science Model: Teaching science for conceptual change', http://theaste.org/pubs/proceedings/2006proceedings/Shope_1%201%20.htm.

## 5.7. The importance of experimental design and scientific methods

The scientists and engineers of the world are problem solvers; they strive to understand how our world and our universe work in order to benefit humanity. Scientists are held to a high standard by society, government and other scientists, and any experiments conducted must follow credible scientific methods.

There are a number of differing methods that scientists can use, but the scientific method is generally held up as a well-respected and well-used model that can be easily applied in the classroom. The scientific method, however, is an ongoing process, starting with an observation of the natural world. A scientist may see a pattern in the way lightning strikes tall objects, or how ants go to higher ground when rain is coming, or how children who live in industrial areas are more likely to develop asthma. The scientist may ask 'Why does this pattern occur?'.

Building on their prior knowledge and previous experiences, scientists, who often work in multidisciplinary teams, then design an experiment or investigation to gather information and data to predict (hypothesise), observe and explain the problem and question of interest. Thus, their findings enable them to construct science conceptions as models, conceptual maps and/or ending with the development of a general theory (a theory consistent with other available data and current theories). An activity that is useful in assisting students in developing their ideas about the variation present in the scientific method is described as follows.

**Figure 5-2 The scientific method helps scientists discover why lightning strikes tall objects**

### 5.7.1. Scientific Method

1. Write the steps provided in the list below on to sticky notes and ask students to put the steps into the 'right' order on a wall to represent the scientific method.
2. Have students compare their ordered lists and explain to each other their choice of placement.
3. Have each student think of a situation when his/her order would not apply.

Steps to consider:

- make observation of the natural world
- develop and conduct experiment to test a hypothesis
- ask questions 'Why does this pattern occur?'

- develop a general theory for why this occurs
- formulate a hypothesis
- gather and analysis data
- accept or reject the hypothesis
- formulate a new hypothesis, or a new set of hypotheses.

#### 5.7.1.1. Scenario – Applying the Scientific Method

You have developed your ideas about what the scientific method is and how it is used. Now join Dr Woinarski and his team to find out how they solved a conservation problem in northern Australia. Go to EnviroNorth – Savanna Walkabout (environorth.org.au/learn/savanna_walkabout/rt_jtr01.html ). This site provides background information in relation to the reduction in population of the northern quoll.

Questions

- How does Dr Woinarski and his team's approach to solve a conservation problem align with your flowchart of scientific method?
- Compare and contrast your flow chart with this method in practice. Why are they different?
- Can you think of other models where either model would not apply and why?

## 5.8. Scientific misconceptions and how we can deal with them

Misconceptions are preconceived notions or conceptual misunderstandings – you might be very sure of something, but evidence may be produced that may show you that your understanding is misplaced. For example, a common misunderstanding might be that the Easter Bunny comes from the South Pole (and, incidentally, that Santa Claus comes from the North Pole). You may have this misconception because of the stories that you were told when you were young. Even if someone proved to you that this was incorrect, you may still be disinclined to believe the truth based on scientific observation there are no rabbits at the South Pole (and therefore that none of them is the Easter Bunny).

#### 5.8.1.1. Critical Thinking Questions

Despite our rather fanciful example, you may understand already that we can all hold on to misconceptions, despite proof that these may be incorrect. A better example, perhaps, is that an object dropped by a person who is moving does not fall straight to the ground.

1. Look at the image of a basketball player (Figure 5.3). If he is moving and drops the ball, what is the path of the ball? Draw an image of the path of the ball after it is dropped if looking from the side.


**Figure 5-3 A basketball player**

Misconceptions may be problematic in that they can become entrenched in society and delay the solution of serious problems. For example, prior to our knowledge of microorganisms (prior to the use of the microscope), there was a common misconception that microorganisms and even larger organisms arose through ‘spontaneous generation’. That is, people thought that living things could arise from inanimate matter and, as a result, they did not realise that you could prevent disease by preventing microorganisms from growing (and that they were often already present in the inanimate matter). There are a number of websites that can explain this in very simple terms. You might like to try the Science Encyclopedia (science.jrank.org/pages/6408/Spontaneous-Generation.html).

Another serious issue that arises from misconceptions is that people can build a body of knowledge based on that misconception and that they can also block the views of people who do not agree. The classic example of this is the view, promoted by the ancient Greek astronomers, such as Ptolemy and Aristotle, that the Earth is the centre of the universe. This view was the only acceptable view in much of Europe for many hundreds of years and, in many places, there was a death penalty or prison sentence imposed for people who opposed this view. There were alternative views suggested, such as those of Copernicus who suggested that the Sun was the centre of the universe (a good history of this is available at Universe Today, www.universetoday.com/32607/geocentric-model/).

You can read about the problems that this caused, for example, for Galileo at the Inquiries Journal (www.inquiriesjournal.com/articles/533/copernicus-galileo-and-the-church-science-in-a-religious-world). The main problem was that the evidence required to oppose this view was either suppressed or difficult to understand.

*Science Reflection*

Apply your understanding to how students might develop misconceptions in their understanding of the scientific method and the Nature of Science in practice. The following common misconceptions reported by year 8 teachers may help from New York Science Teacher (newyorkscienceteacher.com/sci/pages/ miscon/miscon-user-submit-list.php#b), and try ‘Earthquakes are rare events’, for example, or ‘Deserts have virtually no livings things’.

## 5.9. Real world science: reflecting theoretical knowledge

An important, but not necessarily good feature of the modern science classroom is that there is a lot of science to be learned! Much of this may ‘go in one ear and out the other’, and there is a reliance on rote learning for exams that seems to defeat the purpose of teaching people scientific thinking.

One way around this dilemma is to make sure that any scientific theory you are teaching has relevance to the everyday life of your students as well as to modern scientific achievements. The topic of microorganisms mentioned previously is relevant and can be easily related to scientific theories that are applied in disease prevention and health promotion. Some microorganisms cause disease, and some are necessary for us to stay alive, working with us to digest our food for example. It is important, therefore, to talk to students about theories of ecosystems so that they can see where microorganisms fit into the scheme of things. A result of this might be to look at the issues around probiotics that can be purchased in the supermarket, or the issues around fluoridation and dental hygiene.

### 5.9.1. Real world science in the classroom

The easiest way to relate the theories you are teaching to the real world is to use contexts that the students are familiar with. There is more detail about this in Chapter 1.5 (Woolcott & Whannell, 2017), but teachers who know their students will have at least some idea of student interests. For example, in the It’s part of my life project (itspartofmylife.scu.edu.au), one of the pre-service teachers was asked to deliver a lesson based around the concept of recycling. Scientific theory would have us believe that we have a limited number of resources in our closed system that is the planet Earth and students can use this theory in developing ways to recycle. The teacher let the pre-service teacher (PST) know that many of the students in her class played games with a bat and ball at lunchtime each day. The PST, therefore, decided that she would set up, with her class, criteria for judging what a well-made bat and ball should be like. She then asked the class to make a bat and ball from materials in the recycling bin. She made this a team event so that groups could determine whether or not other groups had met the criteria. It was a fantastic success.

There are some valuable resources that are available for students to use in relating their classroom experiences to theories and the work of modern scientists. Some of these are based on the notion of citizen science where students may contribute to a scientific project. The internet has made this a much more achievable objective and there are a number of citizen science projects available that may fit into your classroom plans. For example, you may contribute images of whales travelling up the east coast of Australia (marinesciencetoday.com/2014/02/19/citizen-scientists-help-study-humpbacks), or you may contribute data to the Atlas of Living Australia (www.ala.org.au/get-involved/citizen-science). Some of these, for example, the humpback whale project, are designed around testing a theory of migration and answering associated questions. For example, for the humpback whales, one of the questions being asked is 'How fast do humpback whales travel up the east coast of Australia?'. By sending in images and location coordinates, students can contribute locations of whales that assist in determining their speed.

#### 5.9.1.1. Critical Thinking Questions

Look at Science and Technology Education Leveraging Relevance (STELR) resource (www.stelr.org.au/wind-energy) which outlines classroom experiments that may be carried out to explore renewable energy, in this case energy generated by wind.

1. On what scientific theory(s) is this based?
2. Describe how you might test how much energy different types of blades may generate

### 5.9.2. Emotion and the science classroom

The introductory section mentioned how science helps us to identify and consider emotional states. Emotions play a role in every memory and it is wise to consider how this can affect you classroom environment (Alsop & Watts, 2003). Student emotions have a wide range and can negatively impact on your science class if they are overwhelming for the student. As Alsop and Watts (2003) point out, teaching science may involve an aim of supporting emotional bonds between teacher and students, and positive relationships developed and established. It is important that the teacher's experience is positive as this means that they may feel confident in their teaching (Yeigh et al., 2016).

There are a number of different protocols that deal with setting up and maintaining a positive classroom environment. Chapters 1.5 and 2.5 in Woolcott and Whannell (2017) deal with one of these. Another method you may wish to consider is the RULER Approach (Rivers, Brackett, Reyes, Elbertson, & Salovey, 2013), although this approach is one of many. The approach guides the development of a social and emotional learning program that is grounded in theory and evidence, built around changing the setting of the classroom to improve learning outcomes. The RULER program includes:

- skill-building lessons and activities for recognising emotions in oneself and others
- understanding the causes and consequences of emotions
- labelling emotions with an accurate and diverse vocabulary
- expressing and regulating emotions in socially appropriate ways.

You may like to investigate this and classroom protocols and approaches when you are teaching science. The main idea is to look at the entire set of interactions around your teaching, including student environments, professional development, cultivation of quality relationships with staff, students and community. These can be used to set up and maintain a healthy class environment suitable for science learning.

## 5.10. Review Questions

Comment on the following statements in light of what you have read in this chapter:

1. Science and technology are the same because they result or provide useful products for society.
2. If a scientific method is followed, it is possible to collect and interpret facts without any bias.
3. After a theory has survived many attempts to falsify it, the theory is considered reliable.
4. All the conclusions of experiments conducted by scientists undergo a review by their colleagues.
5. Scientists hold their own bias and must endeavour to minimise and admit their level of bias in their investigation.

## 5.11. Research Topics

Read - The Nature of science and scientific inquiry, Lederman and Lederman (2004), In Venville, G & Dawson, V (eds) The art of teaching science, 2–17.

Write a short paragraph to answer the following:

1. How important is it to have an understanding of the Nature of Science and scientific inquiry?
2. Why do Lederman and Lederman emphasise the importance of context in science?

Read - Lee, JA (2000). Introduction. In JA Lee (ed), The scientific endeavour: A primer on scientific principles and practice, 1–10. San Francisco, CA: Addison Wesley Longman.

Consider the following:

1. What distinguishes science from other approaches to gaining knowledge?
2. What is the value of scientific literacy for everyday life and how would you persuade someone about its value for inclusion in the school curriculum?

## 5.12. Conclusion

This chapter provides pre-service teachers with a scaffolded approach to develop their understanding of the nature of science concepts, its value with the teaching of science education, and then guide them through a series of applications to real-life examples. The pedagogical features reinforce the link between the theory and practice and is aimed to provide inspiration to pre-service teachers. The strategies provided form links between the theoretical science curriculum with the real world and raise awareness of the value of connecting their students to the science around them, pre-service teachers are engaged with activities that can be used to motivate and improve student learning.

The key features outlined regarding modern science education are: the Nature of Science is not just about a particular method, that scientific discovery must always be seen in a social and cultural context, and that scientists may use creativity and imagination as well as observation and hypothesis testing. Through the introduction ED$^3$U inquiry model, pre-service teachers' attention is drawn to the model's usefulness in science education, having arose out of consideration of the Nature of Science. The subsequent reflection questions bare used to demonstrate that through inquiry models, students can learn to do science like a scientist, as well as learning about what scientists have discovered in the past.

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# CHAPTER 6. BOOK CHAPTER 2 - BRINGING REAL WORLD SCIENCE INTO THE CLASSROOM

## 6.1. Introduction

This 'mirror' chapter provides examples for the practical application of learning experiences from Chapter 4, designed to enable students to connect scientific principles to real world scenarios and to develop an understanding of the Nature of Science.

A scientifically literate person can be described as action-oriented (Rennie, 2006) and displays the following:

- interested in and understands the world around them
- engages in the discussions about and of science
- identifies questions, investigates and draws evidence-based conclusions
- is sceptical and questions claims made about scientific matters
- makes informed decisions about his or her own health and wellbeing and environment.

The development of scientific literacy is fostered by integrating explicit, reflective instruction about the Nature of Science together with scientific literacy in traditional science content (Lederman et al., 2013). Essentially, if you create a range of opportunities for students to practice doing science and reflect on what they are doing (as discussed in Chapter 5 and modelled in Figure 5.1), their science learning experiences will be richer, more authentic and more meaningful. The question, therefore, is what activities or strategies can you bring into the classroom to engage authentic, real world experiences for your students – while at the same ensuring that all strands of the Australian Curriculum: Science (ACARA, 2017) are addressed. For a true reflection of science as a way of learning or the Nature of Science, all strands must be integrated. Figure 6.1 depicts the strands of the Australian curriculum as a three dimensions model related to the Nature of Science, which depicts misgivings occurring when an insufficient number of strands is addressed.

