

INQUIRY-BASED SCIENCE IN A PRIMARY CLASSROOM: PROFESSIONAL DEVELOPMENT IMPACTING PRACTICE

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Abstract

The critical factor in determining students' interest and motivation to learn science is the quality of the teaching. However, science typically receives very little time in primary classrooms, with teachers often lacking the confidence to engage in inquiry-based learning because they do not have a sound understanding of science or its associated pedagogical approaches. Developing teacher knowledge in this area is a major challenge. Addressing these concerns with didactic “stand and deliver” modes of Professional Development (PD) has been shown to have little relevance or effectiveness, yet is still the predominant approach used by schools and education authorities.

In response to that issue, the constructivist-inspired *Primary Connections* professional learning program applies contemporary theory relating to the characteristics of effective primary science teaching, the changes required for teachers to use those pedagogies, and professional learning strategies that facilitate such change. This study investigated the nature of teachers' engagement with the various elements of the program. Summative assessments of such PD programs have been undertaken previously, however there was an identified need for a detailed view of the changes in teachers' beliefs and practices *during* the intervention.

This research was a case study of a *Primary Connections* implementation. PD workshops were presented to a primary school staff, then two teachers were observed as they worked in tandem to implement related curriculum units with their Year 4/5 classes over a six-month period. Data including interviews, classroom observations and written artefacts were analysed to identify common themes and develop a set of assertions related to how teachers changed their beliefs and practices for teaching science.

When teachers implement *Primary Connections*, their students “are more frequently curious in science and more frequently learn interesting things in science” (Hackling & Prain, 2008). This study has found that teachers who observe such changes in their students consequently change their beliefs and practices about teaching science. They enhance science learning by promoting student autonomy

through open-ended inquiries, and they and their students enhance their scientific literacy by jointly constructing investigations and explaining their findings.

The findings have implications for teachers and for designers of PD programs. Assertions related to teaching science within a pedagogical framework consistent with the *Primary Connections* model are that: (1) promoting student autonomy enhances science learning; (2) student autonomy presents perceived threats to teachers but these are counteracted by enhanced student engagement and learning; (3) the structured constructivism of *Primary Connections* resources provides appropriate scaffolding for teachers and students to transition from didactic to inquiry-based learning modes; and (4) authentic science investigations promote understanding of scientific literacy and the “nature of science”.

The key messages for designers of PD programs are that: (1) effective programs model the pedagogies being promoted; (2) teachers benefit from taking the role of student and engaging in the proposed learning experiences; (3) related curriculum resources foster long-term engagement with new concepts and strategies; (4) change in beliefs and practices occurs *after* teachers implement the program or strategy and see positive outcomes in their students; and (5) implementing this study’s PD model is efficient in terms of resources.

Identified topics for further investigation relate to the role of assessment in providing evidence to support change in teachers’ beliefs and practices, and of teacher reflection in making such change more sustainable.

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List of Abbreviations

ACKiS	Active Construction of Knowledge in Science
CBAM	Concerns-Based Adoption Model
DEST	Department of Education, Science and Training
DETA	Department of Education, Training and the Arts
FL	Fletcher's List
LOTE	Languages Other Than English
NOS	Nature of Science
PCK	Pedagogical Content Knowledge
PD	Professional Development
PISA	Program for International Student Assessment
PSTE	Personal Science Teaching Efficacy
POE	Predict, Observe, Explain
ROSE	Relevance of Science Education
RTOP	Reformed Teaching Observation Protocol
STEBI	Science Teaching Efficacy Belief Instrument
STOE	Science Teaching Outcome Expectancy
TIMSS	Trends in International Mathematics and Science Study

Statement of Original Authorship

The work contained in this thesis has not been previously submitted to meet requirements for an award at this or any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signature:



Date:

07-04-2010

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Chapter 1: Introduction

The importance of teacher quality in improving educational outcomes is supported by a sound body of research (e.g. Darling-Hammond & Youngs, 2002). The centrality of the teacher's role, especially in the context of science teaching, is emphasised in the *Australian School Science Education National Action Plan 2008-2012*: "The teacher is a critical factor in determining students' interest and motivation to learn science because it is the teacher who implements the science curriculum" (Goodrum & Rennie, 2007, p. 18). The developers of Australia's national curriculum support this view of teacher autonomy, stating that "classroom teachers are the people who will decide how best to organise learning for students" (National Curriculum Board, 2009, p. 15).

This study addresses the reform of science teaching in primary schools, in particular, building the capacity of primary teachers in line with contemporary research findings. This chapter begins with the background of the study into implementation of a science curriculum innovation (Section 1.1), followed by a description the context of the study (Section 1.2), its overarching objectives (Section 1.3), and a summary of the significance of this research (Section 1.5). Finally, there is an outline of the remaining chapters of the thesis (Section 1.6).

1.1 BACKGROUND

Engaging and maintaining children's interest in science is of international concern. As in many other countries, the need for reform has been recognised in Australia, where State and Federal education authorities have developed a range of responses. One of these approaches, particularly targeting primary (elementary) schooling, will be outlined in this section.

1.1.1 THE NEED FOR REFORM IN SCIENCE EDUCATION

Inadequate and/or ineffective primary science education could be seen as one of the causes for the consistent decline in science enrolments in senior secondary schooling which is matched by declining tertiary enrolments in science-related courses and, consequently, an increasing shortage of workers with science,

engineering and technology skills (Goodrum & Rennie, 2007). In Australia, the proportion of students leaving school having studied chemistry, physics or biology declined between 1993 and 2003 (DEST, 2006).

A possible reason for this decline is provided by the 2006 Program for International Student Assessment (PISA) which found that more than half the Australian 15-year-olds surveyed had little or no interest in learning about physics, chemistry or biology (Thomson & De Bortoli, 2008). Students surveyed for the international Relevance of Science Education (ROSE) project (Sjøberg & Schreiner, 2005) generally believed that science and technology are important but most did not wish to become scientists. While students consider science and technology to be important *generally*, their education has not developed a belief that these fields are important to them *personally*.

In a review of international research, Aikenhead (2006) found recurring evidence that traditional school science lacks relevance to the everyday world. He noted that the culture of school science, with its traditional emphasis on “canonical science concepts”, is at odds with students’ self-identities, so science has little personal or cultural value.

1.1.2 THE “PRIMARY” FOCUS

There is an identified need to improve the way science is taught in Australian schools, especially primary schools. Although a major study into “The status and quality of teaching and learning of science in Australian schools” (Goodrum, Hackling, & Rennie, 2001) found great variability, in general the picture was disappointing. Despite progressive curriculum frameworks based on constructivist principles (e.g. Queensland School Curriculum Council, 1999; Queensland Studies Authority, 2007a), the implemented curriculum was found to be quite different from the intended curriculum, and in some primary schools science was not taught at all.

The quality of teaching and learning in schools is dependent on teachers and in turn their own pre-service or in-service education. One of the problems for primary teachers is that they are trained as generalists and are expected to teach a number of subject areas. Primary teacher education includes a science component; however there are at least five other content areas, overlaid by major emphases on literacy and numeracy, which compete for time and attention. In their analysis of the 2007 Trends

in International Mathematics and Science Study (TIMSS), Martin, Mullis and Foy (2008) noted that in Australia most teachers of Year 4 do not have a major or specialisation in science or mathematics, and about half of the primary teachers surveyed did not feel well prepared to teach science. This lack of confidence in teaching science becomes a constraint on how much science is taught (Goodrum & Rennie, 2007), particularly in light of the workload for primary teachers who are typically responsible for up to eight key learning areas. Consequently, it is not surprising to find evidence that science teaching has been given little time in classrooms, with Australian Primary teachers spending only 2.7% of their weekly teaching on science, less than all other subjects except Languages Other Than English (LOTE) (Angus et al., 2004). The 2007 TIMSS (Martin et al., 2008) also surveyed teachers about their teaching practices and found that across Australia, Year 4 teachers reported spending 5% available class time teaching science – one of the lowest levels among the participating countries.

1.1.3 A GOVERNMENT RESPONSE

The *Australian School Science Education National Action Plan 2008-2012* (Goodrum & Rennie, 2007) proposes strategies to address this, including better provision of professional learning for teachers so they can maintain their content knowledge of contemporary science, and “improve their *pedagogical* and *pedagogical content* knowledge, particularly those inquiry-based pedagogical strategies that develop scientific literacy” (p. 20).

Such findings and proposals have triggered a range of responses from Australian governments, one of which was to fund the Australian Academy of Science to develop the *Primary Connections* program (Australian Academy of Science, 2005a), currently being developed and progressively implemented in all States and education jurisdictions in Australia. It comprises “a sophisticated professional learning program supported with rich curriculum resources and is designed to increase teachers’ confidence and competence in the teaching of science and the literacies of science” (Hackling & Prain, 2005, p. 15). The nature of the changes in teachers’ beliefs and classroom practice during the implementation of a *Primary Connections* professional learning program will be the focus of this study.

1.2 CONTEXT

This study was conducted in a government primary (elementary) school in Queensland, Australia. Primary schools in this state generally cover Preparatory to Year 7, with students aged from 4½ to 12 years old. The wider context includes political and policy priorities of a state economy shifting from an agrarian and resource base to a knowledge-generation base. The knowledge economy is driven by knowledge workers who in many circumstances will require sound science, technology engineering and mathematics education, as identified in a recent discussion paper (Department of Education, Training and the Arts [DETA], 2007).

A key influence in the reform of Australian science education programs is the social constructivist view of learning. Queensland has had a science syllabus based on constructivist principles since 1999 (Queensland School Curriculum Council, 1999). The *Primary Connections* program explicitly models constructivist pedagogies and has been endorsed by the Queensland state authority (DETA, 2006) as the preferred model for teaching science in primary schools. Since 2006, a growing number of schools have been adopting the program, although the extent of their implementation is variable. At one end of the scale, some schools have implemented substantial teacher professional development (PD) programs; at the other end, they have simply added the curriculum resource books to their libraries for teachers to use as they see fit.

Several hundred Professional Learning Facilitators have been trained by the Australian Academy of Science project team and their state representatives to support the project's implementation. As one of those facilitators, I have presented many introductory *Primary Connections* workshops. The program I have been trained to facilitate has many features identified in the research as aspects of best-practice in PD programs. These include multiple workshops, opportunities for reflection and collegial support, extended professional engagement and analysis of professional practice based on principles of teaching and learning.

However, because of the time and resourcing constraints, much of the support for *Primary Connections* implementation in schools has, in practice, been limited to short one-off after-school meetings for the whole staff. As such, it necessarily displays features that researchers have identified as making PD programs ineffectual, including:

1. “one-off” PD events (that) seldom have any impact (p. 17)
2. “sheep-dip” seminars that do not acknowledge extant expertise (p. 30).

(Bahr, Dole, Bahr, Barton, & Davies, 2007)

The *Primary Connections* program enacted in classrooms generally varies significantly from the resource writers’ intentions, and this case study was no exception as there was insufficient time to facilitate the full suite of workshops or other key elements of the *Primary Connections* professional learning program. However, the school administration demonstrated a commitment to the implementation of the *Primary Connections* program by setting aside a substantial amount of time (three hours) for whole-staff PD. As well, the teachers involved were highly motivated and generous with their time, so the study is able to provide a detailed view of the effectiveness of the implementation.

1.3 PURPOSES

The present study set out to examine the change in teacher practice during the implementation of a constructivist science learning program. Two teachers, working in partnership, participated in a focussed investigation, discussing their beliefs about science and science education as well as their current practice. Changes in these elements were tracked throughout the implementation of *Primary Connections* in their classroom. The implementation was supported by the PD workshops and published curriculum resources that comprise *Primary Connections* (Australian Academy of Science, 2005a, 2007).

Data collected throughout this process provided a detailed insight into the effectiveness of the *Primary Connections* professional learning program (as well as the state education authority’s implementation strategy) in modifying teachers’ attitudes and practices in science education.

1.4 RESEARCH QUESTIONS

A review of the literature in relevant fields, as detailed in Chapter 2, led to the development of a key research question:

What are the changes in teachers’ beliefs and practices associated with implementing a constructivist-inspired learning program?

To help articulate the response to the key question, three supporting questions arising from the key themes in the literature were considered (Table 1.1).

Table 1.1

Supporting Research Questions

Topic	Question
1. “Structured constructivism”:	In what ways do the professional learning program and the published <i>Primary Connections</i> curriculum units foster the development of inquiry-based science in a constructivist learning environment?
2. Expressed beliefs vs. enacted beliefs:	To what extent are teachers’ expressed beliefs about constructivist learning aligned with their enacted beliefs?
3. Teachers’ perception of student outcomes:	How does implementation of the PD intervention change teachers’ perceptions of student learning in science?

1.5 SIGNIFICANCE

The *Primary Connections* professional learning program is based on sound professional learning principles which are discussed in detail in Chapter 2, as well as in a related conference paper (Fittell, 2008). The professional learning program includes guidelines for six teacher workshops, a DVD, professional readings and guidelines for reflection and journaling (Australian Academy of Science, 2007). This is very comprehensive, however it makes assumptions about the time and resources available for an implementation that may not be practical in many schools. Science is just one of eight *Key Learning Areas* in Queensland (Queensland Studies Authority, 2007a) and has tended to have low priority (Angus et al., 2004). Therefore, time and resource constraints mean that the professional learning program as offered is unlikely to be fully implemented, if at all. Even if implemented, there is likely to be wide variance in the nature of the program elements experienced by students in individual classrooms (Roehrig, Kruse, & Hern, 2007).

The *Primary Connections* program includes an ongoing research component, with reports published on the project website (Australian Academy of Science, 2009). Major elements of this research include a review of the “Stage 2 Trial” (Hackling & Prain, 2005) and a subsequent interim report of the “Stage 3 Trial”

(Hackling & Prain, 2008). These studies provide substantial information about the positive outcomes and influence of the program. They are based predominantly on survey data from relatively large numbers of participants. However, the data tend to be collected “after the fact”, and investigators have not reported in detail on the progress of a teacher throughout a PD program and the subsequent implementation of curriculum resources in their classroom. Roehrig et al. (2007) reported on the critical importance of both observing and talking to teachers about their implementation of an innovation as it is through exploring teachers’ actual practices, as well as the beliefs and knowledge that constrain those practices, that targeted PD programs can be designed.

In contrast to the major *Primary Connections* project reviews, the present study focussed on a particular school, and a professional learning component that fitted within the typical time constraints of the school and teachers. This approach provided detailed insights into the effectiveness of the intervention in changing classroom practice, gleaning rich information on the dynamics of implementing an innovation. The data provide a close-up view of teachers grappling with the PD experience and enacting a novel curriculum that confronts their understandings of teaching science.

At the time of this study, the *Primary Connections* program was in relatively early stages of implementation in many schools. Therefore, it was timely to investigate its impact on teacher development and hence on student learning and engagement with science. In relation to *Primary Connections*, the findings of this study provide specific guidance for professional learning facilitators and school coordinators of this national program while it is still in its implementation phase.

While the specific context of the study is a *Primary Connections* implementation, the review of the literature relating to professional learning presented in Chapter 2 was used to develop a theory-based model for PD that can be applied more generally. Consequently, the research findings provide a useful addition to the literature on teacher PD, in particular, the efficacy of a strategy for promoting change in teachers’ beliefs and practices. This helps to address an identified need to understand, not just the outcomes of an intervention, but the nature of teachers’ interaction with the various elements of a multi-mode professional learning program and the way each of these influence change.

1.6 THESIS OUTLINE

Chapter 1 began with a general introduction to this study, outlining the context, purpose and significance of the research questions. The major focus of the study is the way teachers' beliefs and practices are impacted by a PD program focussed on the implementation of a constructivist inspired curriculum. Chapter 2 is a review of the literature dealing with issues including science education, professional development, the process of change and the constraints to achieving it. Key constraints to the effectiveness of PD programs are identified, and the theoretical background is applied to developing a model for PD that will manage those constraints. Chapter 3 is an explanation of the methodology and provides details of the intervention, and then Chapter 4 is an analysis of the data obtained. In Chapter 5, the implications of the study are presented, including identification of key principles for PD program design and classroom practice. Identified topics for further investigation relate to the role of assessment and of teacher reflection in developing sustainable change in teachers' beliefs and practices.

Chapter 2: Literature review

In this chapter, research on teacher PD in science education is reviewed in order to develop a conceptual framework that explains effective PD. The knowledge required by teachers is considered, as well as current research on effective pedagogies in order to outline a preferred model for classroom practice in primary science teaching. This leads to discussion of the necessary changes in practice required by teachers who seek to conform to that model, the nature of the change process, and professional learning strategies that facilitate such change. From this background, the professional learning component of the *Primary Connections* program is analysed by mapping it against a proposed model of PD derived from the literature. Finally, this chapter identifies gaps in the literature and significant issues in a teacher professional learning program to be addressed by the research project. These help to explain the limited impact on teaching practices of currently-used modes of PD.

2.1 WHAT IS THE PURPOSE OF SCIENCE EDUCATION?

Debate about the role of school science education hinges on the question of whether the aim is to (a) prepare students for tertiary science studies and careers in science, or (b) raise the scientific literacy of the community as a whole (Tytler, 2007). The developers of Australia's national science curriculum identify three possible pathways students need to be prepared for: (a) to make personal decisions on the basis of a scientific view of the world; (b) to become the future research scientists and engineers; and (c) to become analysts and entrepreneurs in the diverse fields of business, technology and economics (National Curriculum Board, 2009). Consideration of the purpose of science education is important to this thesis as it is central to decisions about the way science is taught in primary schools, and consequently, the content and pedagogy of teachers' professional learning programs.

Although secondary teachers historically tend to enact the view that they are preparing students for university, the *Australian School Science Education National Action Plan 2008-2012* (Goodrum & Rennie, 2007) identifies the fundamental purpose of school science education as promoting scientific literacy. The *Action Plan*

extends this view by stating that science not only prepares students for citizenship but “provides firm basis for more specialised, discipline-based subjects in upper secondary school that lead to science courses at university, and prepares students for technical education courses that lead to science-related careers” (p. 3), thus bringing together both sides of the debate.

This focus is in line with Bybee and DeBoer’s (1994) view that scientific and technological literacy are the key purposes for science education “for *all* students, not just those destined for careers in science and engineering” (p. 384), while Hackling and Prain (2005) proposed that scientific literacy should enable individuals to “navigate their way through life” (p. 17), rather than focusing on tertiary studies. The characteristics of scientific literacy will be discussed in the next section in order to set the context for the following examination of science teaching and learning.