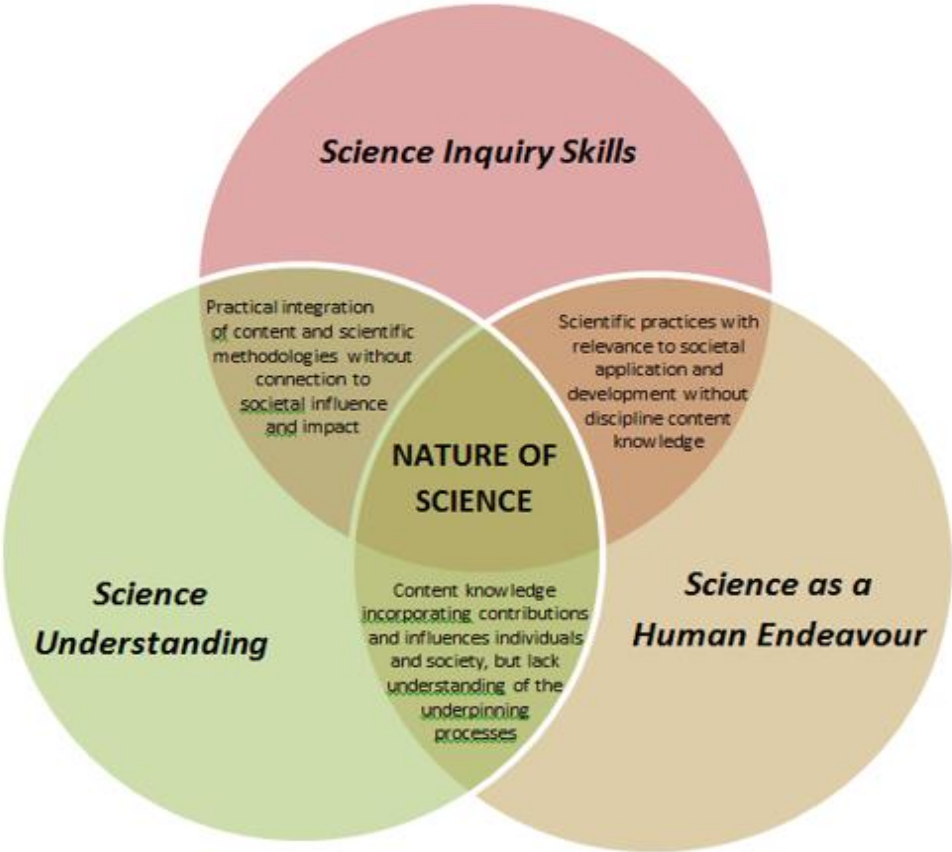


**Figure 6-1 Three dimensions model of the Nature of Science and the Australian**

### 6.1.1. Opening Vignette

Watch the Youtube clip 'Awareness test', www.youtube.com/watch?v=oSQJP40PcGI.

Questions

- How did you go with this? Did you need to watch the video again to check the validity of the statement?

It is often easy to miss the 'obvious' if we are not looking for it. The same concept applies when ensuring the Nature of Science is embedded into your teaching. It is important that all aspects of the Nature of Science are made explicit, irrespective of the context used.

Research has shown (Lederman & Khisfe, 2002; Lederman, 2006) that the explicit approach is more effective than the implicit approach to improving learners' conceptions of the Nature of Science.

Reinforce the importance of explicit awareness by watching 'Test your awareness: Whodunnit?'. www.youtube.com/watch?v=ubNF9QNEQLA.

#### 6.1.1.1. Critical Thinking

1. What is meant by explicit awareness in this context?
2. How does it differ from an implicit awareness in this context?

## 6.2. Nature of Science and application to real world scenarios

As mentioned in Chapter 5, advances in science and technology are having an impact on our food, medicine, living and environmental conditions and this is driving a need for a scientifically literate society. The scenario developed in the lesson below is aimed directly at students developing a better understanding of scientific concepts and principles as well as ways of thinking. The lesson uses a real life, authentic learning context based in a common problem across society, that of lactose intolerance. Through this, students gain an understanding of the dynamic processes, skills and attitudes that underpin the understanding of the natural world and its impact on society – the Nature of Science.

Some people may not produce enough lactase and therefore have trouble digesting the milk sugar lactose. These people are said to have 'lactase deficiency' and are referred to as 'lactose intolerant'. This can happen naturally as people get older, only one-third of people retain the ability to digest lactose into adulthood (Curry, 2013), and it is often an inherited trait. The exact number of people with lactose intolerance in Australia is not known, but certain cultures are more affected by it, including Indigenous Australians, Maoris, South East Asians and some people of Mediterranean descent, according to the CSIRO report, Lactose: A review of intakes and of importance to health of Australians and New Zealanders (Cobiac, 1994).

#### 6.2.1. Example: middle secondary level (year 10)

This scenario has been supported in schools through undertaking the enzymes immobilisation activity provided in Experiment 1 (Appendix 8) and supports the Australian Curriculum: Science (ACARA, 2017). The steps in the process are numbered for easy reference.

##### 6.2.1.1. Lactose intolerance

1. 'What are we going to learn today?' The lesson objective is clearly stated and left in view for the lesson – 'Investigating the role of enzymes and its application to producing lactose-free milk'. This relates to the following outcomes from the Australian Curriculum: Science (ACARA, 2017):

   **Science understanding:**

   *Different types of chemical reactions are used to produce a range of products and can occur at different rates* (ACSSU187).

   **Science as a human endeavour**:

   *Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries* (ACSHE192).

   *People use scientific knowledge to evaluate whether they accept claims, explanations or predictions, and advances in science can affect people's lives, including generating new career opportunities* (ACSHE194).

   **Science inquiry skills**:

   *Analyse patterns and trends in data, including describing relationships between variables and identifying inconsistencies* (ACSIS203).

   *Evaluate conclusions, including identifying sources of uncertainty and possible alternative explanations, and describe specific ways to improve the quality of the data* (ACSIS205)

   *Critically analyse the validity of information in secondary sources and evaluate the approaches used to solve problems* (ACSIS206).

   *Communicate scientific ideas and information for a particular purpose,* *including constructing evidence-based arguments and using appropriate scientific language, conventions and representations* (ACSIS208).

2. Stimulus: the students are shown a 53 second video: Lactose digestion in infants, Howard Hughes Medical Institute, 2011 Holiday Lecture (HHMI BioInteractive, 2011) which introduces the role of the enzyme lactase and its ability to digest lactose by breaking it into glucose and galactose.
3. Questioning is used to find out what the students know and to facilitate their prior knowledge of the nature of enzymes and their effect. The teachers also question the students about the awareness of lactose intolerance and lactose-free products.
4. Present a problem: the teacher presents the students with the concept of 'enzyme immobilisation' and its use in the commercial production of lactose-free products. Students are divided into groups and proceed with the investigation described in Experiment 1.
5. Within-group conclusions about key areas of investigation of enzyme immobilisation are presented. The teacher verifies and corrects where needed, ensuring that each group has captured all issues in their summaries.
6. The class comes back together to discuss what happened for each group. The teacher asks them whether or not their set-up helped solve the problem. The teacher also asks students how the procedure could be adapted to continue the investigation and add to existing understanding. The class discusses whether the lesson objectives have been met. In other words, what did they learn?

### 6.2.2. Science Reflection

Watch the video clip mentioned above: Lactose digestion in infants, Howard Hughes Medical Institute 2011 Holiday Lecture (HHMI BioInteractive, 2011).

Take 10 minutes to reflect on the video and a write brief statement to answer the following:

1. What prior science knowledge would students need?
2. Identify possible negative and positive aspects of using this as a teaching context.
3. How would you ascertain students' alternative conceptions of this topic?

#### 6.2.2.1. Scenario- Pre-service teacher activity 1

Read the investigation outlined in Experiment 1. The process used in this practical lesson is a commercial process called 'enzyme immobilisation' and is used to produce lactose-free milk. Based on the information provided, consider the following questions:

1. How appropriate is this for providing an authentic learning experience?
2. How could this activity be adapted so that it could be used in other contexts?
3. What skills are students developing through undertaking this activity and how do these align with your understanding of the Nature of Science?

#### 6.2.2.2. Teacher profile: Amanda Kilgour

Q: How have you used this resource with your students?

One of my favourite experiments to integrate into my teaching is the effect of lactase on lactose concentration in milk. I have used this resource with my senior chemistry class in a unit 'I've chemistry under my skin'. The unit looks at the role of enzymes and, in particular, the structure and role of amino acid side chains in the formation of active sites. I use the activity to introduce the topic. Providing both an experimental activity and a familiar context helps to increase student engagement.

Q: What value do you see for student learning by promoting real world contexts for science in the classroom?

Learning is a complex process. I believe that one reason students disengage from lessons is not being able to understand the relevance of the activity or how it can be applied outside of school. If we teach through context and make the connections explicit, students will be learning the material more effectively. Real world contexts provide students with a reason for learning. Effective learning also involves recognising familiar patterns and building on these understandings. Contexts that are familiar help students develop long-term storage of concepts and ideas; I would encourage teachers to start where the students are and then use contexts to extend them. In examining aspects of the science as a human endeavour dimension of the Australian curriculum we have the opportunity use contexts to help students emotionally connect with the material which research indicates improves learning.

## 6.3. Inquiry approaches and development of scientific understandings

In Chapter 4 we explored the $ED^3U$ Science Model (Shope & McComas, 2015), an instructional model that emphasises multiple entryways into the iterative and interactive aspects of scientific inquiry. The lesson that we will use to demonstrate this process in designed around the use of drones, increasingly used across the world in a multitude of different scenarios. We will focus here on students starting with developing inquiring questions and supporting them through the Explore, Diagnose, Design, Discuss and Use phases.

Drones are not remote controlled; rather, they are programmed to complete a task autonomously without humans needing to pilot them. With drone technology we can:

- program drones to recognise colour, shape, temperature and patterns
- design drones to perform a simple action when recognising a target
- program drones to follow a certain travel path
- record images and videos along that travel path for review later

- design drones to travel through any medium, including air, water and land.

### 6.3.1. Example: upper primary level (year 6)

The following three scenarios were posed to a year 6 class for discussion and supports the Australian Curriculum: Science (ACARA, 2017).

Science as a human endeavour:

Science involves testing predictions by gathering data and using evidence to develop explanations of events and phenomena and reflects historical and cultural contributions (ACSHE098).

Scientific knowledge is used to solve problems and inform personal and community decisions (ACSHE100).

Science inquiry skills:

With guidance, pose clarifying questions and make predictions about scientific investigations (ACSIS232).

Identify, plan and apply the elements of scientific investigations to answer questions and solve problems using equipment and materials safely and identifying potential risks (ACSIS103).

In this lesson, we use steps in the ED$^3$U Science Model (Shope & McComas, 2015). We start with the concept of Explore (Why?) by asking the students to think first about why we use drones. The stimulus is a magazine-type article you have provided to your students that engages them in thinking about an explanation for the new phenomenon of drone technology. The following are example of stimulus articles that highlights current uses of drones:

- 'Plastic-eating underwater drone could swallow the great Pacific garbage patch' (Boyle, 2012) and

- COTSBot: New robot aims to terminate crown-of-thorns starfish destroying Great Barrier Reef' (McLeish, 2015)

Table 6.1 shows events that can alter an ecosystem. Explain to the students that their task is to design a robotic drone to perform a task specific to one of these events.

In your design, you will need to be specific in the reasoning behind your drone concept. It will need to target a specific aspect of the above issues, e.g., plastic pollution in rivers, noise pollution in suburbs, endangered quoll population, conditions of certain rainforest trees, etc.

**Table 6-1 Events that can alter an ecosystem**

| Oil and pollution spill | Overhunting/fishing/harvesting |
|---|---|
| Algal blooms | Passive monitoring of natural environ-ments |
| Endangered species monitoring | Mapping inaccessible areas |
| Invasive species monitoring | Habitat destruction |
| Flooding and droughts | |

In discussing the Diagnose (Why?) Part of the ED$^3$U process you will lead the students into the Design part of the ED$^3$U process (How?). You will be able to support students in developing approaches and investigations to test their uses for drones? Once they have presented some ideas to the class you can then proceed to the phase Discuss, where all members of the class can contribute ideas, ask questions and propose alternative designs – in short, involve themselves in scientific discourse (but don't tell them that!). The follow-up is the Use phase (Where and When?) where you might ask the students to communicate their findings to other classes or another school, even one on the other side of the world!

#### 6.3.1.1. Critical Thinking Questions

1. How is the Discuss phase different from the Use phase. Illustrate your answer with an example.

2. Name some of the way your students could communicate their findings and evaluate which of these they would be best able to use in your region.

#### 6.3.1.2. Scenario - Pre-service teacher activity 2

The same format can be adapted to provide less scaffolding and greater flexibility for senior students to engage with relevant scientific or STEM-focused news reports.

1. Find a daily media story that discusses an age-related problem or issue for students in your current teaching level. You might use the newspaper or online news and current affair sites. When you choose the problem or issue, justify the use of this issue on the grounds that it will engage/interest the students.
2. Design an age-appropriate experiment that the students could undertake. When designing the experiment provide a written response to each of the following:

   - What prior science knowledge is required?
   - What year level would be appropriate for the experiment?
   - Which syllabus outcomes are addressed?
   - What mathematics outcomes are addressed?
   - What data, results and graphs would be produced by the experiment?
   - Draft a possible conclusion for the experiment. What other alternative conclusions might be drawn?
   - How will reflection be incorporated into the activity?

## 6.4. Formulate clear understanding of concepts and resolve commonly held alternative conceptions or misconceptions

We have all at some time or other made an incorrect or inappropriate conclusion based on observations. Sometimes we find new data or have new experiences that change our conceptions. Here we are going to let students read about other people's observations and then make a decision, first by themselves and then in group discussion or reflection. These examples are drawn from the real world and have a focus on the type of observations that are important in science, namely those where we can compare measurements and other observations in order to come to some kind of consensus. These are part of what is generally referred to as the scientific method. It is important in considering misconceptions to take into consideration the Nature of Science principles. For example, we may need to consider cultural values in making a decision on whether wind farms are important.

#### 6.4.1. Example: lower secondary level (year 8)

1. 'What are we going to learn today?' The lesson objective is clearly stated and left in view for the lesson. 'How does scientific knowledge influence understanding and interpretation of information in society?'

   This relates to the Australian Curriculum: Science (ACARA, 2017) –

   Science inquiry skills:

   Use scientific knowledge and findings from investigations to evaluate claims based on evidence (ACSIS234)

   Summarise data, from students' own investigations and secondary sources, and use scientific understanding to identify relationships and draw conclusions based on evidence (ACSIS145)

   Communicate ideas, findings and evidence-based solutions to problems using scientific language, and representations, using digital technologies as appropriate (ACSIS148).

#### 6.4.1.1. Stimulus

The students in class are given at random one of the following reports to read.

*Report 1: Peppermint oil as an anti-cholesterol agent*

It has been found that rubbing peppermint oil on the backs of patients' hands while in hospital for coronary disease can reduce their cholesterol. Sixteen patients with a cholesterol of above 190 trialled this method for four weeks and it was shown that the peppermint oil treatment, in conjunction with a healthier diet and exercise, greatly reduced patients' cholesterol. The new product, Peppy Peppermint, is available to hospitals to purchase at a price of $150/litre.

*Report 2: Wind farm development stalled by council*

A recent survey was conducted on a beachside community and referred to a wind farm being built on the headlands: 35 per cent of people said they were against the development, 32 per cent said they didn't mind and 33 per cent were in favour of the development. A local council member who does not want the wind farm built has reported to the media that the majority of people in the community were against the development of the wind farm near their town.

*Report 3: Cotton no good by the seaside*

An agricultural scientist has conducted a study into the effects of salinity on cotton plants. They have used 400 cotton plants in pots. The first 100 were given pure water with no salt added; these were used as the controls. The next 100 trials had one per cent salt dissolved in water, then two per cent salt for the next 100 trials, and finally 3.5 per cent for the last 100 trials (equivalent to sea water). At the end of the experiment the height of the plants was measured to assess how their growth had been affected by the salt concentration. The results showed that while cotton can tolerate water with 1 per cent salt, any higher and the growth of the plants was stunted.

The scientist concluded that cotton could not be grown in coastal areas where there was a high salt content in the ground water.

1. Questioning was used to find out what students know about scientific method and the role of observation and inference; experimentation and analysis are applied to validating understanding. The teacher questioned the whole class regarding the processes that scientists use to form their understanding. For example, how would you know that your experimental results are correct? What would you need to know before you start an experiment?
2. Present a problem: the teacher asks the students to place themselves in the role as editor of a scientific magazine. The students' task is to reject or accept the study for publication based on their knowledge of the scientific method and how experiments should be conducted.
3. The teacher divides the class into three groups, one for each of the reports used. The teacher asked students in each group to share with each other if the accepted or rejected the article and why. Each group had to compile a summary of the reasons discussed, based in the evidence provided. Students are also asked to note any different ideas that their group had in comparison to other groups, and if there was any additional information that they think they needed to make their discussion.
4. The class came back together to discuss what happened for each group. The teacher asked them whether their group all had same result, i.e. accepted or rejected. The class discussed whether scientific method was used in each example and, therefore, what problems they faced in understanding the reports. The students were asked whether the lesson objectives have been met – what did they learn?

#### 6.4.1.2. Critical Thinking Questions

1. Why is it important (or critical) to bring the class back together for a discussion at the end of the lesson?
2. What are the steps involved in the scientific method?

## 6.5. Apply theoretical knowledge to examining real world scenarios

This lesson scenario applies theory that students will be exposed to in most science curricula in the senior years of schooling if they are taking subjects such as biology and chemistry, and in some cases physics. The idea here is to transfer the knowledge and skills related to photosynthesis to a different context more akin to the real-world experiences of students. This may avoid the 'go in one ear and out the other' problem mentioned in chapter 1.5, 'Improving science teaching practice through collaboration and reflection' (Woolcott & Whannell, 2017). Photosynthesis is a good topic largely because the detail of the process is a complex problem that cuts across many science subject boundaries. The lesson is aimed at year 11 or 12 students, but we have included relevant sections of the Australian Curriculum: Science for year 10, as this subject is sometimes done in preliminary programs for senior science or in advanced science streams of the middle school.

### 6.5.1. Example: upper secondary level (year 10 and 11)

This scenario has been supported in schools through undertaking of the photosynthesis and light intensity activity provided in Experiment 2 (Appendix 9).

The outline below is for the K–10 Australian Curriculum: Science (ACARA, 2017).

Science understanding:

Biochemical processes in the cell are controlled by the nature and arrangement of internal membranes, the presence of specific enzymes, and environmental factors (ACSBL050).

Photosynthesis is a biochemical process that in plant cells occurs in the chloroplast and that uses light energy to synthesis organic compounds; the overall process can be represented as a balanced chemical equation (ACSBL052).

Science as a human endeavour:

The use of scientific knowledge is influenced by social, economic, cultural and ethical considerations (ACSBL040).

Development of complex models and/or theories often requires a wide range of evidence from multiple individuals and across disciplines (ACSBL038).

Science inquiry skills Identify, research and construct questions for investigation; propose hypotheses; and predict possible outcomes (ACSBL030).

Communicate to specific audiences and for specific purposes using appropriate language, nomenclature, genres and modes, including scientific reports (ACSBL036).

The activity 'Photosynthesis and light Intensity' is provided in full in Experiment 2 provided in the resources section of the companion website. You may choose to watch the video Sinking leaf disks available at: www.youtube.com/watch?v=vw8baZO89oc, to view the experiment being undertaken.

#### 6.5.1.1. Scenario – Pre-service teacher activity 3

Use both the video and practical activity information to help you use the following approaches to apply this understanding in the form of a model to use in the classroom in order to maximise student learning. Online interactive concept mapping tools that you might use in this scenario include inspiration and freeware, such as CMap Tools (https://cmap.ihmc.us/cmaptools/cmap-tools-download/)

1. Draw a concept map to demonstrate your understanding of the concepts of photosynthesis. Indicate how the key ideas are related. Circle the concepts on your map that you think would be prior knowledge for year 11 students in one colour and the concepts that would be extension or taught in senior sciences.

Watch the video 'Lessons from thin air', (Private Universe Project, 1997) www.youtube.com/watch?v=z7qH-GhabiA.
Take 10 minutes to reflect on the following and write a brief response to each:

- Do you think photosynthesis is an authentic and valuable context to teach students?
- List the major alternative conceptions that students present in this video.
- What strategies has the teacher used to help the students develop their understanding of photosynthesis?
- What other strategies could have been implemented?
- Based on the video and your responses, review your concept map.

1. What changes would you make to reflect the relationship between areas of photosynthesis?
2. Identify some local 'real world' contexts that you could use to help your students understand the importance of photosynthesis. You may like to consider local horticultural and agricultural examples.

#### 6.5.1.2. Teacher case study: Debbie Goudie

Q: How have you used this resource with your students?

I have used the leaf disc assay (photosynthesis activity) in my year 11/12 agricultural science class while they were studying a unit on plant science. As a part of the senior agricultural science curriculum, students are required to demonstrate thorough knowledge and understanding of the role and effect of light process of photosynthesis. This experiment was both easy to set up and conduct, along with providing data that was able to be recorded and calculated. Conclusions and recommendations were easily obtained. Hence making this a valuable resource to collected summative academic results from my students.

Q: What value do you see for student learning by promoting real world contexts for science in the classroom?

Students are very astute and will question the relevance of most activities they are asked to complete in class. If teachers are able to place the curriculum content into real-world contexts by providing real life examples, students will be more inclined to both participate and in turn retain this knowledge. It is often hard to find relevant and engaging scientific experiments that produce results in the time constraints of a school day and a school term. I found that by always attempting to provide real life examples of scientific concepts, my students remain engaged.

#### 6.5.1.3. Science Reflection

In the case study above, Debbie has argued that students are more incline to participate in class and retain knowledge when science is given a real-world context.

Reflect on her comments. Do you agree?

## 6.6. Review Questions

1. It has been argued that science and technology are the same because they result or provide useful products for society. How would you respond to this statement?
2. Describe how bias may influence scientists using the scientific method.
3. Consider the statement: after a theory has survived many attempts to falsify it, the theory is considered reliable. What is your view of this statement?
4. Describe the role of the peer review process where the conclusions reached by scientists undergo a review by their colleagues.
5. Do you agree with the statement: scientists hold their own bias and must endeavour to minimise and admit their level of bias in their investigation? Explain your position.

## 6.7. Research Topics

Read the article, 'A longitudinal analysis of the extent and manner of representations of Nature of Science in US high school biology and physics textbooks' (Abd-El-Khalick et al., 2017).

Write a short paragraph to answer the following:

1. How important is it to have an understanding of the Nature of Science and scientific inquiry?
2. Why do Abd-El-Khalick et al. emphasise the importance of NOS or 'science as a way of knowing' in high school science textbooks?

Read 'Chapter One – Introduction. The scientific endeavour: A primer on scientific principles and practice', 1–10. (Lee, 2000)

1. What distinguishes science from other approaches to gaining knowledge?
2. What is the value of scientific literacy for everyday life and how would persuade someone about its value for inclusion in the school curriculum?

## 6.8. Further Reading

- Abd-El-Khalick et al. (1998), The nature of science and instructional practice: Making the unnatural natural. Science Education, 82 (4), 417–36.
- Clough (2007) Teaching the nature of science to secondary and post-secondary students: Questions rather than tenets.
- Lederman and Lederman (2004) The nature of science and scientific inquiry. In Venville, G & Dawson, V (eds) The art of teaching science, 2–17.
- Tytler, Symington, Kirkwood, and Malcolm (2008), Engaging students in authentic science through school–community links: Learning from the rural experience. Teaching Science: The Journal of the Australian Science Teachers Association, 54 (3), 13–8.

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## 6.9. Conclusion

This chapter provides pre-service information and opportunity to consolidate their personal understanding of the nature of science and applications to world scenarios. The scenarios provided were aimed at directly enhancing pedagogical techniques to enhance students understanding of scientific concepts and principles as well as ways of thinking. The lesson on lactose intolerance uses a real life, authentic learning context based in a common problem across society, that of lactose intolerance. The lesson focussed on consolidating their understanding of the dynamic processes, skills and attitudes that underpin the understanding of the natural world and its impact on society – the Nature of Science. The photosynthesis lesson provided a good scenario context, largely because not only is the detail of the process a complex problem that cuts across many science subject boundaries, but also applies knowledge and skills related from a particular context to a context akin to the real-world experiences for students.

The $ED^3$ U model was utilised as an inquiry approach to assist pre-service teachers in development of their understanding of the entryways into the iterative and interactive aspects of scientific inquiry. The lesson on drones providing ideal for this process, enabling student-led inquiry lessons that provides opportunity to understand students inquiring, as well as teacher support through the Explore, Diagnose, Design, Discuss and Use phases. The model demonstrated how inquiry approaches can assist in development of an understanding of working scientifically, scientific knowledge domains and science as a human endeavour.

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# CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

## 7.1. Conclusions

As outlined in the introduction, the research reported on in this thesis reviewed strategies for effective teacher professional development involving scientific content knowledge, investigated teacher confidence in teaching science in relation to interest in professional development, and presented a design for teacher industry internship for enhancing teacher understanding of the nature of science. The objectives of the research have been achieved through the three fundamental phases of the research as discussed in chapter 2, 3 and 4, with chapters 5 and 6 extending the research to address recommendations from chapter 4 to provide a mechanism to support pre-service teacher preparation and understanding for imbedding authentic, real-life contexts and concepts in their pedagogical practice.

The research objectives achieved are stated below as bullet pointed section headers with explanatory text underneath.

- Explore the current nature and extent of science education professional development focused on enhancing secondary science teacher content knowledge

As outlined in chapter 2, a review of three decades of research studies related to secondary science teacher's PD that focused on enhancing teacher science content knowledge showed both a change in the amount of research undertaken as well as to the individual PD design features, aims and outcomes. The substantial increase in the quantity of research, across each decade, from a single paper in 1993 one to nine between 2000 to 2009 and then 24 articles in total from 2010 until 2019, is seen as an increased awareness and understanding of the value of an 'effective' science teacher in influencing student learning. This trend correlating with an increased emphasis on curriculum reform, teacher content knowledge and pedagogical-related content knowledge, along with national and international recognition of the impact and importance of scientific literacy and STEM skills for local and global economic growth.

As indicated in chapter 2 of this thesis, research utilising the four interconnected domains of influence for teacher growth identified in the IMTPG framework, science teacher PD showed sustained growth along with a strong convergence between the PD goals, appropriate pedagogical design features, and positive outcomes across the past three decades. The most substantial growth in IMTPG framework research amounts to the incorporation of the effects on student learning or changes at school level (domain of consequence) on the PD design features.

As discussed in chapter 2, an increased trend towards a more holistic approach to science PD design and delivery occurred with the incorporation of all four domains progressively occurring through the decades examined. This means that an integration has occurred of multiple PD design features that aim to positively influence change in teacher cognition, such as teacher knowledge, attitudes and/or beliefs, classroom practice and salient outcomes, most noticeably student learning. The positive influence of improved PD design features includes: closer alignment with curriculum content knowledge and pedagogical content knowledge; more time spent with active engagement opportunities, and a collaborative approach to teaching with the active participation of many teachers.

Whilst the mode, context and sources of PD stimulus and support (external domain) has varied considerably, most PD studies, irrespective of decade, have been curriculum-focused and have needed substantial timeframes with continuously sustained program delivery (Chapter 2). In these cases, teachers have been supported in absorbing, discussing and practicing their learning across time periods ranging from two weeks to three years, with PDs typically being delivered across several weeks or months to allow the material to be revisited and successful outcomes demonstrated.

Nevertheless, despite these PD successes, there remain two key areas as outlined below for further improvement that require building on best practice to enhance teacher professional learning and student learning:

1. Teachers need to be provided greater opportunities to choose PD based on their own stage within the teaching career as well as their personal learning preference, including their learning style and interest level in science curriculum learning concepts. The responsibility to identify the most appropriate PD should then be the responsibility of the individual teacher working alongside with the school's senior management. In this regard, school management should develop and implement annual internal process for one-on-one recognition and development discussions. This teacher professional development also should align with the Australian professional standards for teachers, which acknowledges the various stages of teacher career development, and more importantly, incorporate teacher continuing professional development (CPD) and an associated self-efficacy tailored to the teacher's professional curricular content knowledge.
2. Professional development providers should strengthen their design and outcomes measure through undertaking evaluation through incorporating evaluations measure before and after any PD opportunities. These should encapsulation both the teachers prior understanding of the PD content focus as well as their belief and attitudes towards the view of the broader conceptions of nature of science. With numerous research papers (e.g.?) having 'verified' assessment/evaluation tools in relation to NOS understanding, PD providers have capacity for ease of implementation into the PD program design. These assessment/evaluation tools can be capture self-perceived or observed outcomes and may take form of quantitative tests/questionnaires or more quantifiable tools such as reflective journals, fieldnotes, videos and interviews, to evaluate PD outcomes. Embedding this process would not only provide valuable feedback to the PD providers regarding the impact and effectiveness of achieve their PD goals but also would provide an

opportunity to deliver their programs at an appropriate participant scientific knowledge level.