2.1.1 SCIENTIFIC LITERACY

In 1996, Coble and Koballa reported that a common teacher attitude was that experiments are simply exercises in verifying theories that explain known phenomena. A decade later similar attitudes persisted, with Abell and McDonald (2006) reporting the “popular myth” that studying science involves memorising facts from textbooks. The views of contemporary science educators are considerably broader than that, and more closely connected to the real world. There are many and varied definitions of scientific literacy in the research literature and in policy documents, but they tend to converge around common themes. To illustrate an international consensus, Table 2.1 merges the four key points of the definition used by the Programme for International Student Assessment (PISA) (OECD, 2006) with commonalities in definitions by Coble and Koballa (1996) from the USA, Eady (2008) from the UK, and Goodrum, Hackling, and Rennie (2001) from Australia.

Table 2.1

Commonalities in Definitions of Scientific Literacy

Key component	Source
Scientific knowledge:	
Using scientific knowledge, including the concepts, principles and theories central to physics, chemistry, biology, and earth sciences, to identify questions, to acquire new knowledge, to explain phenomena, and to draw evidence-based conclusions about science-related issues.	OECD (2006), Goodrum et al. (2001), Eady (2008), Coble and Koballa (1996)
Science is a human construct:	
Understanding science as a form of human knowledge and enquiry, that as such it is <i>tentative</i> in nature, and that it is appropriate to be sceptical and questioning of claims made by scientists and non-scientists about scientific matters.	OECD (2006), Goodrum et al. (2001), Coble and Koballa (1996)
Social context for science:	
Understanding the historical, cultural and technological place of science within our society.	OECD (2006), Goodrum et al. (2001), Eady (2008)
Engaging with science:	
Willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen, applying the knowledge and skills of science when confronting individual and societal problems.	OECD (2006), Goodrum et al. (2001), Eady (2008), Coble and Koballa (1996)
Science influences our choices:	
Understanding the influence of science as we make informed decisions about the environment and our own health and well-being.	Goodrum et al. (2001), Eady (2008)

A common theme in these definitions is that their intent goes well beyond the traditional bounds of the discipline, identifying society-wide and whole-of-life outcomes for effective science education. This has profound implications for educators who are thus challenged to build real-world context and relevance for science.

In developing Australia's national "Science Literacy Progress Map" (Curriculum Corporation, 2006), the writers noted that the PISA model, due to the constraints of its large-scale testing, had not included performance tasks such as conducting investigations. Therefore, the definition developed for the *National Assessment Program: Science Literacy* (Curriculum Corporation, 2006) has merged

the five elements of the PISA model into three domains, and added the key term “investigations” (Table 2.2). It is this model that forms the basis of content for the *Primary Connections* program and hence will guide the PD program developed by this project.

Table 2.2

Three Domains of Knowledge in Scientific Literacy (Curriculum Corporation, 2006)

1	Formulating or identifying investigable questions and hypotheses, planning investigations and collecting evidence.
2	Interpreting evidence and drawing conclusions, critiquing the trustworthiness of evidence and claims made by others, and communicating findings.
3	Using science understandings for describing and explaining natural phenomena.

Teachers’ planning is guided by their understanding of science and what students need to be scientifically literate. If students are to experience consistent learning in scientific literacy, there is a presumption that teachers are in agreement about the meaning of the term “science”, however the literature is clear that this is not the case. The “nature of science” is a foundational aspect of scientific literacy which is examined in the following section.

2.1.2 THE NATURE OF SCIENCE

There is general consensus in the science education literature that developing students’ and teachers’ understandings of the nature of science (NOS) is central to achieving scientific literacy (McDonald, 2008). Teachers’ understanding of NOS forms part of the “hidden curriculum” that influences their teaching (Lunn, 2002), but it is widely misunderstood. Memorising a catalogue of facts and algorithmic solutions to problems was the view of science observed in classrooms during a study (Tobin & McRobbie, 1997) that identified misunderstandings and misrepresentations of NOS by secondary teachers.

Primary school teachers could be assumed to have less formal science education than the secondary teachers in Tobin and McRobbie’s study; Stein, Ginns, and McDonald (2007) identified a broader diversity of ideas and misconceptions in primary classrooms. This is a substantial factor impacting on the quality and consistency of students’ first years of science education, and needs to be considered by professional learning facilitators.

Myths about NOS are found to be widespread, even amongst teachers and in education resources (Harlen & Holroyd, 1997). Bencze and Hodson (1999) analysed a range of school science curriculum documents and identified these seven misconceptions about scientific concepts: (a) observation provides direct and reliable access to secure knowledge; (b) science starts with observation; (c) science proceeds via induction; (d) experiments are decisive; (e) science comprises discrete, generic processes; (f) scientific inquiry is a simple, algorithmic procedure; and (g) science is a value-free activity.

Further evidence that students' misconceptions about science originate in the classroom was provided by Stein, Barman, and Larrabee (2007), who found that many of the students' misconceptions had been learnt from their teachers. However, even if teachers have well developed understandings of NOS, the notion that students will implicitly "catch" informed views of NOS through teacher attitudes and practices is a naive one that has not been empirically supported; there is a consensus in the literature that NOS needs to be taught explicitly (McDonald, 2008).

Since it is clear that teachers' concepts of NOS need to be addressed in professional learning programs, we need to consider what NOS really is, because so far we have only considered flawed perceptions. A very concise definition of science is provided by Cobern and Loving (2001):

Science is a naturalistic, material exploratory system used to account for natural phenomena that ideally must be objectively and empirically testable.
(p. 58)

A more detailed outline of NOS (Bell, Lederman, & Abd-El-Khalick, 2000) lists seven interrelated aspects, namely, that scientific knowledge is (a) tentative, (b) subjective, (c) empirically based, (d) socially embedded, and (e) dependent on human imagination and creativity. It also distinguishes between (f) observation and inference and (g) theories and laws. To put this in a classroom context, Lederman and Lederman (2004) gave these examples of sound NOS concepts in students: "When asked why students who investigated the same question had different conclusions one student said, 'We just think different.' Another student said, 'Nobody did anything wrong, we just looked at things different'" (p. 16).

In her extensive review of the recent literature of NOS, McDonald (2008) identified nine characteristics that were widely accepted as representing an informed or desirable understanding of NOS. These are summarised in Table 2.3.

Table 2.3

Nine Aspects of Nature of Science (McDonald, 2008)

1	Scientific knowledge is empirically based and generally derived from observations of natural phenomena.
2	Scientific knowledge is subject to change and cannot be considered absolute, although generally considered reliable or durable.
3	Science is not characterised by a universal scientific method.
4	Scientific theories and laws are different types of knowledge and serve different roles in science.
5	Scientific knowledge is subjective and theory-laden and recognises a scientist's background.
6	Observations and inferences are different concepts in science.
7	There is a creative and imaginative aspect to scientific knowledge; a major undertaking by scientists involves creating hypotheses, inferences and theories.
8	Scientific knowledge is socially and culturally embedded.
9	Moral and ethical issues influence decisions reached by scientists.

It seems logical that teachers should have a chance to participate in scientific inquiries similar to those scientists conduct in their everyday work (Akerson & Hanuscin, 2007). In a practical response to such calls, some education authorities have implemented policies encouraging teachers to engage with practising scientists. For example, the State of Queensland's *Science Education Strategy 2006-2009* (DETA, 2006) had several initiatives aimed at addressing this issue, including Senior Science Officers liaising with industry and research organisations to provide authentic science experiences for students and teachers.

Understanding NOS is an important component of scientific literacy, which in turn is a priority in science education, so curriculum programs need to address NOS. Since this approach is advocated for students, it is equally relevant for teacher PD programs, so a principle underpinning effective science PD should be the explicit teaching of NOS.

The rest of this chapter examines the literature with a view to developing a soundly-based model for a teacher PD intervention. The first aspect to be addressed relates to the knowledge required by effective teachers of science.

2.2 WHAT DO TEACHERS NEED TO KNOW?

The way science is taught in primary schools is strongly influenced by teachers' beliefs about teaching, learning and science (Keys, 2006). However, these practices and beliefs often do not reflect current theory and accepted models of good practice (Keys & Watters, 2006), so there is a need to consider the knowledge and understandings required by effective teachers of science in contemporary primary schools in order to identify key foci for PD.

Teachers must have a wide range of skills and knowledge to work effectively in whatever context they teach. The concept of "teacher knowledge" comprises diverse elements, which will be outlined in the following section.

2.2.1 TEACHER KNOWLEDGE

Teacher knowledge was described by Keys (2006) as the body of knowledge that comprises teachers' beliefs, as well as five aspects of knowledge: (a) teachers' craft knowledge; (b) teachers' practical knowledge; (c) teachers' practical theories; (d) teachers' personal pedagogical knowledge; and (e) teachers' pedagogical content knowledge. These all act as filters that reshape curriculum.

Craft knowledge (van Driel, Verloop, van Werven, & Dekkers, 1997) consists of teachers' beliefs about their teaching practice, and comes mainly from teaching experience. Changing teachers' beliefs can be a daunting prospect for reformers. Pajares (1992) found evidence that beliefs rarely change during adulthood. He describes the nature of the linkage between beliefs and craft knowledge:

Beliefs influence what teachers say outside the classroom, but their behaviour in the classroom is a result of beliefs (and here is a twist) being filtered by experience... knowledge, not belief, ultimately influences teacher thought and decision making. (p. 312)

Practical knowledge (van Driel, Beijaard, & Verloop, 2001) is constructed by teachers in the context of their work by integrating their experiential knowledge, formal knowledge, and personal beliefs. This dimension is somewhat similar to

practical theories as described by Feldman (2000), where teachers make sense of their practice in a manner similar to scientific reasoning, with conceptual change based on practical experiences.

Personal pedagogical knowledge (Morine-Dersheimer & Kent, 1999) stems from the interaction of teachers' personal practical experience with their personal beliefs and perceptions. Morine-Dersheimer and Kent (1999) emphasise the importance of the interplay between “personal pedagogical knowledge” and “general pedagogical knowledge” which is derived from formal learning.

Pedagogical content knowledge

The opposing priorities of content knowledge versus pedagogical knowledge are linked by the idea that teachers have repertoires of practice specific to particular content areas; for example, in science they may have a range of inquiry activities for developing the concepts of “working scientifically” and “fair tests”. Shulman (1986) used the term *pedagogical content knowledge* (PCK) to describe a kind of knowledge unique to the teaching profession whereby a teacher transforms subject matter knowledge to facilitate student understanding. Shulman (1986) and Abell (2008) distinguish between *subject matter knowledge*, *general pedagogical knowledge* and PCK. Musikul (2007) defined PCK as “a special form of knowledge that bundles subject matter knowledge with knowledge of learners, learning, and pedagogy” (p. 43). Those “bundles” can help teachers to anticipate student difficulties and offer alternative models or explanations to mediate such difficulties.

The PCK needed in an effective science learning environment consists of five components (Magnusson, Krajcik, & Borko, 1999): (a) orientations toward science teaching, (b) knowledge and beliefs about science curriculum, (c) knowledge and beliefs about students' understanding of specific science topics, (d) knowledge and beliefs about assessment in science, and (e) knowledge and beliefs about instructional strategies for teaching science.

Broad representations such as those described by Magnusson et al. (1999) were found by Loughran, Mulhall, and Berry (2004) to be inadequate in terms of identifying PCK in ways that it could be concretely represented to teachers in a PD context. They developed a model for taking a more detailed look at PCK, although they found that an extended time, such as a unit of work, was needed for it to be

clearly described, and that observation still provides a limited view because it is partly an internal construct and needs to be articulated by the teacher. A key finding of their work was that each new topic being taught brings out aspects of PCK specific to that context, leading to their conceptualisation of PCK as two interactive elements: CoRe (Content Representation, linked to the particular science content) and associated PaP-eRs (Pedagogical and Professional experience Repertoires, linked to teaching practice).

The implication for a PD model is that these elements of teacher knowledge need to be accommodated in planning and support, in particular, helping teachers to develop PCK when they have limited content knowledge. Formulation of a theoretical model for teacher PD and a critique of the *Primary Connections* model will be informed by this concept. Consequently, linking teacher knowledge to classroom practice is the focus of the next section, reviewing research that identifies effective science teaching pedagogies.

2.3 WHAT ARE THE CHARACTERISTICS OF EFFECTIVE SCIENCE TEACHING?

A diversity of approaches to science education has been applied in the last several decades (Peers, 2000), including a *didactic* (traditional) approach focussing on content, a *discovery* approach in which students are led to develop conclusions, and a *process* approach which concentrates on the skills of science. Constructivist methodologies focussing on conceptual change have become dominant in the curricula of recent years, and provide the context for this study.

In their review of Australian studies of effective science teaching practices, Hackling and Prain (2005) found the literature converging around six key characteristics, providing a useful outline for assessing the quality of classroom science learning environments (Table 2.4).

Table 2.4

Key Characteristics of Effective Science Teaching (Hackling & Prain, 2005)

1	Relevance to students' lives and interests in a safe and supportive learning environment
2	Classroom science is linked to broader community
3	Students are actively engaged with inquiry, ideas and evidence
4	Students are challenged to develop and extend meaningful conceptual understandings
5	Assessment facilitates learning; focus on outcomes that contribute to scientific literacy
6	ICTs are exploited to enhance learning of science

In the USA, Fletcher, Meyer, Barufaldi, Lee, Tinoca, and Bohman (2004) found considerable agreement between significant national and state (Texas) policies regarding which constructivist pedagogies best foster science literacy for all students. A classroom functioning in line with the agreed recommendations would exhibit the features outlined in Table 2.5.

Table 2.5

Constructivist Pedagogies that Foster Scientific Literacy (Fletcher et al., 2004, p. 2)

1	Student inquiry is the foundation for concept development.
2	All students are given multiple and varied opportunities to pose questions, design investigations, dialogue/collaborate with peers and teacher, collect and evaluate evidence, justify conclusions, and demonstrate their understanding.
3	Students take an active role in directing inquiry activities, explaining concepts to one another, and evaluating themselves.
4	All students participate equally in the learning process.
5	Teachers use assessment and questioning to guide instruction.
6	Students take responsibility for their own learning.
7	Teachers employ multiple and varied instructional and assessment strategies to facilitate conceptual understanding.
8	Students see personal value and relevance in the science they learn.
9	Science literacy for all students is the goal of instruction.

Research from fields including cognition, child development, and brain functioning is compiled in a report of the USA's National Research Council entitled *How People Learn* (Bransford, Brown, & Cocking, 1999) which lists key research

findings on how students learn science, each of which has an implication for teaching practice (Table 2.6).

Table 2.6

How Students Learn Science (Bransford et al., 1999)

Understanding science is more than knowing facts.

Students build new knowledge and understanding:

- of what they already know and believe;
- by modifying and refining their current concepts;
- by adding new concepts to what they already know.

Learning is mediated by the social environment in which learners interact with others.

Effective learning requires that students take control of their own learning.

The degree of “learning with understanding” affects ability to apply knowledge to novel situations, i.e. transfer of learning.

Research in the cognitive and developmental sciences on how students learn science provides a basis for science curriculum. Three such principles of learning identified by Donovan and Bransford (2005) have been linked by Bybee (2006) to some key implications for curriculum design (Table 2.7).

Table 2.7

Principles of learning linked to implications for curriculum design in science

How students learn science (Donovan & Bransford, 2005)	Requirements for curriculum and pedagogy (Bybee, 2006)
Students have preconceptions about how the world works and these need to be engaged.	Facilitates conceptual change.
Students’ competence in science requires factual knowledge and conceptual understanding.	Based on fundamental concepts, supporting evidence and consensus of interpretation.
Students can learn metacognitive strategies to control their own learning by defining goals and monitoring their progress.	Provides opportunities for students to learn and develop metacognitive strategies.

It is unlikely that many of today’s practising teachers, when they were school students, experienced learning environments and principles such as the contemporary models described above. Considering the increasing age of some teaching populations, with almost half the teachers aged over 45 years in one jurisdiction (Auditor-General NSW, 2008), many teachers would have completed their pre-

service studies before these pedagogies were common in teacher education programs. Hence teachers have to “unlearn” old ways and develop a new understanding of contemporary education. Therefore, the following section considers the factors influencing the change required by teachers.

2.4 WHAT CHANGES CONFRONT TEACHERS?

In the 1990s, Appleton and Asoko (1996) observed that teachers generally did not hold constructivist views on learning. A decade later, in the context of implementing curricula based on constructivist learning theory and pedagogy, a case study of four schools in Queensland (Cooper, 2007) found some evidence of constructivist pedagogy, but there were still significant gaps in teachers’ constructivist practice.

In the context of science learning, inquiry-based, open-ended investigations are a significant element of a constructivist approach (Haney, Lumpe, & Czerniak, 2003). Change towards inquiry-oriented teaching and the implementation of constructivist pedagogies are major challenges to the capabilities of teachers, who must modify their classroom management, communication and assessment strategies. Consequently, it is not surprising that Cooper (2007) found a high level of resistance to curriculum change, with 54% of his sample of teachers preferring not to implement new curricula if given a choice.

Inquiry-based science teaching can be done in various ways, with the most student-centred approach being open-ended inquiry. Jones and Eick (2007) identified this strategy as a particular challenge for teachers because it requires them to suspend planned instruction to explore students’ questions. Teachers may perceive this approach as relinquishing control of their teaching.

Inquiry-based teaching also puts increased demands on teachers’ content knowledge, which must be deeper and broader than in traditional teaching in order to cope with the range of students’ questions and investigations (Fishman, Marx, Best, & Tal, 2003). When adapting to a focus on scientific literacy, a range of specific classroom practices may require substantial change, as illustrated in the list by Goodrum et al. (2001) in Table 2.8.