- Discover the level of science content knowledge confidence across all the science strands within Australian Curriculum: Science P-10?

As presented in chapter 3, a study in Queensland teachers shows the confidence of practising secondary science teachers to teach junior secondary science has varied significantly depending on the detailed enquiry into scientific knowledge concepts. When initially asked how confident they were in teacher Year 7 to 10 Junior Science, teachers reported near unanimous confidence to teach the subject. However, when were presented with specific junior science concepts (elaborations) within each science discipline strand, teacher confidence levels declined significantly.

The data provided in this thesis enable the identification of scientific concepts that teachers report strong confidence in the teaching in the various junior science disciplines, and more importantly, the scientific concepts in which there is low teaching confidence. It is the latter that need particular attention and that teachers should be supported with greater urgency.

Only two science concepts had every teacher reporting moderate or high teaching confidence, that is, no teacher said that little or no confidence to teach these concepts. These are states of matter (Chemical Sciences) and science communication and writing (Science Inquiry Skills).

In contrast, the specific junior science concepts where 10% or more of teachers expressed little or no confidence for the teaching the concepts were for: enzymes (Biological Sciences); multicellular organisms and homeostasis (Biological Sciences); disease (Biological Sciences); energy transfer-wave and particle model (Chemical Sciences); rock types and classification (Earth and Space Sciences); astronomy and origins of the universe (Earth and Space Sciences); and motion and energy (Physical Sciences).

When examining the level of teacher confidence at the science discipline strands level, the confidence for Biological Science concepts was the lowest. The highest level of confidence in teaching was for teaching the junior science discipline of Chemical Sciences, closely followed by Science Inquiry Skills and Science as a Human Endeavour. This finding remains puzzling yet was interesting, as it does not align with other research reporting that the teaching of physics and chemistry are deemed more difficult, and thus teachers are less confident to teach this content and are in greater demand.

This study highlighted the need within schools to develop strategies to raise teachers' confidence levels across junior science discipline areas and concepts. Implementing regular needs analysis and self-efficacy surveys on the content knowledge concepts of science curriculum would help identify areas of professional development most needed and desired by teachers, thus ensuring, that any PD provided is not disconnected from their teaching practice and supports the knowledge concepts and skills they want to develop

- Provide a deeper understanding the perceived needs for science professional development in Queensland state schools

After responding to their confidence to teach specific junior science concepts, participating secondary science teachers were then asked to indicate their desire for PD, formal or informal, to enhance their knowledge/understanding across the same scientific elaborations. Whilst the junior science strands with the highest proportion of teachers expressing confidence to teach was reported for chemical sciences, closely followed by science inquiry skills and science as a human endeavour, and with biological sciences having the lowest level, the same pattern was not seen across either the desire or lack of desire for PD in the concepts.

The discipline of greatest overall PD interest was for the science inquiry skills and science as a human endeavour. Not only did this discipline area have the highest proportion of teachers expressing a high or very high desire for PD, but it also had the lowest proportion for no or little PD interest.

When investigating PD desire for the individual scientific concepts, the greatest proportion of teachers expressing of a high level of interest were reported being for: heredity, genetics and DNA (Biological Sciences); chemical reactions' (Chemical Sciences); solar systems and astronomy and origin of the universe (Earth and Space Science); alternative ways of obtaining energy (Physical Sciences) and advances in science and technology (Science Inquiry Skills and Human Endeavour). Overall, the greatest number of respondents expressed interest in undertaking PD in scientific skills, advances and applications within the science inquiry skills and human endeavour in the junior science curriculum.

However, when the cross comparison of individual teachers' reported confidence teaching of scientific concepts was made with their desire to undertake some form of professional development, it was disappointing to identify that some teachers report no confidence to teach the concept but also expressed no desire for any professional development for the same. Being embedded in profession where knowledge growth is a primary objective, albeit for their students, the assumption that as their teachers, we should also espouse the same belief and attitudes.

Overall, the study has reinforced the conclusion that teachers' interest in science PD is not determined by their confidence to teach science content. The finding supports the need for teachers to identify their individual needs and for these to be supported by school administration. Personalised learning is the most suitable approach to delivering science teacher professional learning

- Create a targeted science teacher professional development model for enhancing science knowledge (content and pedagogical) to improve the teaching of science in secondary schools (Chapter 4)

The development of the TII program as a model for enhancing teacher knowledge involved incorporate prior experiences (Chapter1) with the findings from the current research. This included the incorporating aspects of ‘effective’ PD designs features and outcomes measures discussed in Chapter 2. A key conclusion is that the design of PD should aim to focus on the holistic nature of a teacher personal, professional, and societal expectations. In addition, PD design goals should refer to the integrated model identified of the four domains identified with the IMTPG framework: external domain, personal domain, domain of practice and domain of consequence. My work with teachers prior to this thesis has revealed that in general, science teachers struggle to kept up-to-date with real-life, cutting-edge STEM developments as long with the opportunities to embed these into their classroom practice. The TII program (Chapter 4) provides teachers with the opportunity to be immersed in authentic industry/ research opportunities as well as engage with other science educators to share knowledge and related pedagogical practices. Through this inclusion of long-term and collaborative support design features, the influence on the capacity to create on-going teacher change is enhanced. The involvement of online case studies and COP and geographical independent nature of the TII, also provides support opportunities for regional and remote science teachers. Too often, regional, and remote teachers reported that context of many PD did not relate to their student’s life experience, such marine science exemplars when they are located over 300 kilometres from the coast. The connection with their local STEM-based industry not only builds and strengthen the connection to community but also provides teacher and students with known context and applications of their curriculum content.

The TII program also delivers a needs-driven response from the findings of Chapter 3. In the Chapter 3, the Australia Curriculum: Science strands with the highest level of desire for PD in was Science Inquiry Skills and Science as a Human Endeavour. With the concept of ‘*Advances in Science and Technology*’ having the of all curriculum concepts, with only 11.2% have little or no interest in PD in this area. With this in mind, the first-hand authentic experience with STEM industry /researchers of the TII, provides the opportunities to address this desire. The immersive internship component provides the opportunity for teachers to enhance their understanding of ’Nature of

Science' (NOS), encompassing both scientific knowledge and the process of acquiring scientific knowledge (scientific inquiry). As well as an avenue to maintain currency with scientific developments and the integrated and collaborative nature of STEM disciplines, aiding the development of classroom lesson plans and instruction that resembles what is current in the real-world. Through applying the lens of the Integrated Model of Teacher Professional Growth (IMTPG), the TII model has the capacity of to create change and growth in teacher practice and pedagogy.

## 7.2. Recommendations

Several key areas for further research emerge from the study. In particular, the TII model of teacher professional development in this research (Chapter 4) presents a variety of opportunities for future research recommendations, given its emphasis on integrated and sustained industry engagement in its design rather than focusing on a single workshop. A wider implementation of this approach should stimulate renewed interest in the various components that are part of the program, the nature of the relationship between components, and the capacity in creating positive teacher growth. Whilst the model built upon the PICSE model which was successful based on positive teacher and student feedback, there is the need to underpin any the TII with solid research analysis influence of impact and teacher change and growth.

Given the importance of introducing pre-service teachers to the value of integrating real-world science into their pedagogical practice (Chapter 5 & 6), such an approach will provide a good foundation for their future teaching careers. Additional and on-going support also would be appropriate to ensure beginning teachers are able maintain their momentum and commitment to contextual curriculum delivery.  As with other senior secondary curriculum areas such as technology that require a minimum annual industry engagement, it is recommended that education authorities introduce a requirement for industry/research participation expectations secondary science teacher across an extended (five-year) period.  With the requirement that Queensland teachers complete 20 hours of continuing professional development (CPD) as a condition for Queensland teacher registration renewal, this expectation could be integrated into teacher registration conditions.

Overall, the following recommendations and further research are suggested from this thesis:

- annual reviews for practicing teacher efficacy in regard to detailed subject-related concepts (content knowledge) be undertaken to assist schools to maximise the PD opportunities for staff
- secondary science teachers undertaking active partnership and engagement with scientific industry as a mechanism to address aspects of the AITSL 'professional knowledge' standard as well as individual CPD and teacher registration requirements
- provision of a detailed PD program description with desired learning outcomes, to allow individual teacher to make informed evaluation of the extent of knowledge alignment to their personal needs
- implementation of a pre- and post -learning evaluation to include teacher prior knowledge (content knowledge and PCK), understanding of NOS conceptions and teaching self-efficacy. Not only will this further articulate to teachers the specific content and nature of the professional opportunity, but also allow developer/presenters to provide value-added learning experiences.
- further research should be conducted to investigate understanding of current science PD opportunities, available support structures as well as teacher beliefs and attitudes for the teaching primary science education and for the education of pre-service science teacher
- longitudinal studies are required into the PD science teachers undertake across the different stages of their careers (including mandated and voluntary PD), to enhance PD design and delivery to

allow increased ‘fit’ with teacher experience, teacher content knowledge, professional interests, and growth stages.

## 7.3. A Final Reflection

My experience as a secondary science teacher, professional development provider and researcher has been enlightening and empowering. The process has reinforced my desire to continue working within the education sector and to support practicing science teachers however possible, whether this be for the development and delivery of formalised professional development programs and initiatives, responding to individual enquiries or simply as a conduit to connect colleagues with broader science education support networks. This has also strengthened my belief in the need for personalised teachers’ professional growth to play a more central role and be given greater priority by both education authorities and school senior management.

Overall, the process has strengthened my commitment to advocate for the provision of authentic PD opportunities that will allow science teachers to maintain knowledge currency within the rapidly changing STEM fields through engaging with real-world relevant scientific contexts. I feel this is vital to support teachers’ delivery of engaging and relevant education to their students, but also as an acknowledgement and recognition as secondary science teachers as science knowledge specialists.

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# APPENDICES

## Appendix 1 Australian Professional Standards for Teachers – Teaching domains

The Australian Teacher Standards consist of seven standards, which teachers will meet at differing levels depending on their career stage and level of experience. The seven Teacher Standards fall into three teaching domains: Professional Knowledge, Professional Practice and Professional Engagement.

Professional Knowledge

- Teachers draw on a body of professional knowledge and research to respond to the needs of their students within their educational contexts.
- Teachers know their students well, including their diverse linguistic, cultural and religious backgrounds. They know how the experiences that students bring to their classroom affect their continued learning. They know how to structure their lessons to meet the physical, social and intellectual development and characteristics of their students.
- Teachers know the content of their subjects and curriculum. They know and understand the fundamental concepts, structure and enquiry processes relevant to programs they teach. Teachers understand what constitutes effective, developmentally appropriate strategies in their learning and teaching programs and use this knowledge to make the content meaningful to students.
- Through their teaching practice, teachers develop students' literacy and numeracy within their subject areas. They are also able to use Information and Communication Technology to contextualise and expand their students' modes and breadth of learning.

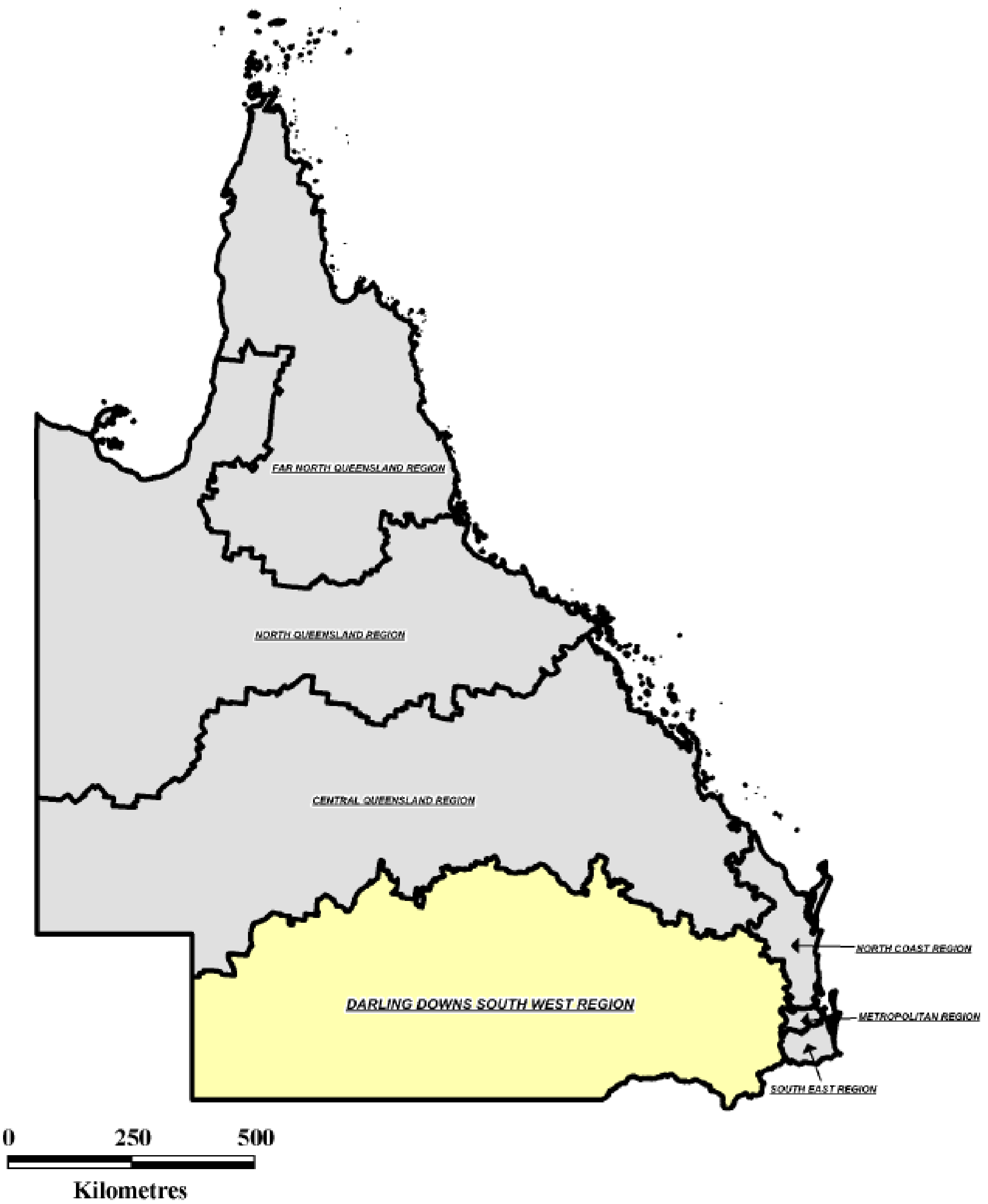
Professional Practice

- Teachers are able to make learning engaging and valued. They are able to create and maintain safe, inclusive and challenging learning environments and implement fair and equitable behaviour management plans. They use sophisticated communication techniques.
- Teachers have a repertoire of effective teaching strategies and use them to implement well-designed teaching programs and lessons. They regularly evaluate all aspects of their teaching practice to ensure they are meeting the learning needs of their students. They interpret and use student assessment data to diagnose barriers to learning and to challenge students to improve their performance.
- They operate effectively at all stages of the teaching and learning cycle, including planning for learning and assessment, developing learning programs, teaching, assessing, providing feedback on student learning and reporting to parents/carers.

Professional Engagement

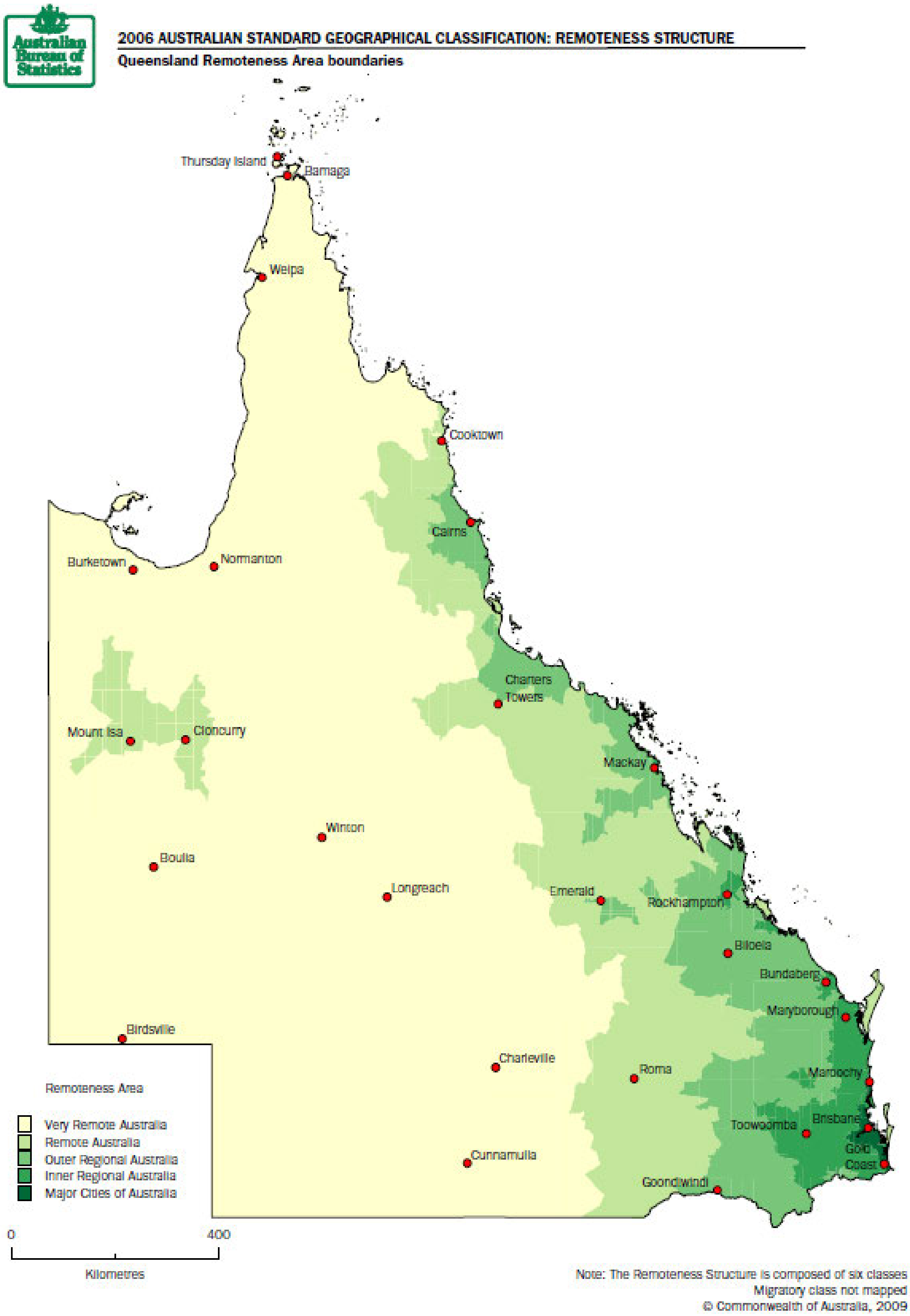
- Teachers model effective learning. They identify their own learning needs and analyse, evaluate and expand their professional learning, both collegially and individually.
- Teachers demonstrate respect and professionalism in all their interactions with students, colleagues, parents/carers and the community. They are sensitive to the needs of parents/carers and can communicate effectively with them about their children's learning.
- Teachers value opportunities to engage with their school communities within and beyond the classroom to enrich the educational context for students. They understand the links between school, home and community in the social and intellectual development of their students.

## Appendix 2 Education Queensland School Regions




Source https://education.qld.gov.au/contact/Documents/qld.pdf

# Appendix 3 Remoteness Area Map Queensland




Source: http://www.tmr.qld.gov.au/~/media/busind/Queensland%20Road%20Freight%20Industry%20Council/QLDRemotenessareamapAtt2.pdf.

# Appendix 4 Ethics Approval

**OFFICE OF RESEARCH**
Human Research Ethics Committee
PHONE +61 7 4631 2690| FAX +61 7 4631 5555
EMAIL ethics@usq.edu.au

UNIVERSITY OF SOUTHERN QUEENSLAND
AUSTRALIA

24 September 2015

Mrs Kay Lembo

Dear Kay

The USQ Human Research Ethics Committee has recently reviewed your responses to the conditions placed upon the ethical approval for the project outlined below. Your proposal is now deemed to meet the requirements of the *National Statement on Ethical Conduct in Human Research (2007)* and full ethical approval has been granted.

| | |
|---|---|
| Approval No. | **H15REA189** |
| Project Title | Effective science professional development for teachers: A case study for Queensland secondary teachers |
| Approval date | 24 September 2015 |
| Expiry date | 24 September 2018 |
| HREC Decision | **Approved** |

The standard conditions of this approval are:

(a) conduct the project strictly in accordance with the proposal submitted and granted ethics approval, including any amendments made to the proposal required by the HREC
(b) advise (email: ethics@usq.edu.au) immediately of any complaints or other issues in relation to the project which may warrant review of the ethical approval of the project
(c) make submission for approval of amendments to the approved project before implementing such changes
(d) provide a 'progress report' for every year of approval
(e) provide a 'final report' when the project is complete
(f) advise in writing if the project has been discontinued.

For (c) to (e) forms are available on the USQ ethics website:
http://www.usq.edu.au/research/ethicsbio/human

Please note that failure to comply with the conditions of approval and the *National Statement (2007)* may result in withdrawal of approval for the project.

You may now commence your project. I wish you all the best for the conduct of theproject.

[redacted]

**Annmaree Jackson**
Ethics Coordinator

University of Southern Queensland
Toowoomba I Springfield I Fraser Coast

usq.edu.au
CRICOS QLD 00244B NSW 02225M
TEQSA PRV12081

# Appendix 5 Teacher Needs Survey

## Effective Science Professional Development for Teachers, Faculty of Health, Engineering & Sciences University of Southern Queensland

Before starting the survey, close down any menu bars or other programs that may be reducing your screen size. You should be able to read the information on the screen without having to scroll from left to right.

This project is being undertaken as part of a PhD study being undertaken by Kay Lembo, PhD student with the Faculty of Health, Engineering and Sciences at the University of Southern Queensland. The purpose of this project seeks to find out what are the professional learning needs for science teachers in Queensland Government schools.

The research team requests your assistance because the information you provide will allow the researcher to comprehensively understand the current professional learning needs, wants and desires of secondary science teachers. The resultant findings can then be used as a foundation for developing a university framework to construct effective, enhanced professional learning experiences.

**Participation**

Your participation will involve completion of a questionnaire that will take approximately 20 minutes, of your time.

The survey contains both fixed response and open-ended questions to identify current teachers' science teaching experience, format and content of professional development accessed and needs for science content learning experiences.

Your participation in this project is entirely voluntary. If you do not wish to take part you are not obliged to. If you decide to take part and later change your mind, you are free to withdraw from the project at any stage. Please note, that if you wish to withdraw from the project after you have submitted your responses, the Research Team are unable to remove your data from the project (unless identifiable information has been collected). If you do wish to withdraw from this project, please contact the Research Team (contact details at the top of this form).

Your decision whether you take part, do not take part, or to take part and then withdraw, will in no way impact your current or future relationship with the University of Southern Queensland.

**Expected Benefit**

It is expected that this project will directly benefit you through the improvement and delivery of professional development experiences that effectively addresses the current learning needs for science teachers in Queensland State Schools.

**Risks**

There are no anticipated risks beyond normal day-to-day living associated with your participation in this project.

**Privacy and Confidentiality**

All comments and responses will be treated confidentially unless required by law.

The names of individual persons are not required in any of the responses for the online survey.

Any data collected as a part of this project will be stored securely as per University of Southern Queensland's Research Data Management policy.

**Consent to Participate**

Clicking on the 'Submit' button at the conclusion of the questionnaire is accepted as an indication of your consent to participate in this project.

**Questions or Further Information about the Project**

Please refer to the Research Team Contact Details at the top of the form to have any questions answered or to request further information about this project.

**Concerns or Complaints Regarding the Conduct of the Project**

If you have any concerns or complaints about the ethical conduct of the project you may contact the University of Southern Queensland Ethics Coordinator on (07) 4631 2690 or email ethics@usq.edu.au. The Ethics Coordinator is not connected with the research project and can facilitate a resolution to your concern in an unbiased manner.

If you have any questions about the study please contact Kay Lembo, Toowoomba on 0407028182 or email kay.lembo@usq.edu.au. For technical concerns or difficulties accessing the survey please contact Ken Askin, University of Southern Queensland, at askin@usq.edu.au.

I declare that I:

- Have read and understood the information document regarding this project.
- Have had any questions answered to your satisfaction.
- Understand that if you have any additional questions you can contact the research team.
- Understand that you are free to withdraw at any time, without comment or penalty.
- Understand that you can contact the University of Southern Queensland Ethics Coordinator on (07) 4631 2690 or email ethics@usq.edu.au if you do have any concern or complaint about the ethical conduct of this project.
- Am over 18 years of age.
- Agree to participate in the project.

☐ **Click here to agree**

**THANK YOU FOR YOUR PARTICIPATION**

To start the survey please click on the 'Next' button below.

# Teacher Profile

**Are you**

- ◯ Male
- ◯ Female

**Please indicate your age range**

- ◯ under 25 years
- ◯ 25 - 30 years
- ◯ 31 - 35 years
- ◯ 36 - 40 years
- ◯ 41 - 45 years
- ◯ 46 - 50 years
- ◯ 51 - 55 years
- ◯ over 55 years

**On what basis are you employed?**

- ◯ Full-time permanent
- ◯ Full-time contract
- ◯ Part-time
- ◯ Other (specify) ________

**How many years have you been teaching?**

- ◯ less than 1 year
- ◯ 1 - 3 years
- ◯ 4 - 6 years
- ◯ 7 - 9 years
- ◯ 10 - 12 years
- ◯ 13 - 15 years
- ◯ 16 - 18 years
- ◯ 19 - 21 years
- ◯ over 22 years

**How long have you been teaching at this school?**

- ◯ less than 1 year
- ◯ 1 - 3 years
- ◯ 4 - 6 years
- ◯ 7 - 9 years
- ◯ 10 - 12 years
- ◯ 13 - 15 years
- ◯ 16 - 18 years
- ◯ 19 - 21 years
- ◯ over 22 years

**For how many years have you been teaching science?**

- ◯ less than 1 year
- ◯ 1 - 3 years
- ◯ 4 - 6 years
- ◯ 7 - 9 years
- ◯ 10 - 12 years
- ◯ 13 - 15 years
- ◯ 16 - 18 years
- ◯ 19 - 21 years
- ◯ over 22 years

# Teacher Profile

**What best describes your highest academic qualifications?**

- ○ 3 year Diploma in Teaching or similar
- ○ 3 or 4 year Bachelor of Education
- ○ 3 or 4 year Bachelor degree AND a postgraduate Diploma of Teaching
- ○ 3 or 4 year Bachelor degree AND 3 or 4 year Bachelor of Education or similar
- ○ Postgraduate degree (ie Masters or PhD) AND postgraduate teaching qualifications
- ○ Postgraduate degree (ie Masters or PhD) without teaching qualifications
- ○ Other (specify) ______

**Do you have an undergraduate science degree?**

- ○ Yes (specify) ______
- ○ No

**What science subjects would you be confident to teach?**

- ☐ Junior Science
- ☐ Senior Biology
- ☐ Senior Chemistry
- ☐ Senior Physics
- ☐ Senior Agricultural Science
- ☐ Senior Marine Science
- ☐ Science21
- ☐ Other (specify) ______

**What year levels are you currently teaching science?**

- ☐ Year 7
- ☐ Year 8
- ☐ Year 9
- ☐ Year 10
- ☐ Year 11
- ☐ Year 12

**What is your school education region?**

- ○ South East
- ○ Metropolitan
- ○ North Coast
- ○ Central Queensland
- ○ Darling Downs South West
- ○ North Queensland
- ○ Far North Queensland

**What is the total student enrolment for your school?**

- ○ Fewer than 50
- ○ 50 - 100
- ○ 101 - 250
- ○ 251 - 500
- ○ 501 - 750
- ○ 751 - 1000
- ○ 1001 - 1500
- ○ 1501 - 2000
- ○ Over 2000

# PD

**What does Professional Development (PD) mean to you?**

[ ]

**How many PD opportunities have you attended in the last 12 months?**

- ○ None
- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ 6
- ○ 7
- ○ 8
- ○ 9
- ○ 10
- ○ Over 10

**Have you requested to undertake PD during the last 12 months and been refused?**

- ☐ Yes. Reason allowed [ ]
- ☐ No. Reason refused [ ]
- ☐ Never requested

**Indicate what you consider to be the top five (5) factors that ENCOURAGED you to undertake PD over the last 12 months?**

- ☐ Cost (Monetary) of attendance
- ☐ Availability/cost of teacher replacement
- ☐ Initiative/Motivation
- ☐ Time involved to attend
- ☐ Volume of work required
- ☐ Location of PD
- ☐ Content relevance
- ☐ Awareness of occurrence
- ☐ Management/Admin
- ☐ Family issues
- ☐ Time to integrate/implement new knowledge
- ☐ Lack of remuneration
- ☐ Timing of PD
- ☐ Other [ ]

**Indicate what you consider to be the top five (5) factors that HINDERED you undertaking PD over the last 12 months?**

- ☐ Cost (Monetary) of attendance
- ☐ Availability/cost of teacher replacement
- ☐ Initiative/Motivation
- ☐ Time involved to attend
- ☐ Volume of work required
- ☐ Location of PD
- ☐ Content relevance
- ☐ Unaware of occurrence
- ☐ Management/Admin
- ☐ Family issues
- ☐ Time to integrate/implement new knowledge
- ☐ Lack of remuneration
- ☐ Timing of PD
- ☐ Other [ ]

# Formal PD 1 Undertaken

The following questions requires you to reflect about ONE specific professional development (PD) opportunity in the last 12 months?