Table 2.8

Changes in Emphasis Required to Teach for Scientific Literacy (Goodrum et al., 2001, p. 168)

Less emphasis on:	More emphasis on:
Memorising the name and definitions of scientific terms	Learning broader concepts than can be applied in new situations
Covering many science topics	Studying a few fundamental concepts
Theoretical, abstract topics	Content that is meaningful to the student's experience and interest
Presenting science by talk, text and demonstration	Guiding students in active and extended student inquiry
Asking for recitation of acquired knowledge	Providing opportunities for scientific discussion among students
Individuals completing routine assignments	Groups working cooperatively to investigate problems or issues
Activities that demonstrate and verify science content	Open-ended activities that investigate relevant science questions
Providing answers to teacher's questions about content	Communicating the findings of student investigations
Science being interesting for only some students	Science being interesting for all students
Assessing what is easily measured	Assessing learning outcomes that are most valued
Assessing recall of scientific terms and facts	Assessing understanding and its application to new situations, and skills of investigation, data analysis and communication
End-of-topic multiple choice tests for grading and reporting	Ongoing assessment of work and the provision of feedback that assists learning
Learning science mainly from textbooks provided to students	Learning science actively by seeking understanding from multiple sources of information, including books, Internet, media reports, discussion, and hands-on investigations

Much research on learning has explored what it means to “teach for understanding”, with recommendations from relevant studies in the 1980s and 1990s summarised by Good (1996) into seven key points: (a) knowledge is constructed; (b) knowledge networks are built around powerful ideas; (c) prior knowledge influences how students integrate new knowledge; (d) knowledge restructuring and conceptual change are important; (e) knowledge is socially constructed; (f) learning needs to be tied to authentic tasks; and (g) teachers should progressively transfer responsibility for managing learning from themselves to learners.

Good's list can be taken as a broad overview of the constructivist approach that has become prominent in curricula developed in the last two decades, and is a major focus of curriculum reform efforts (Peers, 2000). The implications of implementing a constructivism-oriented science curriculum are the focus of the following section.

2.4.1 CONSTRUCTIVISM IN SCIENCE EDUCATION

To place constructivism in the context of science education, Taber (2006) uses the term *Active Construction of Knowledge in Science* (ACKiS), with a set of core assumptions and related research questions outlined in Table 2.9.

Table 2.9

Assumptions Underpinning the ACKiS Research Paradigm (Taber, 2006)

Hard core assumptions	Broad research questions
Knowledge constructed by learner, not received.	How does knowledge construction take place?
Learners come to science with existing ideas about natural phenomena.	What ideas are brought to science classes? What is the nature of those ideas?
Individuals have unique sets of ideas.	How much commonality is there between learners' ideas?
Knowledge is represented as a conceptual structure.	How is knowledge organised in the brain?
It is possible to model learners' conceptual structures.	What are the most appropriate representations?
Learners' existing ideas impact learning in science.	How do ideas interact with teaching?
Science teaching is more effective if existing ideas are considered.	How should "constructivist" teachers teach science?

Teachers using constructivist models see the learner actively engaging with phenomena and ideas to construct knowledge (Tytler, Waldrup, & Griffiths, 2002). In his socio-cultural description of learning, Tytler (2007) identified four important elements of an engaging science learning program: (a) the active role of the teacher in providing opportunities for students to engage with and explore phenomena; (b) the support for students to engage with meaningful contexts; (c) the negotiation of meaning implied in the teacher's guidance of students towards the scientific views; and (d) the meta-cognitive implications of making ideas explicit, and extending and evaluating these.

A significant impact of constructivism within the classroom is that responsibility for learning is transferred from the teacher to the student (McKenzie & Turbill, 1999). This role reversal can represent a difficult, even threatening, change for teachers, particularly when students choose investigations in fields outside the teachers' subject-area knowledge. However this change in the roles of teachers and students does occur. Goodrum's (2006) survey found evidence of substantial change from teacher-direction to a student-centred focus and identified a list of observable classroom behaviours likely to change in a constructivist reform, as presented in Table 2.10.

Table 2.10

Classroom Behaviours Changed in a Constructivist Reform (Goodrum, 2006)

Changes	Examples
Reduced "teacher-directed" teaching evidenced by less:	Notes copied from the board Teacher explanation
Increased "student-centred learning" evidenced by more:	Small group discussion Cooperative learning groups Open-ended questions with wait time Conceptual explanation after activity and experience Investigations Heightened exposure to fewer concepts Formative and diagnostic assessment

The "diagnostic assessment" referred to in the table's list of teacher behaviours implies that teachers will seek to understand their students' understanding of a topic at the start of a unit so that this knowledge can be used to adapt the learning activities to the students' needs. This is an important aspect of constructivist learning models (Bybee, 2006; Nussbaum & Novick, 1982) so we will consider the nature of that prior knowledge.

A key element of constructivist pedagogies is recognising the role of prior knowledge in learning. Most people develop their ideas about science before beginning formal science education. Such ideas persist despite efforts to teach scientifically accepted theories and concepts, according to Stein et al. (2007), who identified a range of terminology for ideas that are at variance with the views

generally accepted by scientists. *Misconceptions* is their preferred term; more neutral options include *alternative frameworks*, *existing ideas* or *alternative conceptions*. Bybee (2006) refers to *naïve theories*. In this study the term *preconceptions* will be used because it is relatively neutral, avoiding negative inferences.

Preconceptions do not necessarily constrain the development of students' reasoning. In their detailed observations of secondary school science students, Hamza and Wickman (2008) noticed that when faulty preconceptions were encountered, they appeared as flawed alternatives that were not actively defended; in fact they may have actually assisted students to develop new concepts.

The process of assisting learners to leave behind flawed or limited preconceptions and take on new ideas is seen by many to follow a predictable sequence, which may be assisted by a structured learning model. Many variations of such models have been proposed, some of which will be outlined in the next section.

2.4.2 CONSTRUCTIVIST LEARNING MODELS

A common feature in constructivist models is an initial stage designed to engage the learner and bring about disequilibrium, based on Bybee's interpretation of Dewey's (1938) instructional model, in which "the teacher presents an experience where the students feel thwarted and sense a problem" (Bybee, 1997, p. 175). A concise example of such a model is Nussbaum and Novick's (1982) three-step strategy:

1. Exposing alternative frameworks (or preconceptions).
2. Creating conceptual conflict.
3. Encouraging cognitive accommodation.

Another framework developed from research on scientific thinking and problem solving is presented by Kober (1993) in Table 2.11.

Table 2.11

Four Stages of Problem Solving in Science (Kober, 1993)

Stage	Example of Process
1. Invitation	A question from a student or teacher invites students to learn more about something that intrigues them.
2. Exploration, discovery, creativity	Students develop experiments and other forms of inquiry to answer the question.
3. Proposing explanations and solutions	Teachers support students to develop explanations consistent with their inquiry's findings.
4. Taking action	Students follow up on what they have learned by initiating action in their homes or communities.

The 5Es instructional model (Bybee, 2006) developed in the 1980s was selected by the Australian Academy of Science as the basis for the curriculum units in their *Primary Investigations* project (Australian Academy of Science, 1998), and its successor, *Primary Connections* (Australian Academy of Science, 2005a). The model provides *experiences* and *time* for students to recognise inadequacies in their current ideas, explore new explanations, reflect on their ideas, and to construct new concepts of the natural world (Bybee, 2006). The five stages of Bybee's model are described in Table 2.12.

Table 2.12

The 5Es Instructional Model (Bybee, 2006)

Stage	Strategy
Engage	Elicit thoughts or actions by the student that relate directly to the lesson's objective.
Explore	Experiences where students' current understandings are challenged by activities, discussions and currently-held concepts to explain experiences.
Explain	Presentations of scientific concepts that change students' explanations to align with scientific explanations.
Elaborate	Activities that require the application and use of scientific concepts and vocabulary in new situations.
Evaluate	Culminating activity that provides the student and teacher with an opportunity to assess scientific understanding and intellectual abilities.

To be effective, Bybee (1997) suggests that the model should be apparent to teachers and students. He also notes that while such a structured sequence of

activities enhances the possibilities of learning, it does not ensure learning as this is too great a demand to place on an instructional model. It is the teacher's role to manage and complete the process of change. Where gaps need to be closed between the actual and the ideal science curriculum, it is teachers who will effect the closure; they are the key to change (Goodrum & Rennie, 2007).

A model proposed by Milne (2008) is similar to Bybee's 5Es but highlights the links between science and creativity (Table 2.13), emphasising the exploration of aesthetic experiences and the resulting desire by learners to explain the phenomena involved. A key element of this model is the final stage of "further investigation" where students are led to wonder about revisiting or extending their inquiries.

Table 2.13

Sequential Elements of Creative Exploration Model for Developing Personal Understanding in Primary Science (Milne, 2008)

Creative Exploration		
Explore	A problem, situation, phenomenon, artefact, model, event, story.	Wonder
Observe	What is happening? What changes happened? What materials are involved? What are the main parts? What are the key aspects? What do these parts/structure do?	Wonder about
Identify evidence	What is the cause and effect of changes? What is the function? What parts are interacting with other parts? What are the outcomes of these interactions? What trends and patterns keep occurring?	
Create explanations	Personal explanations supported by evidence are created and processes to test them are planned.	Wonder at
Investigate	Find out, measure, compare, verify, test, clarify identify.	
Evaluation	A self evaluation of these investigations may lead to new or modified explanations, doubts about existing ideas or tentative conclusions. These tentative explanations need to be communicated to others for peer evaluation and feedback.	
Further investigation	Evaluated explanations can lead to re-exploration, seeking further explanation, leading to further investigation.	Wonder whether

Because this research project is specifically concerned with a program that applies the 5Es model, this section concludes with a consideration of the alignment of the various constructivist learning models that have been discussed (see Table 2.14). Though not presented as a learning model, Tytler's (2007) four elements of an engaging science program are included to provide another perspective on the way

these models, particularly the 5Es, align around common themes. It can be seen that while there are differences in detail, scope and terminology, these approaches have clear alignment with each other and with core principles of a constructivist approach to learning.

Table 2.14

Alignment of Constructivist Learning Models

5Es Stage	Alignment to other models	Elements associated with sociocultural perspectives of learning (Tytler, 2007)
Engage	Invitation (Kober, 1993) Exposing alternative frameworks (Nussbaum & Novick, 1982) Explore/Wonder (Milne, 2008)	(a) The active role of the teacher in providing opportunities for students to engage with and explore phenomena;
Explore	Creating conceptual conflict (Nussbaum & Novick, 1982) Exploration, discovery, creativity (Kober, 1993) Identify evidence (Milne, 2008)	(b) the support for students to engage with meaningful contexts;
Explain	Proposing explanation and solutions (Kober, 1993) Create explanations/Wonder at (Milne, 2008)	(c) the negotiation of meaning implied in the teacher's guidance of students towards the scientific views;
Elaborate	Encouraging cognitive accommodation (Nussbaum & Novick, 1982) Investigate (Milne, 2008)	(d) the meta-cognitive implications of making ideas explicit, and extending and evaluating these.
Evaluate (Extension: elements of models that go beyond the scope of the 5Es)	Evaluation (Milne, 2008) Taking action (Kober, 1993) Further investigation/Wonder whether (Milne, 2008)	

2.4.3 ASSESSING CONSTRUCTIVISM

Considering that constructivism has been the predominant influence on curriculum design for at least the past two decades, it is worth considering briefly whether it is likely to remain so. The fall of constructivism was predicted in 1994 (Solomon, 1994), however a decade further on there was no clear evidence of a new paradigm to overthrow it (Taber, 2006) and it is far from being a spent force. Taber quotes Solomon's postscript in 2000: "I had not reflected then that when an educational perspective is no longer new it is far more susceptible to *change* than to

extinction” (p. 125). So it seems that the current focus on constructivist curricula continues to be warranted, despite the magnitude of the task still remaining to implement the required change.

Implementing authentic constructivist practice may be threatening to teachers with years of experience and training in traditional models, so it will be necessary to explore the nature of change and how it can be achieved if we are to develop an effective model for professional learning. The following section is an examination of research on the nature of change and how it can be facilitated.

2.5 HOW DO TEACHERS CHANGE?

Changing teachers’ practice is problematic. Most teachers believe they develop their teaching skill or “craft knowledge” through classroom experience as they learn how to motivate and manage classes, deal with disruptions and plan interesting, challenging activities, as well as observing colleagues doing the same, and recalling their own experiences as students (Nuthall, 2004). Even before teachers enter the profession, they have years of experience as learners, so their beliefs about teaching and learning are well-established (van Driel et al., 1997). However, many of those learned or observed models focus heavily on memorising facts, so the teaching styles thus learned do not support the deeper understanding of subject matter gained when students are assisted to construct their own knowledge through the process of inquiry (Garet, Porter, Desimone, Birman, & Suk Yoon, 2001).

So it is clear that facilitating pedagogical change (and identifying and quantifying it) is a considerable challenge. For such reform to become widespread in the existing teacher cohort it is essential to foster a culture of professionalism, including professional learning.

2.5.1 TEACHER PROFESSIONALISM

There is an increasing trend for education jurisdictions to formalise and mandate aspects of professional learning. For example, in the context of this study, the state educational authority, Education Queensland, has appointed professional learning coordinators in every school district, and enacted regulations requiring teachers to demonstrate that they have undertaken a prescribed amount of PD that has links to the Professional Standards for Teachers (Queensland College of Teachers, 2006). Perhaps a degree of urgency is brought to the issue by the aging of

the teacher population identified earlier (Auditor-General NSW, 2008), so for many, pre-service teacher training may be a distant memory.

However, imposed innovations are generally ineffective (Pinto, 2004). Besides, the idea of professionalism implies that all teachers will be responsible for their own learning (Day, 1995). This is more likely to occur if PD programs support teachers in developing a stance whereby they can generate knowledge as part of their regular practice. A critical feature of teacher professional learning in the study by Carpenter et al. (2004) was their model for teachers to use student work to engage in their own inquiry into student thinking.

While teachers are often seen as sole practitioners, Larkin, Seyforth, and Lasky (2009) affirmed the importance of a shared philosophical purpose among teachers. The leadership practices they found to be important were those *among* teachers, rather than those coming from school or district administrations.

Earlier sections have discussed the nature of change, especially the influence of constructivism on classroom practice and teaching *students*. However, this project focuses primarily on changing *teacher* behaviours, so the following section considers some implications of teaching adults.

2.5.2 ADULT EDUCATION PRINCIPLES

The same constructivist principles advocated in the classroom are applied by Loucks-Horsley and Matsumoto (1999) to teachers' professional learning with this three-step classroom-focussed learning model: (a) create sufficient *cognitive dissonance* to disturb the equilibrium between teachers' existing beliefs and practices and their experience with content, student learning and teaching; (b) provide time, context and support to resolve that dissonance; and (c) ensure that the dissonance-creating and dissonance-resolving activities are connected to teachers' own students and context.

In a constructivist mode of professional learning, teachers should encounter science and science teaching through the same methods and strategies as students learn science in schools. If professional learning facilitators are to provide authentic learning models they need to "practice what they preach" (Posnanski, 2002).

Making a link from constructivist classroom models such as Bybee's 5Es to PD programs for teachers, Loucks-Horsley, Hewson, and Love (2003) offer a learning

model for developing conceptual understandings in four stages: invite, explore, explain, and apply. This is very similar to the 5Es model used by *Primary Connections*, so provides relevant guidance for facilitators supporting adult learning in the context of that program. Table 2.15 provides detail of how the model translates to actual practice for facilitators.

Table 2.15

What the Professional Developer Does (Loucks-Horsley et al., 2003)

Stage	Facilitator's role
Invite	Create interest Generate curiosity Stimulate dialogue Raise questions Elicit teachers' knowledge and beliefs
Explore, discover, create	Teachers/learners work together without input from facilitator Multiple opportunities to explore idea/strategy/concept Monitor teacher/learner interactions Ask probing questions to redirect dialogue and investigations where necessary Time for teachers/learners to work through challenges Act as consultant to teachers/learners
Explain, propose solutions	Encourage teachers/learners to explain concepts in their own words Ask for evidence and clarification Provide formal definitions and labels Use teachers'/learners' previous experience as the basis for explanations
Apply, take action	Encourage teachers/learners to apply or extend concepts and skills to new situations Remind teachers/learners of alternative explanations Seek evidence of changed thinking or behaviour Ask open-ended questions, e.g. "Why do you think...?" "What evidence do you have?" and "How would you explain ...?"

As outlined above, constructivist models provide a sound basis for promoting reform in teacher practice; however the literature identifies some pervasive factors that work against it. PD models need to target these constraints; therefore some of the relevant research findings are outlined in the following section.

2.6 WHAT ARE THE CONSTRAINTS TO CHANGE?

Among the factors identified as constraints to change, there is considerable literature on the powerful influence of teacher beliefs.

2.6.1 TEACHER BELIEFS

The beliefs that teachers and PD facilitators bring to the PD experience shape how they interpret and implement curriculum reforms (Fetters, Czerniak, Fish, & Shawberry, 2002). The values and beliefs of teachers need to be the central focus of educational reforms and PD initiatives, according to a long-term study by Larkin et al. (2009). A teacher's identity involves interconnected beliefs and knowledge about subject matter, teaching and learning as well as personal self-efficacy and orientation toward work and change (Collopy, 2003). Or, put another way, "changing curriculum and pedagogy is to change a teacher's beliefs on educating a child" (Keys, 2006, p. 43).

In his study of a curriculum reform program, Pinto (2004) found that acceptance of a rationale did not mean it would be put into practice; even a real willingness to implement a curriculum innovation would be negated by teachers falling back on well-established methods that had worked in the past. With that substantial challenge in mind, we will now consider the role of beliefs in the change process as it relates more specifically to our topic of science education.

2.6.2 BELIEFS ABOUT TEACHING SCIENCE

Traditional science teaching has been defined as including didactic approaches to teaching, memorisation of facts and explanations, and summative forms of assessment (Goodrum, 2006). However, teachers in Australia are being urged to embrace a new paradigm which does not focus on simply transmitting information to students but on learning by constructing meaning; to achieve this, teachers may need paradigm shifts in their personal beliefs about knowing, teaching and learning (Brownlee, 2003).

Keys (2006) found three sets of teacher beliefs shaping the science curriculum:

1. Expressed beliefs – that the teacher desired to adopt but was unwilling to make certain sacrifices to achieve;
2. Entrenched beliefs – foundational to actions; provided reasons to not act on expressed beliefs; and
3. Manifested beliefs – subconsciously acted on; outworking of entrenched beliefs.

In Sheffield's (2004) case study of teachers implementing a curriculum innovation, the teachers' *expressed beliefs* about the purpose of science teaching, and about ideal models of teaching and learning, were in line with currently accepted theories of effective practice. However, prior to the innovation these beliefs were not reflected in the teachers' practice (due to perceived constraints, i.e., *entrenched beliefs*) even though many teachers in the study were aware of the mismatch between their current practice and their beliefs about ideal classroom practice.

Awareness of the influence of beliefs goes some way towards explaining why the intended curriculum does not align with the enacted curriculum (see "knowledge filter model", Section 2.6.4). Also central to the shape of the enacted curriculum are teachers' beliefs in their own ability to teach; their "self-efficacy".

2.6.3 SELF-EFFICACY

To aid their studies into the links between beliefs and practices, Riggs and Enochs (1990) developed the *Science Teaching Efficacy Belief Instrument* (STEBI) with two result scales, the *Personal Science Teaching Efficacy Belief* (PSTE) scale and the *Science Teaching Outcome Expectancy* (STOE) scale. This was based on the work of Bandura (1986), who differentiates the two aspects because individuals may believe a particular action will achieve an outcome, but not act because they doubt they have the skill to carry it out. This model of change indicates that beliefs need to change before there will be a change in behaviour. Change occurs when people expect certain behaviours to produce desirable outcomes (*outcome expectancy*), as well as believing in their own ability to perform those behaviours (*self-efficacy*) (Riggs & Enochs, 1990). Their model of change (summarised in Figure 2.1) shows a sequential cause-effect relationship. Developing outcome expectancy and self-efficacy in teachers is considered essential to achieving scientific literacy for all students (Khourey-Bowers & Simonis, 2004).

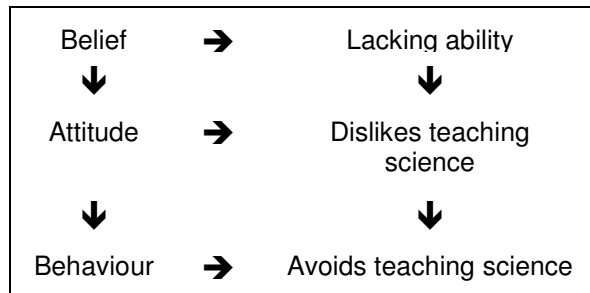


Figure 2.1. Interrelationship of beliefs, attitudes and behaviour.

A study of effective teachers of science found many primary teachers lack confidence teaching science, partly through lack of knowledge, but also because of a lack of exposure to models of how science can be productively taught to primary school children (Tytler et al., 2002). Watters and Ginns (1995) reported similar findings with their pre-service teaching students. The *Primary Connections* program aims to address this issue, not only through its learning model, but with a DVD of classroom examples from trial schools (Australian Academy of Science, 2005b) which present actual classroom practice.

Showing teachers positive models of practice may be beneficial but it will not, on its own, substantially modify beliefs. The following section will lead towards developing a model for professional learning that facilitates durable change and effective implementation of constructivist curricula, in line with the aims of the *Primary Connections* program.

2.6.4 CURRICULUM CHANGE AND IMPLEMENTATION

Sustained change in practice and belief takes time because there is much to *unlearn*, and much that is complex to *learn* (Loucks-Horsley & Matsumoto, 1999). In the constructivist model, teachers' preconceptions and beliefs about teaching will only change if there is hard evidence of the success of an alternative approach. Significant change in teachers' beliefs and attitudes is likely to take place only *after* changes in student learning outcomes are evidenced (Guskey, 2002). Guskey's model of the process of teacher change proposes this sequence:

1. Staff development (*followed by...*)
2. Change in teachers' classroom practices
3. Change in student learning outcomes
4. Change in teachers' beliefs and attitudes

Guskey is quite emphatic about the order of events, stating that only teachers who used new procedures and gained evidence of positive change in their students' learning expressed these changes in their beliefs and attitudes. When there was no such evidence, no significant change in teachers' beliefs or attitudes was observed (Guskey, 2002). A study of pre-service students found evidence in line with Guskey's proposition, namely, that outcome expectancy improved when students successfully implemented teaching programs to children (Watters & Ginns, 1995).

A contrasting view is that changes in student learning are preceded by changes in teacher beliefs, understandings and practices. Sheffield (2004) also developed a linear model in which changed beliefs must *precede* change in practice. Her case study compares teachers' beliefs about their current science teaching practice with their beliefs about ideal science teaching and how these beliefs direct classroom practice. She found that teachers must be able to envision the advantages of incorporating new strategies into their existing practice, and consequently seek to make these changes to their teaching.

Although these findings contrast with Guskey's view that actual belief change follows clear evidence of improved classroom outcomes, perhaps the "envisioning" Sheffield mentions may fill that need for evidence and provides some middle ground between the opposing views. The disparity between these two constructs is worthy of further study.

A few years after the introduction of the constructivism-influenced Queensland Science Syllabus (Queensland School Curriculum Council, 1999), a study of Queensland secondary science teachers (Odgers, 2003) found that 41% supported a constructivist view of scientific knowledge but only 3% of lessons reported by the teachers were based on the constructivist view of learning. Odgers concluded that, despite the constructivist views of science learning and pedagogy apparent in current Queensland science syllabuses and in-service programs, constructivism had not been fully embraced by teachers. In 2007, Cooper found that the term "constructivism" was unfamiliar to almost half his study's sample of Queensland secondary teachers

although there was some limited evidence of constructivist classroom practice. Further research is warranted to see whether the situation is similar with *primary* teachers.

Clearly the classroom practice, and what is being experienced by students, is somewhat different from what was intended by the curriculum designers. Hardy (1993) outlines this situation succinctly, using the terms “Planned Curriculum”, “Implemented Curriculum” and “Experienced Curriculum” to highlight the different perceptions of the designers who write it, the teachers who implement it, and the students who experience it.

Hall and Hord (1987) pre-empted Odgers’ findings with their typical scenario of the implementation of new curriculum: “Policymakers would announce that a change was to occur on a particular date. The innovation would be delivered to the school, and it was assumed teachers used it. It was also assumed that the teachers used the innovation ‘appropriately’” (p. 7). They found that there was more to change than simply “delivering the innovation ‘box’ to the classroom door”; rather, there was a *process* involved. Their *Concerns-Based Adoption Model* (CBAM) for facilitating change provides a useful structure for anticipating much that will occur during a change process. They identify seven *stages of concern*, a set of *levels of use* of an innovation, and *innovation configurations* that identify adaptations to the innovation (Table 2.16).

Table 2.16

The Concerns-Based Adoption Model (CBAM) (Hall & Hord, 1987)

Stages of Concern	Expressions of concern
6 Refocusing	I have some ideas about something that would work even better.
5 Collaboration	I am concerned about relating what I am doing with what others are doing.
4 Consequence	How is my use affecting kids?
3 Management	I seem to be spending all my time in getting materials ready.
2 Personal	How will using it affect me?
1 Informational	I would like to know more about...
0 Awareness	I am not concerned about it.

A key factor in teachers' reluctance to engage with an innovation (in addition to the factors of *time*, *needs* and *context* identified earlier) is that it is imposed from outside. External efforts to change the way science is taught are frustrated by individual teachers who "modify curricula to meet situational needs in ways that may be at odds with the goals of such reforms" (Larkin et al., 2009, p. 829). Their relative isolation as solo practitioners gives teachers the freedom to do this; within the relative privacy of their classrooms and schools, teachers are even able to resist legally imposed changes if they wish to (Sikes, 1992).

Harlen and Holroyd (1997) identified some of the coping strategies employed by primary teachers with low confidence levels in science (Table 2.17). Any teacher may feel pressured to adopt such coping strategies occasionally, but when they become the only, or "normal" strategies, they can severely limit pupils' learning. Harlen and Holroyd's (1997) research suggested that in Scotland this may have been the case for more than half the primary teachers.

Table 2.17

Primary Teachers' Coping Strategies (Harlen & Holroyd, 1997)

Teach as little science as possible.

Concentrate on areas of science in which confidence is highest.

Rely on kits, textbooks, and worksheets.

Emphasize expository teaching methods.

Avoid all but the simplest hands-on work.

Avoid using any apparatus that can go wrong.

Use outside experts whenever possible.

Change to a constructivist approach does not only involve the teacher. Students are active participants and need to be engaged in the change process. Conflicts may arise when there are mismatches between teachers' and students' views: Change may be unpopular with the students themselves, who often resist teachers' attempts to modify their own practice, and consequently, students' mode of learning (Sheffield, 2004). Such conflict can impact on teachers' beliefs about the efficacy of innovations and derail the change process.

In addition to the role of teachers and students in the change process, school administrations have a major impact through their provision of resources and professional learning opportunities for teachers. In their study of the implementation of a Queensland science syllabus, Peers, Diezmann, and Watters (2003) found the five key areas of concern for teachers involved in the change were largely the responsibility of administrators: (1) support for planning, including time; (2) science equipment; (3) support for development of teachers' knowledge, (4) their classroom management strategies, and (5) ways to cope with change.

However, even if these elements are managed effectively, teachers' knowledge and beliefs remain key targets of a change process. They can influence change by serving as a *filter* through which new information is interpreted; as mentioned earlier (Hardy, 1993), teachers may enact lessons that are very different from what curriculum developers or educational reformers intended (Collopy, 2003).

The "knowledge filter" is a term used by Keys (2006) in his model that explains how teacher knowledge shapes curriculum implementation and why the *intended* curriculum does not align with the *enacted* curriculum. As the intended curriculum is processed through various aspects of teachers' knowledge (including pedagogical content, theories and practical knowledge) it is reshaped into the enacted curriculum.

Goodrum (2006) identified the considerable gap between the intended curriculum and the enacted curriculum experienced by students. In a later paper, he highlights the need for curriculum and PD resources that can show teachers how to translate the intended curriculum into classroom practice, as well as demonstrating that an outcomes-focused curriculum can really work to the benefit of students (Goodrum, 2007; Keys, 2006). The suitability of the *Primary Connections* professional learning program in filling that role will be considered, but to do that reliably there will first be a more general review of the literature related to designing effective professional learning programs.

2.7 WHAT ARE THE CHARACTERISTICS OF EFFECTIVE PROFESSIONAL LEARNING PROGRAMS?

The initial discussion of the nature of science and of effective science teaching identified the target area for this study. The following sections then outlined the

nature of the change required by teachers, and some of the issues involved in achieving that change. With that context in place, we can now consider the design of professional learning programs with a view to developing a theoretical model with which to examine the effectiveness of the *Primary Connections* approach.

However, this review will begin with the aspects of programs that are *not* effective since, as Guskey (1997) points out, reviews of the PD literature typically do a better job of documenting inadequacies than prescribing solutions.

2.7.1 CONSTRAINTS TO PROFESSIONAL LEARNING PROGRAMS

There are large discrepancies between what is known to be effective as PD and what teachers actually experience as PD (Loucks-Horsley & Matsumoto, 1999). A typical model for teacher PD in primary schools is a one-off presentation in an after-school meeting of the whole staff. This scenario is roundly criticised by numerous studies (e.g. Bahr, Dole, Bahr, Barton, & Davies, 2007).

Access to time for PD is one of the major concerns for professional learning facilitators; in fact it is one of three key characteristics of *ineffectual* PD consistently identified in the research: (a) time limitations resulting in one-off or short-term events, (b) failure to consider the individual needs of teachers, and (c) failure to link to classroom context. Each of these will be examined in the following sections.

Time

By far the most criticised characteristic of PD involves adequate time. Bahr et al. (2007) found considerable evidence that successful PD is “a process, not an event” (p. 17) and that one-off PD events seldom have any impact on teachers or their practice. This is because of the considerable time it takes for teachers to understand an innovation; to change their views and then their science teaching practice; and finally to be able to identify a positive difference in their students’ knowledge (Akerson & Hanuscin, 2007; Peers et al., 2003).

PD planners need to consider longer-term processes of change, thinking in terms of sequences and combinations of activities rather than isolated courses or events (Eraut, 1995; Lederman & Lederman, 2004).

Birman, Desimone, Porter, and Garet (2000) argue that unless adequate time can be given for meaningful change, it would be better not to provide the program at all. Their substantial review of PD programs (>1000 surveys plus 16 case studies)

found that active reform projects (e.g., study group, teacher network, mentoring relationship, resource centre) were more effective than traditional presentations and workshops, but the difference was largely explained by the extra time involved in these strategies. They found that when traditional activities such as workshops or institutes were longer, they too had better core features and were just as effective. Addressing the question of whether PD should be offered to as many teachers as possible, or focus on a smaller number of high quality, influential programs, Birman et al. recommend that budgets not be spread too thin, but that schools and districts focus on providing *only* high quality programs, either by investing more resources or by supporting fewer teachers.

Both principals and teachers recognise that professional learning sustained over time is more beneficial than short-term programs (Goodrum, 2007). In a survey of over 500 teachers and principals in Ohio (Kahle & Boone, 2000), participants were asked to compare their experience with a PD program that was sustained over time, with a program that provided two- to three-day workshops with no follow-up. Participants who had experienced both, ranked PD programs *sustained over time* above PD *during the school day*. Furthermore, Kahle and Boone's findings dispel the myths that teachers will not volunteer for long-term PD or that principals will not support such activities. They found that both teachers and principals understand that the most effective staff development activities are continuous and ongoing.

Ongoing interactions between teachers and PD facilitators not only nurture their change and evolution process, but as Tinoca (2004) points out, it is a two-way street with facilitators able to collect valuable feedback from teachers and their students to assess and improve PD programs.

Individual needs

The issue of individual needs is also highlighted in the research. In 1986, Guskey found that teachers engaging in PD programs hoped to gain specific, concrete and practical ideas directly related to the daily operation of their classrooms, and that this did not happen if there was a "production line" approach to the mass rollout of an innovation. Two decades later, Bahr et al. (2007) found that professionals still consider that their time is wasted by "sheep-dip" seminars that ignore prior expertise. Teachers hold the ultimate responsibility for bringing about educational reform and consequently, PD designers need to attend more to what

“teachers think, feel, and need in order to improve science instruction in their classrooms” (Dass, 2001, p. 982).

Classroom context

Linking PD to the classroom context is a related issue that is proven to be essential. Programs undertaken in isolation from teachers’ ongoing classroom responsibilities have little impact on teaching practices or student learning (Collopy, 2003; Guskey, 2002). Radford’s (1998) study of a PD program documented changes in teachers’ classroom behaviour in response to increased confidence in their ability. This increased self-efficacy developed through practical hands-on experience of the roles that their students would experience, as detailed in Table 2.18.

Table 2.18

Linking Professional Learning to Classroom Context (Radford, 1998)

Teacher learning outcome	Program strategy
Gained skills in inquiry-based learning.	Designed and completed experiments in PD sessions and with their classes.
Constructed their understanding of science concepts.	Engaged in activities and discussions that replicated ways they were expected to teach.
Increased confidence in their ability to teach science.	Received positive affirmations from project staff (verbally and through journal comments), networks of peers and students as they implemented the program in their classrooms.

The kind of science instruction teachers experienced when they were students differs greatly from the models proposed by current reforms, so many find it difficult to change; consequently teachers benefit from inquiry experiences grounded in the same pedagogical principles they are expected to implement with their own students (Loucks-Horsley et al., 2003). However, a typical PD scenario is where participants “Sit and get. Where they sit there forever and just take notes” (Rogers et al., 2007, p. 524). The study by Rogers et al. emphasises the importance of engaging teachers in the PD program’s activities in a manner similar to that proposed for their students. This leads us to considering, in the following section, how constructivist pedagogies influence professional learning programs.

2.7.2 PRINCIPLES OF PROFESSIONAL LEARNING

Having outlined some of the common problems with PD, this section will examine the research relating to effective strategies. Fetters et al. (2002) developed a concise outline for programs that build primary teachers' confidence to teach science. They found that effective programs will model good inquiry teaching in an encouraging, enjoyable manner; strengthen teachers' science content knowledge; help teachers understand how science can be integrated with other subject areas; and give teachers time to reflect on the growth in confidence that they have experienced.

Those basic program characteristics are often repeated and expanded upon by the extensive literature on teacher professional learning. To provide a concise overview of the trends emerging from the literature (including many of the studies noted elsewhere in this chapter), eight key themes have been identified and compiled in the table on page 42 (Table 2.19). The common themes outlined in the table provide a set of core principles to guide the design or assessment of effective professional learning programs. To address how those principles can be enacted in practice, the following section reviews the literature concerning more specific strategies.

Table 2.19

Major Themes in the Literature on Professional Learning

Time: a long-term and systematic commitment to the enhancement program.

(Akerson & Hanuscin, 2007; Bahr et al., 2007; Coble & Koballa, 1996; Eraut, 1995; Kahle & Boone, 2000; Lederman & Lederman, 2004; Peers et al., 2003; Posnanski, 2002; Radford, 1998; Sikes, 1992; Tinoca, 2004)

Reflection: provide teachers with time to reflect on their learning and their growth in confidence.

(Fetters et al., 2002; Hackling, Peers, & Prain, 2007; Posnanski, 2002; Radford, 1998; Rogers et al., 2007)

Individual needs: recognition of prior expertise, and specific needs of different teachers in diverse contexts.

(Bahr et al., 2007; Dass, 2001; Eraut, 1995; Guskey, 1986; Posnanski, 2002)

Classroom context: learning has clear links to a teacher's current practice and supports integration with other subject areas.

(Appleton & Asoko, 1996; Collopy, 2003; Eraut, 1995; Fetters et al., 2002; Guskey, 2002; Radford, 1998; Rogers et al., 2007)

Collaboration: build a community of teachers who discuss and develop their purposes together, over time.

(Bahr et al., 2007; Ballone & Czerniak, 2001; Ginns & Watters, 1999; Goodrum, 2007; Rogers et al., 2007; Watters, Leung, & Ginns, 2006)

Knowledge focus, including subject content knowledge, pedagogical knowledge and pedagogical content knowledge; as well as the underlying theoretical rationale for new teaching and learning strategies, i.e., understanding the basis of reform efforts.

(Fetters et al., 2002; Fishman et al., 2003; Hackling & Prain, 2005; Kober, 1993; Magnusson et al., 1999; Morine-Dershimer & Kent, 1999; Posnanski, 2002; Radford, 1998; Shulman, 1986; van Driel et al., 2001)

Modelling classroom practice: teachers experience the roles their students will experience in inquiry-based learning.

(Appleton & Asoko, 1996; Fetters et al., 2002; Loucks-Horsley et al., 2003; Posnanski, 2002; Radford, 1998; Rogers et al., 2007)

Focus on learners and learning: highly successful programs emphasise student learning as the principal goal.

(Day, 1995; Guskey, 1997; Posnanski, 2002; Rogers et al., 2007)

2.7.3 PROFESSIONAL LEARNING STRATEGIES

In their comprehensive guide to the design of PD programs, Loucks-Horsley et al. (2003) provide a list of fifteen key strategies. The list is non-hierarchical, with the writers suggesting that a program designer's challenge is to assemble, from the list, a combination that best meets the goals and context (Table 2.20).