**What was the duration of the PD?**

[ ] hours

**What was the general topic involved?**

- ☐ Pedagogical
- ☐ Subject Area Specific
- ☐ Administrative
- ☐ Student focussed
- ☐ Other (specify) [ ]

**What was the requirement of the PD?**

- ○ Voluntary
- ○ Mandated

**Who organised the PD?**

- ○ Principal/Admin
- ○ Faculty staff eg HoD
- ○ Yourself
- ○ Other (specify) [ ]

**Who conducted the PD?**

- ○ School staff
- ○ QCAA
- ○ DET District Office
- ○ Other DET employee
- ○ Private Provider (specify) [ ]

**When was the PD held?**

- ○ In school time (8.30 - 3.30)
- ○ After school hours (directly before or after)
- ○ Student Free Day
- ○ Weekend/Evening
- ○ Vacation

**How would you describe its main format?**

- ○ Online Seminar
- ○ Face-to-face Seminar (Information transmission)
- ○ Face-to face Workshop (Interactive)
- ○ Other (specify) [ ]

**How would you rate its usefulness for increasing your Content Knowledge?**

○ Very Good ○ Good ○ Unsure ○ Poor ○ Very Poor

**How would you rate its usefulness to your teaching and/or classroom practice?**

○ Very Good ○ Good ○ Unsure ○ Poor ○ Very Poor

# Formal PD 2 Undertaken

The following questions requires you to reflect about a SECOND specific professional development (PD) opportunity in the last 12 months?

**What was the duration of this PD?**

[ ] hours

**What was the general topic involved?**

- [ ] Pedagogical
- [ ] Subject Area Specific
- [ ] Administrative
- [ ] Student focussed
- [ ] Other (specify) [ ]

**What was the requirement of the PD?**

- ○ Voluntary
- ○ Mandated

**Who organised the PD?**

- [ ] Principal/Admin
- [ ] Faculty staff eg HoD
- [ ] Yourself
- [ ] Other (specify) [ ]

**Who conducted the PD?**

- ○ School staff
- ○ QCAA
- ○ DET District Office
- ○ Other DET employee
- ○ Private Provider (specify) [ ]

**When was the PD held?**

- ○ In school time (8.30 - 3.30)
- ○ After school hours (directly before or after)
- ○ Weekend/Evening
- ○ Vacation time
- ○ Student Free Day

**How would you describe its main format?**

- ○ Online Seminar
- ○ Face-to-face Seminar (Information transmission)
- ○ Face-to-faceWorkshop (Interactive)
- ○ Other (specify) [ ]

**How would you rate its usefulness to your teaching and/or classroom practice?**

○ Very Good ○ Good ○ Unsure ○ Poor ○ Very Poor

**How would you rate its usefulness for increasing your content knowledge?**

○ Very Good ○ Good ○ Unsure ○ Poor ○ Very Poor

# Informal Professional Learning

Other than formal professional development opportunities you have undertaken (over the last 12 months), please indicate your use of any of the following INFORMAL professional learning tools. For each, you will be asked to indicate how frequently you access science information/knowledge from the following sources.

**Scientific journals (print)**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Scientific journals (online)**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Science textbooks**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Television programs**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Videos, CDs, DVDs**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Online content (podcasts, blogs, clickview etc.)**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Scientific Organisations website (CSIRO, NASA etc.)**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Professional Education organisations (ASTA, STAQ, etc.)**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Social media (YouTube, Facebook, TED talks)**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Conferences**

○ Daily ○ Weekly ○ Fortnightly ○ Monthly ○ Occasionally ○ Never

**Science teachers in your school**

| | | | | | |
|---|---|---|---|---|---|
| ◯ Daily | ◯ Weekly | ◯ Fortnightly | ◯ Monthly | ◯ Occasionally | ◯ Never |

**Science teachers in other schools**

| | | | | | |
|---|---|---|---|---|---|
| ◯ Daily | ◯ Weekly | ◯ Fortnightly | ◯ Monthly | ◯ Occasionally | ◯ Never |

**Undertaking formal tertiary study**

| | | | | | |
|---|---|---|---|---|---|
| ◯ Daily | ◯ Weekly | ◯ Fortnightly | ◯ Monthly | ◯ Occasionally | ◯ Never |

**Other (specify) If not applicable type NIL**

Type

Frequency

# Confidence to Teach Curriculum Content Knowledge and Understanding

Indicate your level of CONFIDENCE to teach the relevant science content concept.

| **BIOLOGICAL SCIENCES** | Not Confident | Low | Moderate | High | Very Confident |
|---|---|---|---|---|---|
| Classification system | ◯ | ◯ | ◯ | ◯ | ◯ |
| Plants, animals and micro-organisms | ◯ | ◯ | ◯ | ◯ | ◯ |
| Food chains and webs | ◯ | ◯ | ◯ | ◯ | ◯ |
| Cell structure and function | ◯ | ◯ | ◯ | ◯ | ◯ |
| Organs and systems | ◯ | ◯ | ◯ | ◯ | ◯ |
| Enzymes | ◯ | ◯ | ◯ | ◯ | ◯ |
| Reproduction | ◯ | ◯ | ◯ | ◯ | ◯ |
| Multicellular organisms and homeostasis | ◯ | ◯ | ◯ | ◯ | ◯ |
| Disease | ◯ | ◯ | ◯ | ◯ | ◯ |
| Ecosystems and communities | ◯ | ◯ | ◯ | ◯ | ◯ |
| Heredity, genetics and DNA | ◯ | ◯ | ◯ | ◯ | ◯ |
| Evolution and natural selection | ◯ | ◯ | ◯ | ◯ | ◯ |

## Confidence to Teach Curriculum Content Knowledge and Understanding

Indicate your level of CONFIDENCE to teach the relevant science content concept.

| CHEMICAL SCIENCES | Not Confident | Low | Moderate | High | Very Confident |
|---|---|---|---|---|---|
| Mixtures and Solutions | ○ | ○ | ○ | ○ | ○ |
| States of matter | ○ | ○ | ○ | ○ | ○ |
| Elements, compounds and mixtures | ○ | ○ | ○ | ○ | ○ |
| Chemical changes | ○ | ○ | ○ | ○ | ○ |
| Atomic structure | ○ | ○ | ○ | ○ | ○ |
| Law of Conservation | ○ | ○ | ○ | ○ | ○ |
| Chemical reactions | ○ | ○ | ○ | ○ | ○ |
| Combustion | ○ | ○ | ○ | ○ | ○ |
| Acid and Bases | ○ | ○ | ○ | ○ | ○ |
| Energy transfer: wave and particle model | ○ | ○ | ○ | ○ | ○ |
| Periodic table | ○ | ○ | ○ | ○ | ○ |
| Rates of reaction | ○ | ○ | ○ | ○ | ○ |

## Confidence to Teach Curriculum Content Knowledge and Understanding 2

Indicate your level of CONFIDENCE to teach the relevant science content concept.

| PHYSICAL SCIENCES | Not Confident | Low | Moderate | High | Very Confident |
|---|---|---|---|---|---|
| Force and motion | ○ | ○ | ○ | ○ | ○ |
| Gravity | ○ | ○ | ○ | ○ | ○ |
| Types of Energy ie kinetic, potential, heat, | ○ | ○ | ○ | ○ | ○ |
| Sources of Energy | ○ | ○ | ○ | ○ | ○ |
| Energy transfers and transformations | ○ | ○ | ○ | ○ | ○ |
| Energy conservation | ○ | ○ | ○ | ○ | ○ |
| Motion and Energy | ○ | ○ | ○ | ○ | ○ |
| Alternative way of obtaining energy | ○ | ○ | ○ | ○ | ○ |

## Confidence to Teach Curriculum Content Knowledge and Understanding 3

Indicate your level of CONFIDENCE to teach the relevant science content concept.

| EARTH AND SPACE SCIENCES | Not confident | Low | Moderate | High | Very confident |
|---|---|---|---|---|---|
| Earth and Seasons | ○ | ○ | ○ | ○ | ○ |
| Renewable and Non-renewable resources | ○ | ○ | ○ | ○ | ○ |
| Water cycle | ○ | ○ | ○ | ○ | ○ |
| Rock types and identification | ○ | ○ | ○ | ○ | ○ |
| Rock cycle | ○ | ○ | ○ | ○ | ○ |
| Plate tectonics | ○ | ○ | ○ | ○ | ○ |
| Astronomy and Origin of Universe | ○ | ○ | ○ | ○ | ○ |
| Earth systems and cycles | ○ | ○ | ○ | ○ | ○ |
| Solar system | ○ | ○ | ○ | ○ | ○ |

## Confidence to Teach Curriculum Content Knowledge and Understanding 4

Indicate your level of CONFIDENCE to teach the relevant science content concept.

| SCIENCE INQUIRY AND HUMAN ENDEAVOUR | Not Confident | Low | Moderate | High | Very Confident |
|---|---|---|---|---|---|
| Human influences and practice in science | ○ | ○ | ○ | ○ | ○ |
| Scientific models and theory | ○ | ○ | ○ | ○ | ○ |
| Advances in Science and Technology | ○ | ○ | ○ | ○ | ○ |
| Scientific methodology | ○ | ○ | ○ | ○ | ○ |
| Planning and conducting investigations | ○ | ○ | ○ | ○ | ○ |
| Data analysis and evaluation | ○ | ○ | ○ | ○ | ○ |
| Science communication and writing | ○ | ○ | ○ | ○ | ○ |

## Interest in Curriculum Content Professional Development

Indicate your DESIRE for professional development (formal or informal) to enhance your knowledge/understanding in the specific content area.

| BIOLOGICAL SCIENCES | No Interest | Low | Moderate | High | Very Interested |
|---|---|---|---|---|---|
| Classification system | ○ | ○ | ○ | ○ | ○ |
| Plants, Animals and micro-organisms | ○ | ○ | ○ | ○ | ○ |
| Food chains and webs | ○ | ○ | ○ | ○ | ○ |
| Cell structure and function | ○ | ○ | ○ | ○ | ○ |
| Organs and systems | ○ | ○ | ○ | ○ | ○ |
| Enzymes | ○ | ○ | ○ | ○ | ○ |
| Reproduction | ○ | ○ | ○ | ○ | ○ |
| Multicellular organisms and homeostasis | ○ | ○ | ○ | ○ | ○ |
| Disease | ○ | ○ | ○ | ○ | ○ |
| Ecosystems and communities | ○ | ○ | ○ | ○ | ○ |
| Heredity, genetics and DNA | ○ | ○ | ○ | ○ | ○ |
| Evolution and natural selection | ○ | ○ | ○ | ○ | ○ |

## Interest in Curriculum Content Professional Development

Indicate your DESIRE for professional development (formal or informal) to enhance your knowledge/understanding in the specific content area.

| CHEMICAL SCIENCES | No Interest | Low | Moderate | High | Very Interested |
|---|---|---|---|---|---|
| Mixtures and Solutions | ○ | ○ | ○ | ○ | ○ |
| States of matter | ○ | ○ | ○ | ○ | ○ |
| Elements, compounds and mixtures | ○ | ○ | ○ | ○ | ○ |
| Chemical changes | ○ | ○ | ○ | ○ | ○ |
| Atomic structure | ○ | ○ | ○ | ○ | ○ |
| Law of Conservation | ○ | ○ | ○ | ○ | ○ |
| Chemical reactions | ○ | ○ | ○ | ○ | ○ |
| Combustion | ○ | ○ | ○ | ○ | ○ |
| Acid and Bases | ○ | ○ | ○ | ○ | ○ |
| Energy transfer: wave and particle model | ○ | ○ | ○ | ○ | ○ |
| Periodic table | ○ | ○ | ○ | ○ | ○ |
| Rates of reaction | ○ | ○ | ○ | ○ | ○ |

## Interest in Curriculum Content Professional Development 3

Indicate your DESIRE for professional development (formal or informal) to enhance your knowledge/understanding in the specific content area.

| EARTH AND SPACE SCIENCES | No Interest | Low | Moderate | High | Very Interested |
|---|---|---|---|---|---|
| Earth and Seasons | | | | | |
| Renewable and Non-renewable resources | | | | | |
| Water cycle | | | | | |
| Rock types and identification | | | | | |
| Rock cycle | | | | | |
| Plate tectonics | | | | | |
| Astronomy and Origin of Universe | | | | | |
| Earth systems and cycles | | | | | |
| Solar system | | | | | |

## Interest in Curriculum Content Professional Development

Indicate your DESIRE for professional development (formal or informal) to enhance your knowledge/understanding in the specific content area.

| PHYSICAL SCIENCES | No Interest | Low | Moderate | High | Very Interested |
|---|---|---|---|---|---|
| Force and motion | | | | | |
| Gravity | | | | | |
| Types of Energy ie kinetic, potential, heat, | | | | | |
| Sources of Energy | | | | | |
| Energy transfers and transformations | | | | | |
| Energy conservation | | | | | |
| Motion and Energy | | | | | |
| Alternative way of obtaining energy | | | | | |

## Interest in Curriculum Content Professional Development

Indicate your DESIRE for professional development (formal or informal) to enhance your knowledge/understanding in the specific content area.

| SCIENCE INQUIRY AND HUMAN ENDEAVOUR | No Interest | Low | Moderate | High | Very Interested |
|---|---|---|---|---|---|
| Human influences and practice in science | ○ | ○ | ○ | ○ | ○ |
| Scientific models and theory | ○ | ○ | ○ | ○ | ○ |
| Advances in Science and technology | ○ | ○ | ○ | ○ | ○ |
| Scientific methodology | ○ | ○ | ○ | ○ | ○ |
| Planning and conducting investigations | ○ | ○ | ○ | ○ | ○ |
| Data analysis and evaluation | ○ | ○ | ○ | ○ | ○ |
| Science communication and writing | ○ | ○ | ○ | ○ | ○ |

# Appendix 6 Views of Nature of Science Questionnaire

*VNOS–Form C*

1. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?