Table 2.20

Professional Development Strategies (Loucks-Horsley et al., 2003)

Curriculum development and adaptation
Workshops, institutes, courses and seminars
Immersion in inquiry into science and mathematics
Immersion in the world of scientists and mathematicians
Curriculum implementation
Curriculum replacement units
Action research
Case discussions
Study groups
Examining student work and student thinking and scoring assessments
Coaching and Mentoring
Partnerships with scientists and mathematicians in business, industry, and universities
Professional networks
Developing professional developers
Technology for professional learning

The relative effectiveness of the professional learning strategies listed in Table 2.20 was the basis of a review by Tinoca (2004), who applied meta-analysis to studies of thirty-seven PD programs that had measured a strategy's effect on student learning outcomes. He found considerable differences in their impact on learning, as outlined in Table 2.21.

Table 2.21

Impact of Professional Learning on Student Learning (Tinoca, 2004)

Impact	PD strategy
High impact	Curriculum replacement Curriculum development
Medium impact	Curriculum implementation Partnerships
Low impact	Workshops, seminars Partnership with scientists Case discussion Inquiry
No impact	Action research

The PD programs identified by Tinoca as having a larger impact on student learning had a set of common characteristics:

1. Emphasis on
 - (a) curriculum development, replacement or implementation;
 - (b) scientific inquiry;
 - (c) pedagogical content knowledge.
2. Substantial time commitment
 - (a) lasting over 6 months;
 - (b) total duration of at least 100 hours.

Tinoca notes that the “100 hours” figure is somewhat arbitrary, and that further research is needed to find whether there is an optimal minimum threshold. In his study, that time was made up by two 20-hour week-long workshops and a series of bi-monthly four-hour meetings. As it stands, that amount of time is far in excess of what most teachers can access for topics considered “core business” like literacy or numeracy, let alone one like science which is often viewed as “marginal” (Tytler, Smith, Grover, & Brown, 1999) or “deemphasized” (Forbes & Davis, 2007). However, there are alternate, more cost-effective ways to offer teachers extended engagement with new pedagogies. One such solution is the use of *educative curriculum materials* (Schneider & Krajcik, 2002). Since this is a key element of the

Primary Connections program, the nature of these materials, and some researchers' experiences with their application, are discussed in the following section.

2.7.4 CURRICULUM REPLACEMENT AND EDUCATIVE CURRICULUM MATERIALS

Curriculum replacement is one of the “high impact” strategies on Tinoca’s list which has particular relevance to this study so it will be discussed in more detail. Curricula that illustrate ways for teachers to explicitly teach NOS elements within inquiry lessons go a long way to supporting teachers (Akerson & Hanuscin, 2007) at the same time as they are serving a complementary purpose of enhancing student learning (Bybee, 2006), as well as providing models for teachers to follow in developing their own follow-up units.

Curricula designed with the intent of achieving teacher learning have become known as educative curriculum materials (Schneider & Krajcik, 2002). A key design element that makes a curriculum resource “educative” is making pedagogical judgements visible, that is, helping teachers see why particular tasks were applied rather than just directing their actions (Davis & Krajcik, 2005). In this way, teachers move beyond just adding new ideas to their repertoire and learn to make connections between theory and practice that inform their own curriculum designs.

A potential constraint to the effectiveness of educative curriculum materials is that they may encourage an overtly structured “recipe book” approach by teachers. Hackling explained the rationale behind the structure of the *Primary Investigations* program (Australian Academy of Science, 1998): “The majority of practical activities in the Primary Investigations curriculum are fairly closed because the curriculum was written for teachers who lacked confidence in teaching science and therefore was highly structured” (Hackling, 2005, p. 3). The logic of this approach is clear, but it could be seen as modelling a form of ‘structured constructivism’, leaving open the question of whether those same teachers, as they gain confidence with science, will be able to transition to more open-ended inquiry-based modes of science teaching.

In their longitudinal study of three beginning elementary teachers, Forbes and Davis (2007) found the teachers engaged in a substantial degree of curriculum design, drawing on a myriad of sources to adapt various textbook-based programs to suit their local needs. This move from being a curriculum “consumer” (using

provided programs) to designing their own quality curriculum materials independently can be daunting for teachers, but another element of educative curriculum materials can be templates and scaffolding for curriculum design to facilitate that aspect of professional learning. An example is the *Primary Connections* “Unit Planner” template (Australian Academy of Science, 2005a) which supports use of the 5Es learning model.

In the context of this study, educative curriculum materials are of great interest because they offer potential to mitigate three major constraints to professional learning that were identified earlier (see Section 2.7.1): time, individual needs, and classroom context. Unlike workshops and other resource-intensive strategies, teachers are able to use innovative curriculum materials over an extended period of time. They are able to adapt the implementation to suit their own and their students’ individual needs, and nothing is more closely related to current classroom context than the curriculum a teacher is presently using (Schneider, Krajcik, & Marx, 2000). Educative features of curriculum materials are offered at the teacher’s point of need, thus giving relevance and immediacy that is difficult to achieve with other professional learning strategies.

The discussion of PD has so far looked at principles for facilitators, including those compiled in Table 2.19 as well as specific strategies such as educative curriculum materials. However, we also need to consider the nature of teachers as learners, and in particular, what influences their learning. Two key “teacher behaviours” found to have a significant impact on their professional learning are reflection and collaboration. These will be addressed in the following sections with a view to understanding how they can best support a learning program.

2.7.5 REFLECTION

As noted earlier, time is a critical factor in successful implementation of change. Much of the need for time hinges on teachers’ need to reflect on the implications of program content and changes in their practice. Keys (2006) proposes moving beyond a traditional model of PD (that just provides knowledge and skills) by including reflective practices to make a connection with existing teacher beliefs. He highlights the work of Fetters et al. (2002) who found it difficult for PD facilitators to properly understand the participants’ response without seeking teacher reflections that gave insight into their thinking about the change process. Fetters et al.

found value in programs that empowered teachers by providing opportunities to continually reflect upon their beliefs, thus becoming true partners in managing a complex change. This empowerment may mitigate the negative effects of imposed change identified earlier (Larkin et al., 2009; Sikes, 1992).

Keys and Watters (2006) found that the transformative process can be largely achieved by reflective tasks. A focus group in their study impacted on teacher learning by providing a reflection opportunity:

What also became apparent was that each of the learning experiences was not sufficient in itself and had to be linked together in the learner's mind. The focus group session unintentionally had achieved this. (p. 4)

Guskey (2002) points out, in the model of change discussed earlier, that where change in beliefs is preceded by evidence that a new program or innovation actually works in classrooms, it is critically important to build feedback and reflection into the program so that teachers have time to consider their successes and robust change can occur.

Informal or structured reflection is often carried out individually, however there is substantial evidence that it can be a core activity of collaborative communities of teachers, so the literature on that topic is addressed in the next section.

2.7.6 COLLABORATIVE COMMUNITIES

In their major report on teaching and learning in Australian schools, Goodrum et al. (2001) highlighted evidence that collaboration is essential for quality. Subsequently, Goodrum (2007) added that “the power for improvement lies in the collegial efforts of teachers and their profession” (p. 2). Because teaching is fundamentally a social activity, teacher PD is critically dependent on such social interactions (Tytler et al., 1999).

In their evaluation of effectiveness of PD strategies in Queensland, Bahr et al. (2007) make nine recommendations. Most of these explicitly or implicitly promote collaboration, including partnerships between schools and universities, establishing “communities of learners”, collaborative PD programs, and a requirement for connection and discussion with colleagues about PD experiences. Roehrig et al.

(2007) made a similar finding, that curriculum implementation was strongly influenced by the presence of a supportive network at the school sites they studied.

In planning a PD strategy, Watters et al. (2006) cited extensive research to support their emphasis on collaborative principles including cooperative planning, peer tutoring, mentoring, and critical friends. A collaborative environment is particularly important for beginning teachers who need the support of peer teachers and school principals to help them identify and analyse their successes (Ginns & Watters, 1999). Their view is reinforced by Ballone and Czerniak (2001), with the six items in their list of essential aspects of pre-service training all implying a degree of collaboration: collaboration with others using the same strategy; visiting other classrooms; observing student and teacher successes; developing instructional materials; practising with colleagues to receive feedback; and participating in and presenting PD activities.

A further benefit of collaborative learning for teachers is that they are likely to encourage similar behaviour in their classrooms. When Tytler et al. (2002) observed a group of highly effective science teachers, they found that they viewed learning as a collaborative activity where children expressed ideas and developed shared understandings.

Coteaching

The concept of coteaching has specific relevance to this case study of two teachers working in tandem. Tobin (2006) describes a “step-back, step-forward, step-back cycle” which is typically repeated often in a lesson as teachers alternate between roles. Common examples of such transitions occur when a coteacher provides clarification or an alternative explanation, or when one steps aside to support an individual. When two or more teachers work together, professional learning occurs whether or not they are aware of it, as “teachers begin to teach like one another and in so doing they expand their range of teaching practices” (Tobin, 2006, p.135). This mode of informal learning may have particular relevance in the field of science teaching where it is common for teachers to have limited content knowledge or pedagogical content knowledge and they are able to provide mutual support.

2.7.7 SECTION SUMMARY

This chapter has so far outlined the research base for a set of key principles and characteristics of effective teacher PD in science. Those principles can now be applied to a critique of the professional learning design in the *Primary Connections* program as we consider its potential to bring about changed practice in primary classroom science. The background thus developed will provide guidance in moving towards implementing and evaluating a professional learning intervention.

2.8 THE *PRIMARY CONNECTIONS* PROGRAM

A trial of the *Primary Connections* program (Hackling & Prain, 2005) has provided considerable evidence of positive change in teachers' science teaching self-efficacy. The most significant advances were with teachers who came from a very low starting point. One such teacher (Lloyd, 2007) reported that her experience with *Primary Connections* enhanced her students' learning outcomes, their confidence in using scientific terminology and their ability to transfer their learning to new situations. The students were now planning, conducting and evaluating their investigations independently. This section considers attributes of the program that may have supported such effective change.

2.8.1 ELEMENTS OF THE PROGRAM

One element of the *Primary Connections* professional learning program is a set of model curriculum units, broadly covering the primary science curriculum, which provide classroom contexts for a suite of constructivist pedagogies. Teachers are encouraged to use these units to gain confidence with a suite of constructivist pedagogies, albeit in a relatively structured form, before using the provided unit planning template to develop their own programs which align with constructivist principles of learning. To support implementation of this process, the Australian Academy of Science has trained professional learning facilitators from all Australian states, territories and education jurisdictions. Facilitators are trained to present a program that includes an introductory two-hour workshop, followed by a set of 90-minute modules: "Linking science with literacy"; "5Es teaching and learning model"; "Investigating"; "Assessment for learning"; and "Cooperative learning strategies".

Each module is based on the 5Es model and is supported by a detailed set of resources, including presenter's notes, PowerPoint presentation, worksheets and handouts, self assessment matrix and an evaluation form. A DVD (Australian Academy of Science, 2005b) provides related examples of classroom practice and reflections from trial program teachers.

2.8.2 PRIMARY CONNECTIONS PROFESSIONAL LEARNING MODEL

Fishman et al. (2003) noted that although new materials for science education are usually accompanied by PD programs, such activities are frequently treated as an afterthought, ancillary to the research and development of the program. *Primary Connections* is an exception to this pattern, with "Teacher professional learning" identified as the central component, supported in part by curriculum materials, as indicated in Figure 2.2.

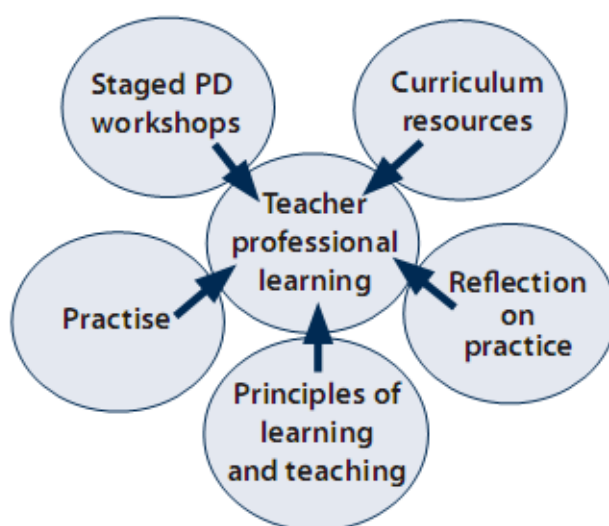


Figure 2.2. The *Primary Connections* professional learning model (Hackling & Prain, 2005, p. 1).

The program was based soundly on current research, displaying features consistent with contemporary "best practice". Table 2.22 maps the program's key elements against literature discussed elsewhere in this chapter.

Table 2.22

Research Findings Supporting the Primary Connections Professional Learning Model

Elements of the <i>Primary Connections</i> professional learning model	Supporting literature
Professional learning workshops based on a constructivist model.	Bybee, 1997, 2006; Loucks-Horsley & Matsumoto, 1999; Posnanski, 2002, Rogers et al., 2007
Exemplary curriculum resources.	Akerson & Hanuscin, 2007; Bybee et al., 2006; Davis & Krajcik, 2005; Schneider & Krajcik, 2002
Opportunities for reflection and collegial support.	Fetters et al., 2002; Keys & Watters 2006; Sikes, 1992
Analysis of professional practice based on principles of teaching and learning.	Loucks-Horsley et al., 2003; Tytler, 2002; Bybee, 1997; Sheffield, 2004; Tinoca, 2004
Extended professional engagement.	Bahr et al., 2007; Birman et al, 2000; Goodrum, 2007; Kahle & Boone, 2000
Links between science and literacy.	Norris & Phillips, 2003
Scaffolded and collegial opportunity to develop new curriculum units.	Forbes & Davis, 2007; Schneider, Krajcik, & Marx, 2000.

To provide another mode of analysis, a set of principles for effective PD program design compiled by Loucks-Horsley et al. (2003) are applied as a rubric to assess the structure of the *Primary Connections* professional learning program. It is apparent from the resultant outline (Table 2.23) that the program was built around a set of elements that, in combination, effectively address the seven key principles.

Table 2.23

Mapping the Primary Connections Professional Learning Program Against Seven Principles of Effective PD Experiences

Principles of effective PD (Loucks-Horsley et al., 2003)	Primary Connections professional learning program (Australian Academy of Science, 2007; Hackling & Prain, 2005)
1 Well-defined image of effective classroom learning and teaching.	Curriculum resources model teaching and learning strategies. Planning template supports extended use of the learning model.
2 Teachers build knowledge and skills – in-depth subject knowledge as well as pedagogical content knowledge.	Workshops provide relevant knowledge (content, pedagogical and PCK) as well as modelling practice. Teaching of model curriculum units embeds knowledge of new pedagogies.
3 Modelling classroom strategies – explicitly connecting PD with classroom practice.	Principles of learning and teaching modelled in workshops and curriculum resources, including 5Es model, cooperative learning strategies, investigation planning outlines.
4 Building a learning community – teachers learn and share together.	Scaffolded and collegial opportunity to develop new curriculum units Pairs or year-level groups of teachers from a school are encouraged to participate in the program, collaboratively learning, implementing, reflecting.
5 Teachers in leadership roles – supporting others, promoting reform.	Workshops provide training in facilitating professional learning for colleagues.
6 Links within the system – integration with curriculum and assessment frameworks, school and district agendas.	Program is aligned with national learning statements (and consequently, state ones as well). Supported as a state-wide initiative by government and independent jurisdictions. Mapped against state Essential Learnings and assessment frameworks (Queensland Studies Authority, 2008).
7 Ongoing assessment – review and improve programs.	Reflecting and journaling after workshops. Deep reflection modelled using 5Rs model (Reporting, Responding, Relating, Reasoning and Reconstructing). Evaluation surveys of all professional learning events.

While the designers of *Primary Connections* emphasise that the published curriculum materials are to be used in conjunction with the other components of the PD program, they are the most visible component and may be the only part many teachers encounter. Such materials alone can be an effective source of PD if they are intentionally designed to be “educative” (Forbes & Davis, 2007). This situation is certainly the case with *Primary Connections*, where implementing a unit is not an

end in itself; rather, it is intended as a means of modelling constructivist pedagogies. These pedagogies will then be applied in the units subsequently planned by the teachers. Thus, two key components of the project are *curriculum replacement* and *curriculum development*, the two PD strategies identified earlier as having high impact on student outcomes (Tinoca, 2004).

2.8.3 CURRICULUM REPLACEMENT

The Australian Academy of Science is developing *Primary Connections* curriculum units for all years of primary school and addressing all four strands of the National Statement and Profile for Science: Life and Living, Earth and Beyond, Energy and Change, and Natural and Processed Materials (Australian Academy of Science, 2005a). These units all use a common framework that includes: the 5Es instructional model; open-ended inquiries; collaborative learning strategies; integrated literacy; and assessment for learning. It is anticipated that teachers who replace their current science programs with these units will become comfortable with the constructivist pedagogies, which will then carry over to other aspects of their teaching (Davis & Krajcik, 2005).

2.8.4 CURRICULUM DEVELOPMENT

Developers of the program have explained in public forums that the *Primary Connections* curriculum units are not intended to become a complete science curriculum; in fact, they do not plan to produce enough units to cover the whole primary science curriculum. Once teachers have used some of the exemplary *Primary Connections* units, it is intended that they will be supported in writing their own units based on the same model, with the assistance of planning templates. Doing this collaboratively, with appropriate support, is an effective way to achieve sustainable change (Forbes & Davis, 2007; Loucks-Horsley et al., 2003).

2.8.5 IMPLEMENTATION ISSUES

The *Primary Connections* professional learning package provides facilitators with all the materials needed to comprehensively implement the program with its associated pedagogies and resources, but here we again confront the issue of intended curriculum versus enacted curriculum, because the professional learning program will be implemented in schools within all the usual constraints of time, resources, and competing priorities. Providing a suite of well-designed professional

learning resources is a substantial achievement, but school administrators and PD facilitators are left to solve perhaps the most difficult problem of implementation, that of finding and allocating resources. My recent experience facilitating the above-mentioned presentations suggests that it is unlikely that many, if any, schools will be able to implement the program in full.

This brings us back to the advice of Birman et al. (2000), that it is better to do a small number of high quality programs, or programs with fewer participants, than to compromise outcomes by spreading the budget too thinly. District and school professional learning coordinators have a complex balancing act in deciding which aspects of the professional learning program will be offered to which teachers.

However, regardless of whether teachers are able to access some, or all, of the professional learning program, or they just download unit outlines from the website, key elements of the constructivist model should be clearly apparent. How effectively this combination of factors can facilitate meaningful change is a focus of this study.

This chapter has now provided an outline of key principles and strategies for a professional learning program that will support teachers in establishing constructivist science learning environments. Those principles have been mapped against the *Primary Connections* model, which displays a high degree of convergence with contemporary research findings. Having laid this groundwork, a basis has been established for planning a school-based intervention to implement the *Primary Connections* program in a way that encourages authentic constructivist pedagogies.

2.9 PROFESSIONAL DEVELOPMENT MODEL

This study investigated a professional learning program in the target school. Details of the strategy are outlined in Chapter 3, but a set of guiding principles drawn from the literature will be discussed here.

Following their Stage 2 Trial of *Primary Connections*, Hackling and Prain (2005) made a number of recommendations to guide the program's professional learning. These were applied in the current study, as outlined in Table 2.24.

Table 2.24

Elements of PD Model Mapped Against Hackling and Prain's Recommended Principles

Recommended principles for program implementation (Hackling & Prain, 2005, p. 96)	Implemented PD model
Whole-school implementation (where possible).	Introductory PD workshops presented to whole staff.
Implementation based on both professional learning and curriculum resources.	Program based on implementing existing <i>Primary Connections</i> unit in classroom, supported by PD workshops.
Professional learning workshops to be facilitated by <i>Primary Connections</i> trained facilitators.	The researcher is an accredited facilitator.
Professional learning workshops to be presented by facilitator plus a trial teacher (where facilitators are not trial teachers).	There was no trial teacher available.
Team-based school coordination to ensure succession planning.	Implementation team included the two teacher subjects supported by the school's Head of Curriculum and Deputy Principal.

In keeping with the advice for PD facilitators to “practise what they preach” by incorporating advocated strategies in their own learning models, the intervention was based on a constructivist learning model. A number of such models was discussed in Section 2.4.2; any of those models could have been adapted to this intervention but it was considered most appropriate to apply the 5Es as used in *Primary Connections* to more closely align the professional learning component with the classroom units. As noted in Chapter 2, the model provides *experiences* and *time* for learners to recognise inadequacies in their current ideas, explore new explanations, reflect on their ideas, and to construct new concepts (Bybee, 2006). However Bybee (1997) cautioned that while such a structured sequence enhances the *possibilities* of learning, a model alone cannot *ensure* learning. In classroom contexts, it is the role of teachers to manage and complete the process of change. In this intervention where the model is being applied to teachers’ professional learning, there is no presenter or facilitator involved for much of the time, so a constraint to positive change will be the degree to which other elements of the program, in particular the educative curriculum materials (Schneider & Krajcik, 2002), are able support ongoing learning.

Table 2.25 is an outline of the sequence of activities, as well as links to a selection of the literature cited in this chapter that provided an informed basis for

design. These links are grouped in two rows: (a) *Constraints to be managed* highlights key issues of concern that were considered at each stage, and (b) *Change-model stages* links each step to elements of the various models of change discussed earlier.

Table 2.25

Model for Professional Development

5Es model →	Engage →	Explore →	Explain →	Elaborate →	Evaluate
<i>Activity</i>	Orienting: Introductory workshop(s) engage whole staff in inquiry-based learning models. Diagnostic assessment of teachers guides the facilitator(s).	Planning: Teachers explore the structure of the <i>Primary Connections</i> model as they plan implementation. Diagnostic assessment of students informs the planning.	Implementing: Through the practice of implementing a unit, teachers develop their understandings of constructivist pedagogies and accommodate these into their PCK. Formative assessment of students guides implementation.	Designing: Teachers use planning template to design next unit and elaborate on the model. Summative assessment of students consolidates teacher learning and informed planning of next unit.	Reflecting: Teachers reflect on the process and their learning journey. Implications for future planning are considered.
<i>Professional learning focus</i>	Model 5Es and inquiry-based learning strategies through hands-on activities. Diagnostic assessment of teacher participants.	Support adaptation of resources to local context. Support development of content knowledge. Build collaborative partnerships and mentoring processes.	Support implementation of unit, address teachers' concerns. Focus on PCK.	Model and support use of planning template.	Facilitate collaborative reflection process to clarify and consolidate teachers' learning and change.
<i>Constraints to be managed</i>	Limited self-efficacy beliefs. Flawed NOS concepts. Individual needs (Bahr et al., 2007; Guskey, 1986).	Time to adequately consider and understand rationale for new models (Bahr et al., 2007). Teachers' "knowledge filter" (Keys, 2006) modifies unit to fit existing beliefs (Cuban, 1990).	Student resistance to changed learning environment (Sheffield, 2004). Teachers' entrenched and manifested beliefs resist changed practice (Keys, 2006). Adequate teaching resources and equipment (Peers et al., 2003).	Time and support for planning (Peers et al., 2003). Teachers' "knowledge filter" (Keys, 2006) modifies unit to fit existing beliefs (Cuban, 1990).	Time for reflection (Fetters et al., 2002; Hackling, Peers, & Prain, 2007).
<i>Change-model stages</i>	Highlighting preconceptions (M. Stein et al., 2007). Create cognitive dissonance (Bybee et al., 2006; Loucks-Horsley & Matsumoto, 1999; Nussbaum & Novick, 1982).	Teachers envision advantages of incorporating new strategies (Sheffield, 2004).	Provide time, context and support to resolve cognitive dissonance (Loucks-Horsley & Matsumoto, 1999). Successful implementation supports improved outcome expectancy (Watters & Ginns, 1995).	Heightened self-efficacy supports ongoing change (Riggs & Enochs, 1990). Encourage cognitive accommodation (Nussbaum & Novick, 1982).	Evidence of improved student outcomes causes positive change in beliefs (Guskey, 2002). Ensure dissonance-resolving activities are relevant to local context (Loucks-Horsley & Matsumoto, 1999).

For clarity, a simple sequential outline of the above model is presented in Figure 2.3. This shows the five phases of the process, based on the 5Es model. Some of the key positive and negative influences on the change process are identified, and at which stages in the sequence they were expected to have the greatest impact. The constructivist basis of the strategy is highlighted by including the three overlapping phases of Nussbaum and Novick's (1982) learning model.

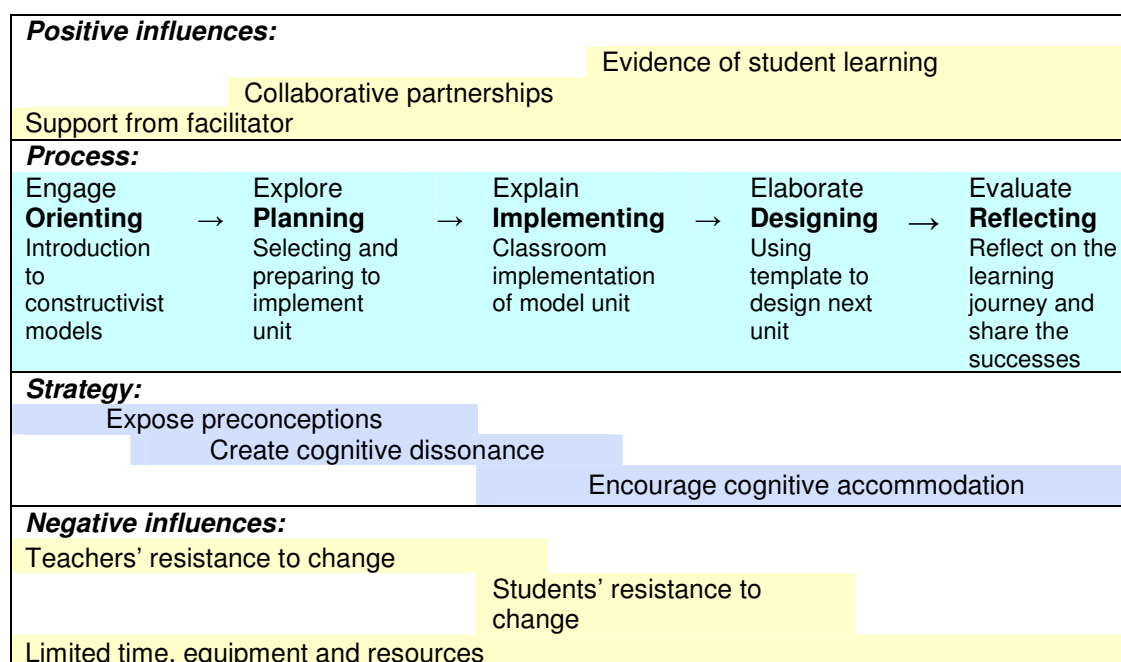


Figure 2.3. A simplified representation of the PD model.

This PD intervention provided a context for study of the change process in sample classrooms. Further details of the program and how it linked to the various aspects of data collection will be discussed in Chapter 3. This chapter has now outlined, from the literature, a research-based foundation for the study and the PD intervention, so we are now able to consider the specific research questions that focused the study.

2.10 RESEARCH QUESTIONS

The PD model suggested a means of facilitating change in teachers' practice towards constructivist-inspired learning environments. Many aspects of that change process warrant further investigation, however the scope of this study required that only a few specific issues were targeted, as outlined in this section.

There is a need for curriculum and PD resources that "show teachers how to translate the intended curriculum into classroom action and to demonstrate that an

outcomes-focused curriculum can really work and benefit students” (Goodrum, 2007, p. 1), or in other words, for the planned curriculum to become the enacted curriculum. A key question for primary educators in Australia is whether the *Primary Connections* professional learning program fills that role. Therefore, the key research question for this study is:

What are the changes in teachers’ beliefs and practices associated with implementing a constructivist-inspired learning program?

To help articulate a response to the key question, four issues arising from the literature provide the basis for supporting research questions.

1. Structured constructivism

In the same way that university educators bemoan the fact that “there’s still a lot of lectures about constructivism”, one may ask whether a *structured* program like *Primary Connections*, with prescribed lesson plans and content and written for teachers who lack confidence in teaching science, can support significant change towards constructivist pedagogies that are responsive to student input (as discussed in Section 2.7.4). Despite the professional learning program, teachers may see the program as a set of books to be used as a “resource” in a traditional teacher’s repertoire, rather than a model for a fundamentally new way of working. **In what ways do the professional learning program and the published curriculum units foster the development of inquiry-based science in a constructivist learning environment?**

2. Expressed beliefs vs. enacted beliefs

In some Queensland secondary schools, there is a vast gap between the degree of constructivism in expressed beliefs and what is enacted in the classroom (Cooper, 2007; Odgers, 2003) but there is a lack of evidence about whether there is a parallel situation in primary schools. Consequently, this case study in a primary school setting has addressed the following question: **To what extent are teachers’ expressed beliefs about constructivist learning aligned with their enacted beliefs?**

3. Teachers’ perception of student outcomes

The ultimate goal of an educational reform is to improve student learning, and this constitutes a measure of the efficacy of the change in a teacher’s practice. **How**

does implementation of the PD intervention change teacher perceptions of student learning in science?

The key research question, with its supporting questions, is represented diagrammatically in Figure 2.4.

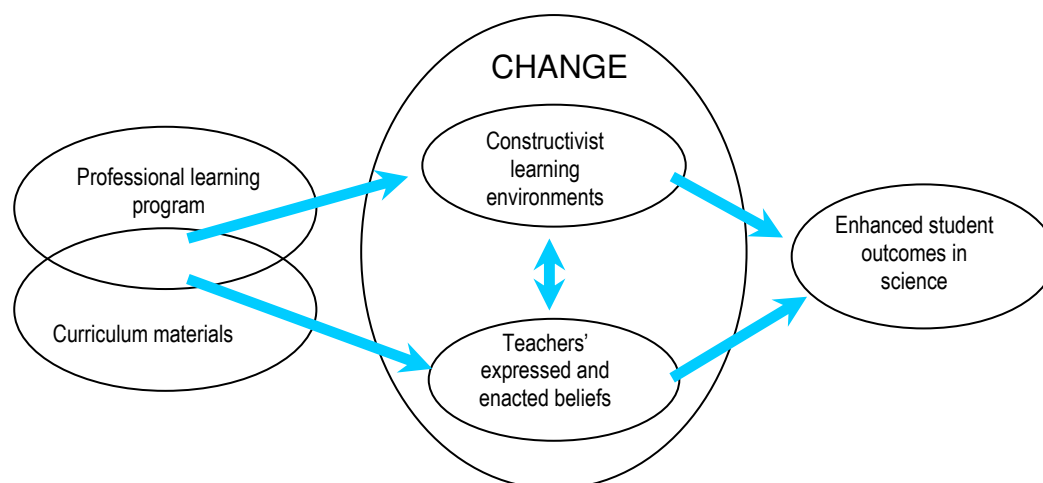


Figure 2.4. Representation of the research questions.

As can be seen, the key research question, regarding the nature of change in a classroom learning environment resulting from the implementation, can be answered to some extent by considering the three elements contained within the overall “change” domain, and can also be assessed by observing the resultant student learning outcomes. While the scope of this study did not allow for thorough investigation of all the areas identified, a number of key elements were targeted, as detailed in Chapter 3.

2.11 CHAPTER SUMMARY

The literature related to the nature and purpose of science teaching has been addressed in this chapter, including issues related to change in teachers’ beliefs and practices in response to constructivist reform agendas. Research findings related to teacher learning and factors impacting on that change process have been applied to the development of a PD intervention; this was the subject of further investigation into the process of change in teachers’ beliefs and practices. The development of procedures for recording and analysing that change will be the focus of Chapter 3.

Chapter 3: Research design

This chapter is an explanation of the research design used to examine the change in teachers' beliefs and practices during implementation of a constructivist science learning program. The research question is elaborated in relation to data collection, how this was implemented, and the strategies for data analysis. The setting and the participants are profiled, and the chapter concludes with discussions of ethical and validity aspects of the research.

3.1 RESEARCH QUESTIONS

As outlined in Chapter 2, there is a need for curriculum and PD resources that show teachers how to translate the intended curriculum into classroom action; in other words, for the planned curriculum to become the enacted curriculum. In this case, the planned curriculum is intentionally based on constructivist principles which, if faithfully enacted, provide students with opportunities to construct knowledge in a social context. The *Primary Connections* professional learning program has been designed to fill that role in Australian primary classrooms. Therefore, the key research question for this study is:

What are the changes in teachers' beliefs and practices associated with implementing a constructivist-inspired learning program?

A set of supporting questions helps to make more explicit the *nature of change* referred to in the key question. Table 3.1 expands upon the research question and links its elements to the required evidence and the tools for collecting that evidence. The nature and purpose of each of these data collection methods are discussed later in Section 3.7.

Table 3.1

Elaboration of the Research Question, Evidence and Data Collection

Research question: What are the changes in teachers' beliefs and practices associated with implementing a constructivist-inspired learning program?		
Supporting questions	Nature of change	Data collection
1. Structured constructivism: In what ways do the PD program and the published curriculum units foster the development of inquiry-based science in a constructivist learning environment?	Evidence of open-ended inquiry-based learning with students making key decisions about their learning. (e.g. Table 2.6)	Lesson observations; student survey
2. Expressed beliefs vs. enacted beliefs: To what extent are teachers' expressed beliefs about constructivist learning aligned with their enacted beliefs?	Evidence that expressed aims align with classroom practices, which in turn demonstrate constructivist pedagogies.	Interviews; journals; lesson observations
3. Teachers' perception of student outcomes: How does implementation of the PD intervention change teacher perceptions of student learning in science?	The teacher reports evidence of improved scientific literacy and science learning outcomes.	Interviews, teacher assessments; interviews

3.2 DESIGN

This study aimed to understand a process of change within a *bounded system* (Creswell, 2005), with a clearly defined context within one school, and with an identified beginning and end time for the intervention and the study. Even though the researcher guided the intervention, the autonomy of teachers' behaviour negated the possibility of substantial control over the outcomes.

A case study design was appropriate, according to Yin (2003), when “how” or “why” questions are posed; when the investigator has little control over events; and when the focus is a contemporary process within a real-life context. This study aligned with those three elements. Yin defines a case study, in part, as an empirical inquiry where “the boundaries between phenomenon and context are not clearly evident” (Yin, 2003, p. 13). This point is particularly relevant when the context might have a significant impact on the process being investigated, as in the current study within a school environment.

Three key types of case study are identified in Yin's model: exploratory, descriptive, and explanatory. The explanatory mode is appropriate for testing theories (Cohen, Manion, & Morrison, 2007). In this study, principles of effective PD were enacted within the school, based on the model proposed in Section 2.9, and various forms of monitoring helped to explain the experiences of teachers participating in this process. Thus it was appropriate to describe this study as an empirical design, in the form of an explanatory case study.

To clarify the rationale for this choice, the research question was aligned with the concept of theory testing by re-stating it in the form of a hypothesis: the intervention will facilitate change that results in evidence of increasingly constructivist classroom environments and pedagogies. A rival theory (Yin, 2003) that could equally have been developed from the literature presented in Chapter 2 is that the identified constraints to change will prevail, providing evidence that only superficial change in teacher beliefs and practices has occurred.

Yin describes four types of case study design: single or multiple case studies, with each of these modes including either single or multiple units of analysis. In this study, the formal PD program was provided to the whole staff, but just two of these teachers were identified as the subject cohort, and supported to work in a collaborative partnership as they planned and implemented a *Primary Connections* unit, and then developed follow-up programs. A range of data collection methods (detailed in Section 3.7) was used throughout this process to gain insights into the way the teachers managed the change process, and to identify which elements of the PD program and curriculum resources were adopted into their teaching repertoire of practice.

When aligning the current study with one of Yin's four designs, the process described in the previous paragraph leaves several options open. A major factor in selecting the most suitable design is the limited time and resources available, making multiple cases or multiple units of analysis less feasible. It was anticipated that any one of the teachers at the school could potentially represent a critical case (Yin, 2003) providing ample evidence for testing the propositions embodied in the intervention. However, as circumstances played out in the school, it was decided that the final analysis would take the form of a single-case holistic case study design, based on data from two teachers working in partnership.