2. What is an experiment?

3. Does the development of scientific knowledge **require** experiments?
   - If yes, explain why. Give an example to defend your position.
   - If no, explain why. Give an example to defend your position.

4. After scientists have developed a scientific theory (e.g., atomic theory, evolution theory), does the theory ever change?
   - If you believe that scientific theories do not change, explain why. Defend your answer with examples.
   - If you believe that scientific theories do change: (a) Explain why theories change? (b) Explain why we bother to learn scientific theories? Defend your answer with examples.

5. Is there a difference between a scientific theory and a scientific law? Illustrate your answer with an example.

6. Science textbooks often represent the atom as a central nucleus composed of protons (positively charged particles) and neutrons (neutral particles) with electrons (negatively charged particles) orbiting that nucleus. How certain are scientists about the structure of the atom? What specific evidence **do you think** scientists used to determine what an atom looks like?

7. Science textbooks often define a species as a group of organisms that share similar characteristics and can interbreed with one another to produce fertile offspring. How certain are scientists about their characterization of what a species is? What specific evidence **do you think** scientists used to determine what a species is?

8. It is believed that about 65 million years ago the dinosaurs became extinct. Of the hypotheses formulated by scientists to explain the extinction, two enjoy wide support. The first, formulated by one group of scientists, suggests that a huge meteorite hit the earth 65 million years ago and led to a series of events that caused the extinction. The second hypothesis, formulated by another group of scientists, suggests that massive and violent volcanic eruptions were responsible for the extinction. How are these **different conclusions** possible if scientists in both groups have access to and use the **same set of data** to derive their conclusions?

9. Some claim that science is infused with social and cultural values. That is, science reflects the social and political values, philosophical assumptions, and intellectual norms of the culture in which it is practiced. Others claim that science is universal. That is, science transcends national and cultural boundaries and is not affected by social, political, and philosophical values, and intellectual norms of the culture in which it is practiced.
   - If you believe that science reflects social and cultural values, explain why. Defend your answer with examples.
   - If you believe that science is universal, explain why. Defend your answer with examples.

10. Scientists perform experiments/investigations when trying to find answers to the questions they put forth. Do scientists use their creativity and imagination during their investigations?
    - If yes, then at which stages of the investigations you believe scientists use their imagination and creativity: planning and design, data collection, after data collection? Please explain why scientists use imagination and creativity. Provide examples if appropriate.
    - If you believe that scientists do not use imagination and creativity, please explain why. Provide examples if appropriate.

## Appendix 7 Intent to Integrate NOS Questionnaire

**What is nature of science?** Nature of science refers to the characteristics of scientific knowledge and describes science as a way of knowing about the natural world. Nature of science includes aspects of the history and philosophy of science.

Items related to Intention:

| Considering your own teaching, to what extent do you agree with the following statements? | Strongly Disagree 1 | 2 | 3 | 4 | 5 | 6 | Strongly Agree 7 |
|---|---|---|---|---|---|---|---|
| I will try to integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I plan to integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I intend to integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to Attitude:

| For me, to integrate nature of science into science instruction is ... | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 7 | 6 | 5 | 4 | 3 | 2 | 1 | |
| Useful | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Useless |
| Important | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Unimportant |
| Valuable | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Worthless |
| Correct | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Incorrect |
| Reasonable | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | Unreasonable |
| Worthwhile | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | A waste of time |

Items related to behavioural belief strength:

| If I integrate nature of science into science instruction: | 1 Strongly Disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly Agree |
|---|---|---|---|---|---|---|---|
| Students easily understand science topics | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students understand the interaction among science, technology, society, and environment better | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students are raised as critical thinkers | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students differentiate science (physics, chemistry, biology) from other disciplines (e.g., history, philosophy) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students distinguish between science and pseudoscience (e.g., astrology, acupuncture) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students realize that science is part of everyday life | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students' misconceptions related to nature of science are eliminated | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students realize that scientists are not different from other people | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Students start to critically evaluate scientific news in the media | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I become professionally developed | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to outcome evaluation:

| How important to you are the following situations? | 1 Not important at all | 2 | 3 | 4 | 5 | 6 | 7 Very important |
|---|---|---|---|---|---|---|---|
| That students easily understand science topics | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| That students understand the interaction among science, technology, society, and environment better | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Development of students as critical thinkers | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| That students differentiate science (physics, chemistry, biology) from other disciplines (e.g., history, philosophy) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| That students distinguish between science and pseudoscience (e.g., astrology, acupuncture) | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| That students realize that science is part of everyday life | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Eliminating students' misconceptions related to nature of science | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| That students realize scientists are not different from other people | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| That students start to critically evaluate scientific news in the media | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Developing myself professionally | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to subjective norm:

| To what extent do you agree with the following statements? | 1 Strongly Disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly Agree |
|---|---|---|---|---|---|---|---|
| People/Institutions whose opinions I value expect me to integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Most of the people/institutions that I think to be important to my teaching career expect me to integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Most people who are important to me will be disappointed if I do not integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to normative belief strength:

| The following people/institution expect me to integrate nature of science into science instruction: | 1 Strongly Disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly Agree |
|---|---|---|---|---|---|---|---|
| Department of Education | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Faculty members | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| School administrators | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| Science teachers | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to perceived behavioural control:

| To what extent do you agree with the following statements? | 1 Strongly Disagree | 2 | 3 | 4 | 5 | 6 | 7 Strongly Agree |
|---|---|---|---|---|---|---|---|
| For me to integrate nature of science into science instruction is possible | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| For me to integrate nature of science into science instruction is easy | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| To integrate nature of science into science instruction is up to me | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I can overcome any problems that could prevent me from integrating nature of science into science instruction if I want to | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to control belief strength:

| During your in-service teaching career, to what extent do you expect the following factors will be present? | Not possible at all 1 | 2 | 3 | 4 | 5 | 6 | Certainly possible 7 |
|---|---|---|---|---|---|---|---|
| I will have sufficient knowledge of nature of science | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I will have experience for integrating nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I will be sufficient in integrating nature of science in science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| I will be able to use appropriate teaching strategies to effectively integrate nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

Items related to power of control factor:

| **The presence of the following factors will facilitate integrating nature of science into science instruction:** | Strongly Disagree 1 | 2 | 3 | 4 | 5 | 6 | Strongly Agree 7 |
|---|---|---|---|---|---|---|---|
| My having sufficient knowledge of nature of science | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| My having experience for integrating nature of science into science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| My being sufficient in integrating nature of science in science instruction | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |
| My ability to use appropriate teaching strategies to effectively integrate nature of science | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ | ☐ |

## Appendix 8 Enzyme Immobilisation Experiment

Effect of Lactase on Lactose Concentration in Milk

Teacher Background

Sodium alginate is derived from seaweed and is a commonly used as a food thickener and is a popular "molecular gastronomy" ingredient. Alginate is a polymer which is exacted from the cell walls of brown algae, that when added to water, forms a viscous substrate known as a hydrocolloid. A hydrocolloid can simply be defined as a substance that forms a gel in contact with water. Such substances include both polysaccharides and proteins which are capable of: thickening and gelling aqueous solutions, stabilizing foams, emulsions, and dispersions and preventing crystallization of saturated water or sugar solutions.

The formation of the 'spheres' in this experiment is due to the reaction between sodium alginate and the calcium ions in the calcium chloride. Sodium alginate is a salt containing polysaccharide (a long chain of sugar molecules) and has a negative charge when dissolved in water. When it meets the positively charged calcium ion, it immediately forms a gel as the calcium ions bind the alginate chains together tightly. The outside layer can become firm enough to hold the droplet's shape, as well as acting as a barrier to keep additional calcium away from the liquid at the centre of the sphere. At this stage of formation is often referred

TEACHER'S NOTES

Preparation time required: 30 minutes

Lesson time required: 40 minutes

- 1% = 1g/100ml, w/v
- Use distilled or deionised water to make up solutions
- When preparing sodium alginate solution, use magnetic stirrer and slowly add powder. This will minimise the formation of lumps
- The alginate bead can be refrigerated but will only keep for a few days
- Some UHT milk may test positive for glucose as the heat treatment may hydrolyse some of the lactose.

to ‘sodium alginate caviar’. The spheres can completely solidify by increasing the exposure time with the calcium ions.

Immobilisation of biological material

Calcium alginate is a widely used medium used for immobilising cells. It is especially suited to living cells as it tends not to damage them. Alginate immobilisation has been used for a wide range of scientific purposes, including cells in bioreactors, entrapment of plant protoplasts and plant embryos (‘artificial seeds’) for micropropagation, immobilisation of hybridomas for the production of monoclonal antibodies, and the entrapment of enzymes and drugs. Refer to table below for detailed applications.

Enzymes

Enzymes are proteins that act as biological catalysts i.e., they increase the rate of the chemical reactions that occur in the cells of living things. There are about 4000 different enzymes in human cells and have varying degrees of specificity.

Some act specifically with only one reactant (called a substrate), while others react with substrates with similar functional groups or side chains. The basic method by which enzymes catalyse chemical reactions begins with the binding of the substrate/s to the active site on the enzyme. The active site is the specific region of the enzyme which combines with the substrate. The binding of the substrate to the enzyme causes changes in the chemical bonds of the substrate. This process facilitates the reactions that lead to the formation of products.

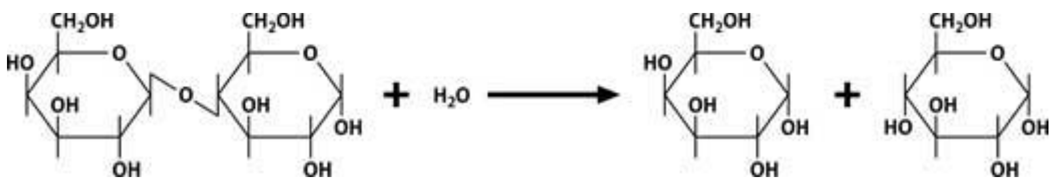
Enzyme action (the ability to speed up a reaction) can be affected by the environmental conditions that surround it. The molecular structure of enzymes are sensitive to pH and temperature. Not surprisingly, most enzymes in humans work best at normal body temperature, around 37$^{o}$C. Enzyme activity can also be affected by the concentration of both enzyme and/or substrate as well as the presence of inhibitors.

| Cells | Product or purpose | Cells | Product or purpose |
|---|---|---|---|
| Bacteria | | Algae | |
| *Erwinia rhapontici* | Isomaltulose | *Botryococcus braunii* | Hydrocarbons |
| *Pseudomonas denitrificans* | Cleaning of drinking water | Plant cells | |
| *Zymomonas mobilis* | Ethanol | *Chatharanthus roseus* | Alkaloids for cancer therapy |
| Cyanobacteria | | Various species | Artificial seeds |
| *Anabena* sp. | Ammonia | Plant protoplasts | Cell handling, microscopy |
| Fungi | | Mammalian cells | |
| *Kluyveromyces bulgaricus* | Hydrolysis of lactose | Hybridomas | Monoclonal antibodies |
| *Saccharomyces cerevisiae* | Ethanol | Islets of Langerhans | Insulin/implantation |
| *Saccharomyces bajanus* | Champagne production | Fibroblasts or lymphomas | Interferons (α or β) |

Source: NCBE- Immobilised Yeast

This experiment involves using the enzyme 'lactase' which is involved in the biochemical reaction that hydrolyses lactose, a sugar in milk and milk products. Lactase (beta-galactosidase) catalyses the hydrolysis of lactose to glucose and galactose:

Lactose → D-glucose + beta-D-galactose




Both of these sugars taste sweeter and are more readily digestible than lactose.