3.2.1 THE RESEARCHER'S ROLE

The research was conducted within the context of a PD intervention facilitated by the researcher. Providing such a program for the teachers introduced an element of reciprocity, with subjects more likely to apply their time and effort to research activities if they perceived a personal benefit from the associated learning program. To some extent the researcher was a *participant observer* (Cohen et al., 2007) by presenting formal workshops and informal planning support. However, in other aspects of the research such as classroom observation and interviews, the researcher took on the role of non-participant observer. The researcher's role in facilitating the intervention implies a possible risk of bias towards a positive outcome. This has been addressed through a range of measures which will be described in Section 3.10.

3.3 PROCEDURES AND TIMELINE

The study progressed in stages, loosely aligned with the 5Es model on which the intervention was based. In brief, the aim was to: (a) assess teachers' prior knowledge and beliefs and introduce them to the learning model; (b) assist them to select and plan their use of a provided *Primary Connections* unit; (c) support the implementation of the unit with their classes; (d) support their development of a new unit based on a provided model; and (e) facilitate reflection on their learning process. Figure 3.1 maps key elements of the intervention strategy, the research focus and the data-gathering methods at each of those stages.

Intervention stages:				
Engage	Explore	Explain	Elaborate	Evaluate
Orienting Introduce constructivist models and pedagogies	→ Planning Select and prepare to implement unit	→ Implementing Classroom use of model unit	→ Designing Use template to design next unit	→ Reflecting Reflect on the process and the learning journey
Intervention strategy:				
Diagnostic assessment; Introductory workshops	Supporting the planning phase; facilitate collaborative partnership	Formative assessment; supporting in-class implementation	Unit planning; support design of new unit	Summative assessment; facilitate collaborative reflection & planning
Research focus – seek evidence of:				
- subjects' prior knowledge and preconceptions	- cognitive dissonance and concerns with the process	- the <i>implemented</i> curriculum, to compare with the <i>planned</i> curriculum	- changed beliefs and practices; cognitive accommodation	- change in expressed and enacted beliefs
Data-gathering tools and methods:				
Pre-intervention interviews; STEBI-A staff survey	Interviews, planning documents	Lesson observation; Interviews; documents: lesson plans, student work samples	Documents: unit planning, evaluation of student outcomes	Interviews; journals

Figure 3.1. Research outline.

The sequence of activities had a considerable overlap in some elements. In particular, the data analysis began concurrently with the data collection and continued through the study, consistent with Yin's (2006) advice that early analysis can help to adapt the study (perhaps even the current interview) in response to emerging themes.

3.4 SETTING

The study was based at a government school of about six hundred students, located in an inner suburb of Brisbane, Queensland. Cohen et al. (2007) describe settings on a continuum, with *artificial* environments such as laboratories and clinics at one extreme, where participants are acting outside of their usual roles, while at the other extreme, a *natural* setting for a school education study would include teachers and students enacting their usual practice in classrooms and playgrounds. The setting for this study was relatively natural for both teacher participants and their students because (a) it was conducted within their own school environment; (b) it was based on a curriculum resource that is currently being introduced in many similar schools; (c) the PD intervention was based on a model being widely used in Australian primary schools; and (d) resources and support for teachers were not substantially

different from what could be expected in similar schools implementing the *Primary Connections* program. Consequently there was minimal disruption to participating teachers or their classes, and any such disruption was the result of advocated change which conformed to policies promoted by the education authority (DETA, 2006).

The selection of school and participants was somewhat opportunistic, in that identification of a school and teachers were partly influenced by convenience of location, and dependent on a principal and staff volunteering to participate. However, there were significant elements of purposive selection (Neuman, 2006), in that: the selected school was relatively typical of Queensland primary schools, or at least has no apparent features that would make it a deviant case; there had not yet been a whole-school focus on the *Primary Connections* program; and the teachers were selected from those with little or no previous exposure to *Primary Connections*.

3.4.1 STAFF PROFILE

Discussions with the school administrators indicated that the school had a relatively experienced and stable teaching staff. At the conclusion of the second PD session, teachers were invited to voluntarily complete a *Science Teaching Efficacy Belief Instrument (STEBI-A)* (Riggs & Enochs, 1990). The purpose of this was to gain a general view of the teachers' science teaching self-efficacy as part of understanding the context, as well as to provide another form of diagnostic assessment that may help target the second PD session more accurately to the local needs. More than half the group returned surveys, mostly anonymously. The analysis indicated that this group of teachers' *efficacy beliefs* relating to science teaching were quite typical of the wider primary teacher population, although there was an anomaly that will be discussed later.

3.5 PARTICIPANTS

3.5.1 SELECTION

Once the Principal's approval had been granted, the PD intervention was offered to the whole staff prior to selecting two teachers as subjects for the study. It was intended to select, in consultation with the Deputy Principal, subjects who identified themselves as having low self-efficacy in teaching science. The reason for this is that one of the aims of the *Primary Connections* project is to increase the amount of science taught in those classrooms where it currently gains little time, and

it was teachers with low initial self-efficacy who were identified as making the greatest gains in the Stage 2 Trial study (Hackling & Prain, 2005).

In practice, this selection criterion was overridden by another local agenda. The study coincided with the trial of a new state-wide assessment program, Queensland Comparable Assessment Tasks (QCATs) (Queensland Studies Authority, 2009b), and this school was to trial the Year 4 Science assessment. Consequently, the school administrators decided that this program, with its focus on science, would be beneficial for the teachers involved in that assessment, so the administrators asked for volunteers from the Year 4/5 teachers to participate as subjects for the case study (I was not party to those discussions). Note that this occurred after the PD sessions, so the volunteers were able to make an informed decision on whether the intervention would be beneficial for their classes. When both of the resultant volunteers initially identified themselves as being confident and enthusiastic teachers of science, it appeared that the study had been somewhat compromised, but this was not the case, as will be discussed later.

3.5.2 PARTICIPANT PROFILE

The two participants, “Chris” and “Dean” (pseudonyms), were mid-career male teachers who each taught a mixed class of Year 4 and 5 students, with student numbers shown in Table 3.2. Three other teachers in the school had Year 4/5 classes, but they were not directly involved in the study and were not using *Primary Connections* at this time.

Table 3.2
Class Numbers

	Year 4	Year 5	Total students
Chris’s class	16	12	28
Dean’s class	17	11	28

The school is located in a suburb with a relatively high socio-economic profile, and both teachers noted that their classes had a wide range of abilities, but few significant problems. Chris described his class as “above average to very above average” and with “high parental involvement, low behaviour problems, or what I do have is easily dealt with.” He had two students with identified learning difficulties

and two who spoke English as a second language. Dean identified a similar profile, with some students “really struggling to cope with the basics of Year 4”, while many other students were performing at a high level. Some of his Year 4s were easily managing the more complex aspects of Year 5 work.

Dean and Chris had small, traditional classrooms in the same building. Between their classrooms was a spare classroom, and folding doors between all three rooms could be opened so there was a generous amount of space when both classes were working together.

Further details of the participants’ profiles, in particular their beliefs and pedagogy, will be discussed in Chapter 4 in the context of the study’s findings.

3.6 THE INTERVENTION

Recent work by Goodrum (2007) highlighted the need for curriculum and PD resources that can show teachers how to translate the intended curriculum (Keys, 2006) into classroom practice, as well as demonstrating that an inquiry-based curriculum can really work to the benefit of students. The intervention in this study, based on the *Primary Connections* professional learning program and curriculum resources, provided an opportunity to closely observe teachers as they engaged with the process. The intervention consisted of a number of interconnected elements, so the aim was to establish in what ways each of these elements influenced change in the subjects’ beliefs and practices.

3.6.1 KEY ELEMENTS OF THE PD

Elements of the intervention were (a) teacher PD sessions and (b) provision of curriculum resources for teachers to implement. The design of the intervention was based on the review of relevant literature presented in Chapter 2, with details of the program design presented in Section 2.9. Principles of professional learning were considered (Section 2.7.2), and specific strategies targeted an identified set of key constraints to effective PD (Section 2.7.1). The intervention design also addressed the principles for program implementation recommended in Hackling and Prain’s (2005) *Primary Connections* Stage 2 trial report (see Table 2.24). The intervention was structured around the 5Es model (Bybee, 2006) used in the *Primary Connections* units. The following sections describe how it was enacted in each stage.

Engage phase

The initial focus was orienting and awareness-raising, including the formal PD presentations. Once the school Principal had given approval for the research to go ahead, the Deputy was given responsibility for overseeing the study in the school. She was already aware of *Primary Connections* and was keen to have support with implementing it in the school, so was prepared to commit time for whole-staff presentations when I offered to facilitate these. This time commitment consisted of a ninety-minute session on the student-free day at the start of Term 3, and another one-hour follow-up session at an after-school staff meeting a week later.

By placing these sessions within scheduled whole-staff meeting time, the Administration effectively affirmed the importance of the PD and implied that participation was compulsory. Such compulsion has, in my experience, sometimes resulted in disengaged and non-cooperative participants, but this was not the case in this instance, with a high degree of enthusiasm and active engagement displayed by participants. I did not have a prior opportunity to identify any specific needs of the staff, but was informed by the Deputy Principal that none of the teachers had previously been trained in *Primary Connections* or used it in their classroom.

The PD sessions were designed to model as many *Primary Connections* pedagogical strategies as possible. Each was based on a 5Es model, and started with a hands-on investigation that teachers could begin as soon as they arrived in the room. For example, to *Engage* teachers as they arrived for the first session, they were invited to start collecting data from multiple trials of the “stretchy snakes” activity, and to also start noting scientific terminology they used in that process.

Session One was attended by about forty staff, including the school’s Principal and Deputy Principal. It was based on the “Introduction to *Primary Connections*” professional learning module provided in *Making Connections – a guide for facilitators* (Australian Academy of Science, 2007).

While providing a basic outline of the *Primary Connections* structure and methodology, the session was built around a number of engaging activities. The initial activity (Figure 3.2) involved participants measuring and documenting the “stretchability” of lolly snakes. Following this, they were asked to record a glossary of any scientific terminology they used while carrying out this task and discuss the types of decisions they made about how to do this task.

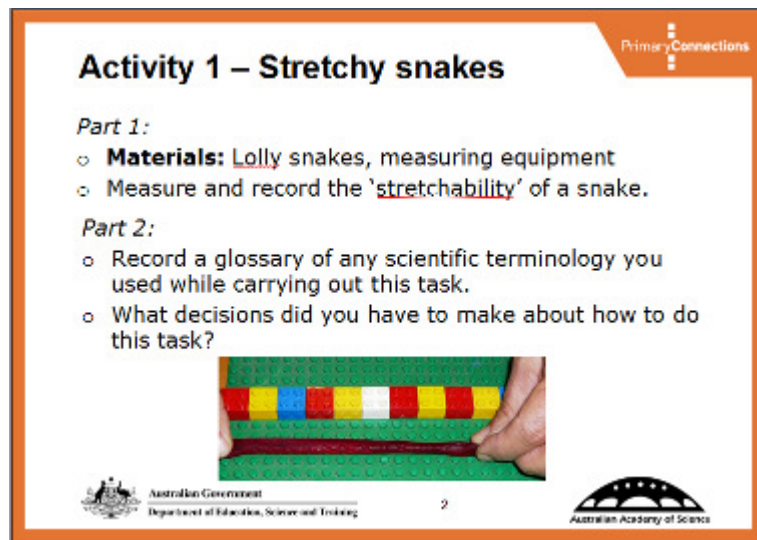


Figure 3.2. Sample PowerPoint slide for Activity 1 from PD Session 1.

Guided by Nussbaum and Novick's (1982) constructivist instructional model, it was considered important to start by gaining an understanding of the participants' prior knowledge, attitudes and preconceptions. They were asked to consider these two questions:

1. How important is science in primary school?
2. How would you rate the teaching and learning of science in this school?

Teacher responses (on sticky notes) were compiled into "consensograms" (Figure 3.3), which indicated a general view that science is important, but not taught well.



Figure 3.3. "Consensogram" of the importance of science in education.

A follow-up question prompted further discussion of science teaching in the local context, to provide guidance for the focus of the PD sessions:

In your group, discuss:

“What are the main constraints and issues that influence the science curriculum in this school?”

A speaker for each group was given the opportunity to report to the whole group, which provided me with useful information about their specific PD needs. This process also identified some concerns, such as limited background knowledge in science and the lack of scientific equipment, that are effectively addressed by the *Primary Connections* model, so I was able to highlight those points later in the sessions.

The investigative approach of *Primary Connections*, modelled in the introductory activity, was further experienced by rolling toy cars down ramps and recording distance data (Figure 3.4). Groups of participants then each selected a different variable to measure and planned fair tests.

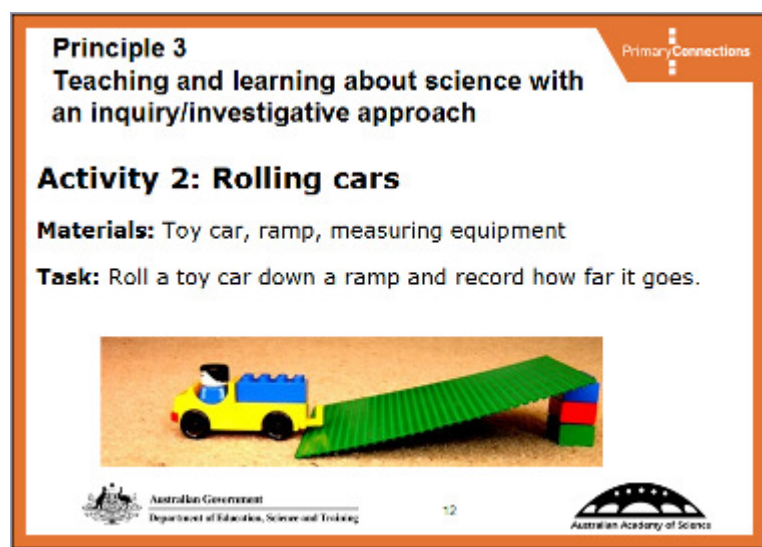


Figure 3.4. Sample PowerPoint slide for Activity 2 from PD Session 1.

The *Primary Connections* cooperative learning model, allocating roles of Speaker, Director, and Manager, was modelled for the activities, as was the *Predict, Observe, Explain* (POE) strategy for encouraging focused discussion about phenomena.

The session concluded with time for teachers to examine copies of all the available *Primary Connections* units and discuss possible selections for their classes.

Session Two was based on the 5Es professional learning module from the facilitators' guide. Most of the same participants attended this session. Again, the program was based on hands-on activities. This time, a simple challenge, “How many water drops can you fit on a 5¢ coin?” was used as the *Engage* activity, as well

as being revisited in the *Elaborate* phase when participants again identified variables and planned an investigation.

The simple investigation activities in the two sessions were to play an unexpected role in teachers' implementation of *Primary Connections*, as will be discussed later. More detailed outlines of the PD sessions can be found in Appendices A and B.

In the PD sessions, the teachers had an opportunity to examine all the published *Primary Connections* units available at that time. These unit plans provide appropriate background scientific information and detailed lesson plans. However these plans were substantially changed and added to because of the mismatch with the age of the students. The teachers did not see this as a difficult problem to manage.

Explore phase

This phase included the teachers' selection and planning of *Primary Connections* units. The teachers had discussed the selection during the second PD session. An initial half-hour planning meeting with the two case-study participants and the school's Head of Curriculum finalised selection of a unit. Because the Olympics was about to begin, they were keen to find a link to that, so they suggested linking the "Push Pull" unit on energy to investigations related to sports. Once the unit had been decided, I gave them each a copy of the relevant book. It was decided that the basic structure of the unit was still relevant, and that the learning activities could be readily adapted to suit students older than the target age group. This decision was in line with Cuban's (1990) observation of the way teachers alter the content, even if it is mandated, to conform to what they consider their students' best interest. At this stage, both subjects had expressed some reservations about using *Primary Connections*, so were keeping control of the content and pedagogy agendas.

A later meeting developed more details of the unit implementation. I was involved in these discussions and provided some input, but the key decisions about unit selection and planning were made by the teachers. A local *Primary Connections* facilitator could be reasonably assumed to provide a similar level of support to teachers. As the unit progressed, I still had some incidental discussions with the subjects about planning and implementation, but was generally a non-participant observer.

Explain phase

The participants' understanding of the *Primary Connections* model was developed more thoroughly in this phase when they implemented the unit with their classes. As they applied pedagogies that had been modelled in the initial PD sessions, they thought more deeply about how to use them and how well they worked. This was also where they asked more specific questions about the structure of *Primary Connections* and about science in general. This phase was where the findings indicate that observation of student learning was a powerful catalyst for change in the teachers' beliefs and practices, as will be detailed later.

Elaborate phase

The initial expectation was that this phase would involve using the *Primary Connections* template to develop a new science unit to follow up the first one. However, because there was a large element of redesigning the initial unit before implementation, this phase overlapped somewhat with the earlier two. Also, having now worked more closely with the curriculum materials, the participants had come to appreciate their design. The idea of developing their own, which had some appeal when discussed in the early planning meetings, was now not as attractive as immediately using another published *Primary Connections* unit with their classes.

Because the second unit they selected was for the appropriate age juncture, planning it was much less complex. A significant observation at this stage was the way the teachers readily linked other resources, including a Technology project from the QSA Assessment Bank (Queensland Studies Authority, 2009a), to build a new, larger unit. However it was clear that they were intentionally keeping the *Primary Connections* unit structure as the core framework.

Evaluate phase

This phase again has some overlap with previous ones, but the focus is on consolidating and reflecting on learning. Much of the teachers' reflective thinking was documented in interviews, and in their "aside" comments to me during lessons. At the start of the unit, each teacher was given a note book and encouraged to keep written reflective notes after each lesson, however only a small sample of notes were retrieved. This phase was where further evidence was obtained of the impact of student engagement and learning on the teachers' beliefs and practices.

3.7 DATA COLLECTING

The data collection consisted of a series of *semi-structured interviews* developed around aspects of the change process involved in each stage of the implementation, *classroom observations* using a protocol designed to highlight constructivist modes of teaching and learning, and samples of teacher and student documents including teachers' planning, a student survey and students' science journals (Table 3.3).

Table 3.3

Data Collection Methods

Semi-structured interviews	Based on <i>Inside the Classroom: teacher interview protocol</i> (Horizon Research Inc, 2000).
Classroom observations	Guided by <i>Reformed Teaching Observation Protocol – RTOP</i> (Sawada & Piburn, 2000)
Teachers' planning documents	
Student survey	
Students' science journals	

The multiple data sources enabled triangulation of data supporting each research question, as represented in *Figure 3.5* which makes it clear that the interviews provided data informing all three sub-questions, while the other sources strategically target specific topics to provide focussed detail. Each of the methods, and its role in answering the research question, will be discussed in the following sections.