Additional Resources:

Anwar, A., Ul Qader,S.A., Raiz, A., Iqbal, S. & Azhar, A., 2009, Calcium Alginate: a Support Material for Immobilisation of Proteases from newly isolated strains of Baccillus subtilise KIBGE_HAS, World Applied Sciences Journal7 (10): 1281-1286

CurioCity 'Custom Caviar', www.explorecuriocity.org/content.aspx?contentid=1644

Knorr, D & Sinskey A.J (1985) *Biotechnology in Food Production and Processing*, Science, 20 September, pp1224-1229

Lersch, M. (2007) *First experiments with sodium alginate*, Kyymos, http://blog.khymos.org/2007/03/30/first-experiments-with-sodium-alginate/

Madden, D. (2007) "Better milk for cats", NCBE, www.eurovolvox.org/Protocols/catmilk.html

Video clip: *Lactose Digestion in Infants*, Howard Hughes Medical Institute 2011 Holiday Lecture; http://www.hhmi.org/biointeractive/evolution/lactose_digestion.html

7 Tips for Making Spherification Caviar :Molecular Recipes -

http://www.molecularrecipes.com/spherification/7-tips-making-spherification-caviar/

Materials:

You will need the following for each group of students:

- Small piece of nylon gauze
- 10ml plastic syringe (without needle)
- 4mm plastic tubing to fit syringe nozzle (approx. 7cm)
- Tube clamp for plastic tubing
- Retort stand and clamp
- 3 x 250ml beaker
- 2 x 50 ml beaker
- 10ml measuring cylinder
- 100ml measuring cylinder
- Strainer (fine)
- 6 x Glucose test strips
- Glass Stirring rod
- Lactase enzyme - Commercial preparation "Lacteeze"
- 100ml Milk
- 20ml sodium alginate solution (2%)
- 150ml calcium chloride solution (1.5%)
- Distilled water

Procedure:

**1.** Make 20ml of a 2% solution of sodium alginate by slowly adding 0.4 g sodium alginate to 20ml of warm distilled water.

**2.** Pour 10ml of the 2% sodium alginate into a beaker using a 10ml syringe.

**3.** Add 8 drops of the lactase solution 'Lacteeze' into the sodium alginate solution.

**4.** Mix well and then draw all the solution (10ml) back into the syringe.

**5.** Using a measuring cylinder, add 100ml of 1.5% calcium chloride to a clean 250ml beaker.

**6.** Holding the syringe above the beaker containing the calcium chloride, add the alginate-enzyme mixture 1 drop at a time until the syringe is empty.

**7.** Allow the beads that form to harden (approx. 2 minutes).

**8.** Attach a short plastic tube to the end of the syringe.

**9.** Remove the barrel of the syringe and place a a nylon gauze disc into the syringe (this will prevent the bead blocking the nozzle) – do not re-place the barrel.

**10.** Clamp the syringe in the retort stand and attach the tube clip.

**11.** Pour the calcium chloride solution containing the beads through the strainer.

**12.** Carefully add the beads to the syringe.

**13.** Place about 10ml milk into a 50 ml beaker – test for glucose using the glucose test strips.

**14.** Record the colour of the glucose stick and the concentration of glucose (as per the code).

**15.** Place the milk into the syringe and then place the beaker under the tubing.

**16.** Open the clip and allow the milk to run through.

**17.** Collect the milk and test again for glucose – recording colour and con-centration.

**18.** Repeat steps 14-16 four more times. You should now have 6 glucose readings.

Results:

Tabulate and graph your results:

| **Reading** | **Glucose strip colour** | **Glucose level** |
|---|---|---|
| **Initial** | | |
| **1st** | | |
| **2nd** | | |
| **3rd** | | |
| **4th** | | |
| **5th** | | |

Explain your results.

Some people may not produce enough lactase and therefore have trouble digesting the milk sugar lactose and are said to have “lactase deficiency” and are referred to be “lactose intolerant.”

This can happen naturally as people get older, (only one-third of all people retaining the ability to digest lactose into adulthood) and is often an inherited trait.

The exact number of people with lactose intolerance in Australia is not known but certain cultures are more affected by it, including Aborigines, Maoris, South East Asians and some people of Mediterranean descent, according to a CSIRO report, *Lactose: A Review of Intakes and of Importance to Health of Australians and New Zealanders,* 1994.

1. What are the common symptoms of the disease in humans?
2. The process used in this practical is a commercial process called ‘enzyme immobilisation’ and is used to produce lactose free milk for cats and marsupials as well as human food products.
3. What are the outcomes if kittens or marsupials are fed ‘normal’ milk in significant amounts?
4. For the following enzymes, state where they are found, what substrate they hydrolysis and at what pH do they operate.

| Enzyme | pH | Substrate | Where found |
|---|---|---|---|
| Lactase | | | |
| Catalase | | | |
| Amylase | | | |
| Trypsin | | | |
| Pepsin | | | |
| Cellulose | | | |

# Appendix 9 Photosynthesis Experiment

Leaf Disc Assay: Photosynthesis and Light Intensity

Teacher Background

Photosynthesis is a series of chemical reactions that take place in some cells within plant leaves. Plants are autotrophic organisms that are able to use carbon from the atmosphere to produce key organic molecules, particularly molecules that are utilised as energy sources. Photosynthesis is a 'building' or 'anabolic' set of reactions, this means that plant cells are able to produce complex molecules from simple ingredients. The reactions for photosynthesis take place in chloroplasts in leaf cells. These organelles contain a number of pigments (coloured compounds) that are able to 'capture' energy from sunlight to generate energy and then utilise the energy to produce carbon containing compounds.

Simplified reaction for photosynthesis

$6\ CO_2 + 12\ H_2O$ + energy (solar) $\rightarrow$
$C_6H_{12}O_6 + 6H_2O + 6O_2$

The supply of energy from light is a key driver of photosynthesis and thus can affect the rate (or speed) of the reactions. Light wavelength and light intensity both affect how plant pigments absorb and process light. Wavelengths less than 400nm and

TEACHER'S NOTES

Preparation time required: 30 minutes

Lesson time required: 45 minutes

- Liquid Soap is added to the sodium bicarbonate solution to wet the hydrophobic surface of the leaf allowing the solution to be drawn into the leaf
- If leaf discs are difficult to sink, add a little more soap
- If a light source with adjustable brightness isn't available, then sunlight, artificial light and cupboard can be substituted
- A small section of plastic straw can be substituted for a hole punch
- Avoid using plants with hairy leaves as infiltration of solution is difficult
- Avoid large veins when punching the leaf discs
- Students may wish to remove leaf discs as they float to the surface, as to avoid possible leaves sinking when solution is agitated

above 700nm are generally not utilised by plants. Optimum light intensity for most plants occurs between 1.200 and 200 lumens.

The biology behind the leaf disc assay

This experiment will be examining the effect of light intensity on the rate of photosynthesis (indirectly) using leaves. It is not by measuring rate of photosynthesis directly as this is a complex process. Indirect measurements will be made based on the following facts:

- Plants utilise gas (carbon dioxide) for photosynthesis – this enters the leaf via the stomata (in solution).
- One of the products of photosynthesis is oxygen. As it is produced oxygen is released into the air spaces within the leaf from the cells. Eventually it is released back to the atmosphere via the stomata on the surface of the leaves.

In this practical, all the carbon dioxide and oxygen is removed from the leaf, as the leaf discs float, normally. However, when the air spaces are infiltrated with the sodium bicarbonate solution, the overall density of the leaf disc *increases and the disc sinks. The bicarbonate ion serves as the carbon source for* photosynthesis.

$$2NaHCO_3 \rightarrow Na_2CO_3 + H_2O + CO_2$$

As photosynthesis proceeds oxygen is released into the interior of the leaf which changes the leaf buoyancy, which in turn causes the discs to rise. Since cellular respiration is taking place at the same time, consuming oxygen, the rate that the discs rise is an indirect measurement of the net rate of photosynthesis.

Additional Resources:

Carolina 'Leaf Disc Assay: Teacher Manual' www.carolina.com/text/teacherresources/instructions/miscbiology/leaf_disc_assay_teacher.pdf

Furbank, B., 2012, *Sunlight shines New Hope on Yields Breakthrough*, GRDC Ground Cover Issue 97, Mar –Apr 2012, Online: www.grdc.com.au/director/events/groundcover?item_id=83354E650815B44249CF9BCFAC2E659E&article_id=C281745A9F935EA03F6BFBBC5C4CB15C

ksbioteacher, *Sinking Leaf Disks*, 2012, video demonstration of the infiltration technique: http://video.google.com/videoplay?docid=-5132122273591816972&hl=en#

Williamson B., *The Floating Disc Assay for Investigating Photosynthesis,* Exploring Life Community, www.elbiology.com/labtools/Leafdisk.html

Materials:

You will need the following for each group of students:

- Spinach leaves
- 60 mL plastic syringe (without needle)
- Hole punch or a plastic straw
- Microscope light source with variable control
- 500 mL 0.2% sodium bicarbonate solution + 2 drops liquid soap
- 50 mL beaker
- 2 x small clear plastic cups
- Timer/stopwatch
- Distilled water

Procedure:

1. Using the hole punch, cut out at least 10 discs from your leaf, do not punch out areas that contain major veins.
2. Remove the plunger from your plastic syringe.
3. Select 10 discs from the ones that you have cut and carefully place them into the syringe barrel.

4. Replace the plunger into the barrel and gently push down until only a small amount of air remains with the discs – do not crush the discs.
5. Pour a small amount of the sodium bicarbonate solution (30 mL) into the beaker.
6. Place the syringe into the beaker and draw up around 10-15 mL into the syringe.
7. Tap the syringe to make sure that the discs are suspended in the solution.
8. Place your finger over the tip of the syringe and gently draw back to form a vacuum. Hold the vacuum for 10 seconds, gently swirling the discs to keep them in solution.
9. Release the vacuum by removing your finger. Check to see if the discs are still floating.
10. Repeat the action if discs are floating; you made need to do this 2-3 times. Do not repeat again as it might damage the plant tissue.
11. When the discs have sunk to the bottom you are ready to continue.
12. Take a plastic cup and, holding the syringe over the cup, carefully remove the plunger allowing the solution and discs to fall into the cup.
13. Add bicarbonate solution into the cup until it is just below the first line. Make sure that you use the same depth for each run.
14. For a control, infiltrate leaf discs with a solution of only water with a drop of soap, no bicarbonate.
15. Set the microscope light control to your allocated setting. The settings will provide you with varying intensities of light.
16. Set your stopwatch to ‘0’ before you place the cup under the light.
17. Place the cup (containing the leaf discs) under the light source, make sure that the arm of the light source is touching the top of the cup.
18. Record the number of discs that are floating (should be zero but occasionally not all sink).
19. Start your timer/stopwatch.

20. At the end of each minute record the number of floating discs and then gently swirl the discs to dislodge any that are stuck together or on the side of the cup.
21. Continue recording until all discs are floating OR until10 minutes.
22. Repeat the process for other light intensities.
23. Data will be recorded on the board. Calculate the mean for each intensity and graph your results.

Results:

Record your individual group results and then add to the class table on the board (to calculate average).

Individual group results

| **Intensity 1 ________μmol photons/m²/s** | | **Intensity 2 _____________μmol photons/m²/s** | |
|---|---|---|---|
| **Minutes** | # discs floating | Minutes | # discs floating |
| **1** | | 1 | |
| **2** | | 2 | |
| **3** | | 3 | |
| **4** | | 4 | |
| **5** | | 5 | |
| **6** | | 6 | |
| **7** | | 7 | |
| **8** | | 8 | |
| **9** | | 9 | |
| **10** | | 10 | |

Class results

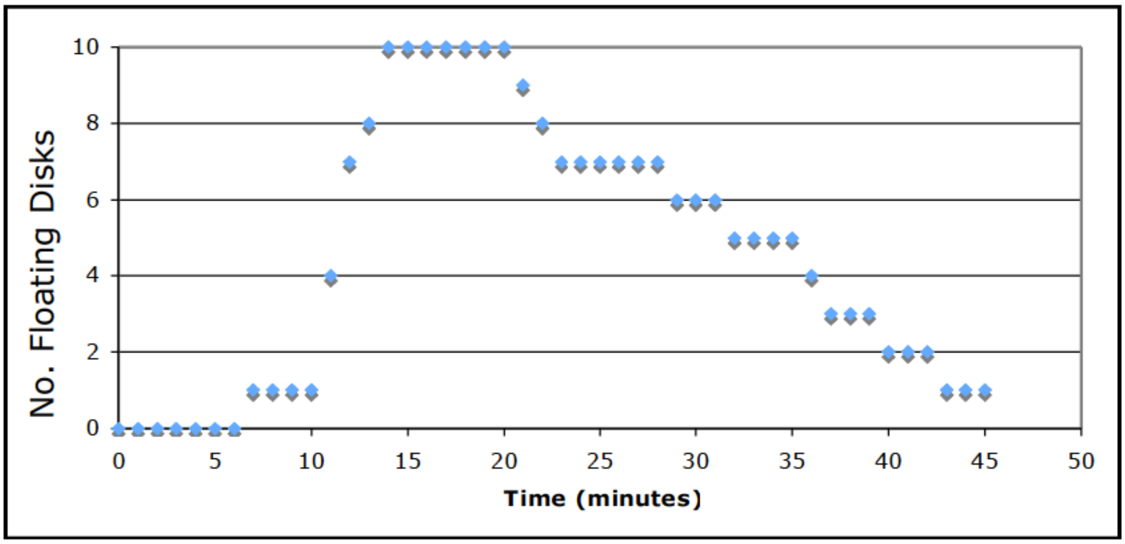
| | **Intensity** ____ | **Intensity** ____ | **Intensity** ____ | **Intensity**____ |
|---|---|---|---|---|
| **Minutes** | # discs floating | # discs floating | # discs floating | # discs floating |
| **1** | | | | |
| **2** | | | | |
| **3** | | | | |
| **4** | | | | |
| **5** | | | | |
| **6** | | | | |
| **7** | | | | |
| **8** | | | | |
| **9** | | | | |
| **10** | | | | |

| **Setting** | **Approximate light intensity (μmol photons/$m^2$/s)** |
|---|---|
| **3** | 110 |
| **4** | 260 |
| **5** | 600 |
| **6** | 800 |
| **Sunlight (clear day)** | 2000 |
| **Laboratory** | |

Discussion:

1. Is the rate of photosynthesis the same for each level of light intensity?
2. Describe the pattern that you see.
3. What was the role of the sodium bicarbonate in this experiment?
4. If the leaf discs were boiled, what kind of result would you expect? Explain.

5. The same experiment was conducted where 10 leaf discs were placed in a sodium bicarbonate solution and placed in the light. Every minute, the number of floating discs were counted and recorded. After 14 minutes, the leaf discs were moved into the dark and the numbers of floating discs were recorded every minute. Below is a graphical representation of the data.




a. Why did the leaf discs begin to sink after being placed in the dark?

b. What could the rate of leaf discs sinking be correlated to?

c. Using your data, what can you deduce about the intensity of light used to obtain the data in the graph?