Supporting research questions:	Interviews	Classroom Observations	Planning documents	Student survey	Students' science journals
RQ 1: Structured constructivism	✕	✕	✕	✕	✕
RQ 2: Expressed beliefs vs. enacted beliefs	✕	✕	✕		
RQ 3: Teachers' perception of student outcomes	✕			✕	✕

Figure 3.5 Matrix of supporting questions and data sources

3.7.1 TIMELINE

Table 3.4 details the timing of key elements of the intervention and data collection. The intervention began on the first day of Term 3, 2008, with the first teacher PD sessions. The teachers implemented the first *Primary Connections* unit during that 10-week term. They had agreed to participate in a study that was expected to take place entirely within that term however they readily agreed to further interviews and collection of documents through to the end of the following term. They subsequently used more *Primary Connections* resources and strategies in Term 4, independent of the researcher's involvement. While it may have been desirable to extend the study even further, the two teachers had already been generous with their time and indicated that they were ready to conclude their involvement at the end of the school year.

Table 3.4

Intervention and Data Collection Timeline

Week	Date	Event	Data collected	Phase of study
1	14-7-08	Teacher PD Session 1	Session outline PowerPoint presentation Photos of 'consensograms'	Engage (orienting)
	15-7-08	Teacher PD Session 2	Session outline PowerPoint presentation STEBI-A survey	
3	31-7-08	Planning meeting - topic selection	Meeting notes	Explore (planning)
4	7-8-08	Planning meeting - finalise unit outline	Meeting notes	
	8-8-08	'Push-pull' Lesson 1 & 2	Audio recording – Lesson Observation 1 (LO-1) Observation notes Teacher worksheets Science journal entries: • Push pull pics • Push pull activities	Explain (implementing a <i>Primary Connections</i> unit)
5	14-8-08	Chris Interview #1 Dean Interview #1	Audio recording – CI-1 Audio recording – DI-1	

6	22-8-08	'Push-pull' Lesson 3 & 4	Teacher worksheet Science journal entries: What sinks? What floats?	
7	29-8-08	'Push-pull' Lesson 5 & 6	Audio recording – Lesson Observation 1 (LO-2) Observation notes Science journal entries: - Think/Pair?Share - Air is found.../Air is not found... - Predict/Observe/Explain	
8	5-9-08	'Push-pull' Lesson 7 & 8	Audio recording – Lesson Observation 1 (LO-3) Observation notes Science journal entries: - Helicopter investigation - Investigation planner	
10	16-9-08	Chris Interview #2	Audio recording – CI-2	
14	13-10-08	Dean Interview #2	Audio recording – DI-2	
	17-10-08	'Material world' Lesson 1	Science journal entries: 'Glove guide' 'Gripping glove'	
	26-10-08	'Material world' Lesson 2 Part 1	Science journal entries: What is a fair test?	
	20-11-08	'Material world' Lesson 2 Part 2	Science journal entries: - Rot or remain? - POE - decomposition	
21	1-12-08	Dean Interview #3	Audio recording – DI-3	
22	10-12-08	Student survey	Student responses	
	12-12-08	Chris Interview #3	Audio recording – CI-3	Evaluate (reflect on the journey)

3.7.2 INTERVIEWS

The six interviews were a key data source, providing rich data to inform all three supporting research questions. The interviews were audio recorded and

transcribed for detailed analysis. They were semi-structured, based on elements of *Inside the Classroom: teacher interview protocol* (Horizon Research Inc, 2000) (see Appendix C). This instrument was designed to collect information on teachers' perceptions of the factors influencing their practice, including administrative support, teacher PD, teacher beliefs about curriculum and about students, and the physical environment.

The first supporting research question (RQ 1) was informed by questions about curriculum resources being used and whether they have been adapted or modified (e.g., Questions 10-12) and questions about the teacher's degree of acceptance of the content and pedagogies (Questions 13-15). RQ 2 was also touched upon by responses to the same questions. RQ 3 was addressed by specific questions on those topics.

3.7.3 OBSERVATION

Classroom observations of a sample of the *Primary Connections* lessons were conducted during the unit implementation phase. Complicated timetables made it difficult for the teachers to find mutually suitable times to combine the two classes for science lessons. Their solution was to work together less often, but for extended sessions which each addressed two *Primary Connections* lessons. The duration of each of these sessions was approximately 110 minutes. The recorded observations have documented the teaching of six of the eight lessons in the *Primary Connections* unit *Push-pull*.

The *Reformed Teaching Observation Protocol (RTOP)* (Sawada & Piburn, 2000) provided guidance for the documentation and initial analysis, although it was not used as a structured analysis tool. These lessons were also audio recorded, with key exchanges transcribed. Video recording was considered and rejected on the grounds that it can be a distraction to students and teachers, compromising the natural classroom environment. It was considered that audio recordings and observation notes provided ample detail, especially when complemented by interview and documentary data.

The issue of *structured constructivism* (RQ 1) was addressed by seeking evidence of open-ended inquiry and student-directed learning. The extent to which the *Primary Connections* unit plan was used as a structured "recipe book" to rigidly guide teacher and student actions was a key indicator of the resource's effectiveness in promoting a constructivist environment.

Observations were the main source of evidence about teachers' *enacted beliefs* (RQ 2), which were compared with data about their *expressed beliefs* gained from interviews and journals, with elements of congruence or disagreement being identified.

Classroom dialogue, including aside comments to me during lessons, also provided evidence for RQ 3 relating to the teachers' perception of student learning, including development of scientific literacy.

3.7.4 DOCUMENTS

A range of document samples was collected. These include teachers' lesson outlines, activity sheets and assessment items, as well as student work samples. Photographs were taken to document notes and illustrations created on classroom whiteboards during lessons, as well as the "word wall" vocabulary list that was developed throughout the unit. These documents added to the detailed picture of the teachers' beliefs and practices throughout the intervention.

At the beginning of the teaching unit, all students were provided with exercise books to use as their 'science journals', documenting their activities for the term. These provided rich documentation of all the class' science lessons, including ones that weren't observed, during the six months of the study. The details of lessons that were enacted in Term 4, after the formal observation phase had concluded, are valuable in that they provide data less likely to be influenced by an 'experimental effect'. In this term, the teachers had already fulfilled their voluntary agreement to support the study and there was no sense of implied or actual obligation to engage any further with the intervention. Much of the student documentation recorded in Term 3 can be matched with observations for a detailed baseline view of practice in the classroom. The lessons recorded in Term 4, from the unit *Material world*, provide evidence of teacher practice at a time when there was little chance of influence from a researcher.

The subjects were provided with notebooks, with the intention that they would keep reflective journals throughout the process. However, time pressures meant that only a small amount of material was gathered this way.

3.8 DATA ANALYSIS

Thematic analysis was applied to the qualitative data. The audio-recorded interviews were considered a foundational data source because of their depth and

richness, and the way their semi-structured nature could adapt to focus on emerging themes. The other rich source of data was the set of lesson observation transcripts. In particular, they added detail to the baseline recording of classroom practice which could be compared with the science learning experiences documented in students' science journals later in the study. An unexpected bonus with the observation transcripts was that both teachers regularly made "aside" comments to me about things they had noticed or how they felt the lesson was progressing. These "on the run" reflective comments have an immediacy that provides an important window into their thinking, and made up for the limited data available from personal journals. The remaining data sources helped to illuminate thematic trends observed in interviews and journal entries.

Five ways of organising and presenting data are suggested by Cohen et al. (2007): (a) by groups of participants; (b) by individuals; (c) by issues; (d) by research questions; and (e) by instrument. This study used a combination of (c) and (d): each of the three supporting research questions used as initial themes, with more specific sub-themes developed as issues arose from the data. A process of pattern matching (Yin, 2003) was used to compare and contrast themes from the data with the theoretical positions embodied in the research questions.

To build reliability, themes from the interviews were triangulated (Cohen et al., 2007) with data from multiple observations and documents. Analysis began early in the data collection process and emerging themes were identified and targeted in subsequent interviews and observations. This provided opportunities to challenge tentative ideas by seeking supporting or conflicting data. Such progressive analysis avoided the risk that, when key issues are identified prior to data collection, the study may be unresponsive to additional relevant factors as they emerge.

3.8.1 INTERVIEWS

Audio recordings were transcribed, and the text coded to identify key themes. Coding was reviewed as the data collection and analysis progressed, to support development of emerging themes and progressively identify links to other data sources.

3.8.2 OBSERVATIONS

The observation notes were used to identify significant sections of the audio recordings for transcription and detailed analysis, with coding to identify themes.

3.8.3 DOCUMENTS

Lesson outlines, activity sheets and assessment items, as well as student work samples and photographs of classroom data were coded to identify themes and their links with other data sources.

3.9 ETHICAL CONSIDERATIONS

The research complied with Queensland University of Technology ethical guidelines, as well as the Queensland Government requirements for conducting research in state education sites (DETA, 2004). Participants were volunteers, remained anonymous, and had the option to withdraw without penalty at any time.

3.9.1 APPROVALS

Multiple levels of ethical clearance and permission were obtained:

Institutional: Ethical clearance by QUT Human Research Ethics Committee (UHREC) was gained for a Level 1 “low risk” activity – ethics approval number 0800000272.

Organisational: Education Queensland is the relevant authority. An *Application for conducting research in Queensland state education sites* (DETA, 2004) was approved.

Specific site: Subsequent to the Education Queensland approval, the Principal of the school granted approval for the study to proceed.

Participants: Informed consent from teacher participants was obtained, using the relevant QUT template.

3.9.2 IDENTITY AND PRIVACY

To avoid disclosing identities of subjects and school, pseudonyms have been used. Appropriate security of storage is being used for all documents and recordings.

3.9.3 RECIPROCITY

The participants in the study were volunteers who committed a substantial amount of time to the PD program, unit implementation and research tasks. In keeping with the principle of reciprocity, the researcher (an accredited *Primary Connections* facilitator) provided PD programs for the entire staff at the school, as well as incidental professional support for the key subjects.

3.10 VALIDITY

Yin's case study model (Yin, 2003) describes four tests commonly used to establish the quality of empirical research, and apply to case studies such as this one. The four aspects of validity will be addressed in turn.

Construct validity

Case studies can be challenged on the grounds of overt subjectivity. This could apply in this study if the nature of change in the research question was left open. That is why Table 3.1 explicitly details the evidence used to answer the questions. Construct validity is further ensured by using the multiple sources of data described in Table 3.3 to *triangulate*, or “establish converging lines of evidence to make the finding as robust as possible” (Yin, 2006, p. 116). Those data were used to build a *chain of evidence* with transparent links from method to resultant data to conclusions.

Internal validity

This aspect of validity is most problematic for causal or explanatory case studies. Consequently, in this study care is taken to avoid inferring causal relationships but rather to concentrate on descriptive analysis. The focus is on providing data and explanations consistent with the preliminary theoretical perspectives and, again, providing a chain of evidence that clearly links these together.

External validity

This aspect is a particular concern for a study such as this one with a very small sample size, and no explicit strategy for selecting typical setting and subjects. Care has been taken to avoid unsupported generalisations; however the detailed observations of a change process should be able to sustain careful *analytical* generalisations that provide useful insights for professional learning designers and facilitators (Yin, 2003).

Reliability

The goal here is to control errors and bias in the study. Careful recording of all data (including data that supports conflicting or alternate themes) was used to enhance the reliability, as was extensive citing of data sources in the analysis and conclusions. The multiple data sources and ongoing sampling in this study built a rich database that supports resultant findings with a rich set of evidence.

Bias was identified as a particular risk because the researcher was a trained *Primary Connections* facilitator with considerable prior engagement with the program, as well as being the presenter of this study's PD component. This leaves open the suggestion that the researcher may have had a particular interest in demonstrating the success of the intervention. However, this prior involvement has already been mentioned (Section 1.2) as the source of concerns which gave rise to the study. In particular, concerns relating to the extent to which the *Primary Connections* professional learning program is typically abridged by resource constraints, and what kinds of change could be facilitated by remaining elements of the program. Consequently, a simple confirmation of the efficacy of a program was not necessarily a desired outcome of the study. Therefore, such a confirmatory outcome, which might be expected from researcher bias, does not support the stated research questions (Section 3.1) which address the *nature* of change. For this reason, the analysis of the data has sought to incorporate any rival explanations or alternative perspectives (Yin, 2004) that could be identified. Such potentially negative findings are consistent with the aims of the study as indicated by the research questions, again mitigating possibilities of bias towards a positive outcome.

Balanced against the risk of a researcher with a vested interest is the benefit to the study of that prior involvement of an insider who has a deep and detailed understanding of the intervention model, as well as experience with related interventions in similar contexts. If the investigation was conducted by a neutral researcher with no prior engagement with the program being studied, there is a real risk that the quality of analysis would be compromised and significant details may be overlooked. To further address the issue of perceived bias, the next section considers the study in the light of an established set of guidelines for supporting credibility.

3.10.1 CREDIBILITY OF A QUALITATIVE STUDY

Guba and Lincoln (1989) proposed six techniques to verify the credibility of qualitative studies: (1) prolonged engagement; (2) persistent observation; (3) peer debriefing; (4) negative case analysis; (5) progressive subjectivity; and (6) member checks. This study's design aligns with the majority of these elements, as described below.

Prolonged engagement

The initial "Engage" phase of the study involved two PD sessions on subsequent days. The following "Explore" and "Explain" phases involved

observation of the implementation of a *Primary Connections* unit by the two subjects over a school term. In the following school term, the “Elaborate” phase was where they independently selected, adapted and implemented further elements of *Primary Connections* units and pedagogies. *Prolonged engagement* was demonstrated by the six month engagement period, providing sufficient time after the initial PD for the subjects to reflect on the intervention and selectively adopt the proposed pedagogies. The data from the Elaborate phase relating to their use of *Primary Connections* are important because in the second term, after the subjects’ commitment to the study had expired and formal lesson observations had concluded, they continued to adopt and refine the elements of the intervention, providing support for the view that an ‘experimental effect’ was not a substantial factor in their ongoing use of the resources and pedagogies promoted by the intervention. The length of engagement between the researcher and subjects also enabled establishment of a comfortable rapport and detailed understanding of the context, sufficient to minimise misconceptions.

Persistent observation

The time spent with the two subjects in different modes (PD sessions, planning meetings, lesson observations, interviews and informal conversations), as well as the use of a range of documents, adds a degree of depth to the broad scope provided by the prolonged engagement.

Peer debriefing

The researcher’s two supervisors in the role of "critical friends" provided guidance to the project, particularly with advice relating to data collection and analysis. While not exactly the 'disinterested peers' proposed by Guba and Lincoln (1989), it seems reasonable to assume that these two experienced academics would be suitably objective in their professional support.

Negative case analysis

Because the two subjects working in tandem were treated as a single case, this technique is not applicable to this study.

Progressive subjectivity

"Monitoring the researcher's own developing construction" (Guba & Lincoln 1989) is addressed by an interpretive approach that involved analysis of data throughout the study. Because the study is deductive, working from a structured

model (see Section 2.9), the analysis is framed around a change process model. Progressive subjectivity is enacted by being sensitive to anomalous data and actively seeking to identify contradictory data. The semi-structured interview strategy enabled refinement of data collection through adapting questioning within and between interviews.

Member checks

This technique was carried out informally in interviews as well as unstructured exchanges during lesson observations when the subjects were able to clarify the researcher's ideas to reduce misconceptions, however the subjects' time constraints meant it was not able to be used in a rigorous way so is not considered to have been applied in this study.

3.11 SUMMARY

In Chapter 1, the context, nature and purpose of the study were explained. Chapter 2 contained an examination of the role and nature of effective science teaching as well as professional learning programs, leading to presentation of a model for a PD intervention based on the research literature. This chapter contains and explanation of the way that the PD model was used as the basis for a case study, investigating the nature and extent of change as teachers implement a program. The findings from the study have provided insights into how a research-based professional learning program is able to overcome the identified constraints to bring about increasingly constructivist learning environments. These findings will be detailed in the next chapter.

Chapter 4: Findings and discussion

In this chapter, the findings of the study are presented and analysed. Data will be presented to show how this analysis has led to the development of four assertions relating to the case being studied: (a) the *Primary Connections* professional learning strategy supported the development of inquiry-based science in a constructivist learning environment; (b) changing teachers' beliefs and practices requires extended time; (c) promoting student autonomy enhanced science learning; and (d) authentic science investigations promoted enhanced scientific literacy and understanding of the nature of science.

The chapter begins with background information about the two subjects and their classes, providing a context for the later discussion. Next, the sequence of the intervention is revisited to support an understanding of the subjects' engagement with it. Then, an initial scan of the data will be presented, mapped against a list of classroom behaviours that were expected to be changed by a constructivist reform. Following these introductory sections, the body of the chapter provides a more detailed analysis of the data as it relates to the overall research question, aligned to each of the four supporting questions.

4.1 PARTICIPANTS

This study was conducted in a team-taught combined classroom situation with two teachers, as detailed in Chapter 3 (Sections 3.4 and 3.5). In this section, the characteristics of teachers and students are revisited, in the context of their engagement with the intervention.

4.1.1 THE TEACHERS

The two teachers, Chris and Dean (pseudonyms) worked together throughout the study, collaboratively planning the science program and combining their classes for science lessons to share the teaching. Both were confident, experienced teachers displaying a comprehensive repertoire of effective teaching and classroom management strategies. Their classes ran smoothly, the students clearly familiar with established routines. They often worked together in various informal ways, but their decision to coteach (Tobin, 2006) a structured unit with combined classes was

apparently a new experience for both teachers and their students. In this context, the two teachers worked effectively as a team, seamlessly exchanging the lead in lessons and discussions, as indicated by this brief exchange during the first lesson:

Dean: I heard the word ‘fulcrum’ used there.

Chris: That’s a great word for our Word Wall.

When asked to comment about teaching collaboratively with combined classes, Chris said, “That’s been good. I’ve seen some things that Dean does really well, he knows how to ask those good questions, so it’s been good” *Chris – Interview 2 (CI-2)*. This aligns clearly with Tobin’s (2006) description of coteaching as a mode of professional learning (see Section 2.7.6).

Dean’s response to a similar question indicated that the arrangement worked well organisationally, but didn’t imply there was learning component for him:

It’s been good working with Chris but it hasn’t made me do any things differently. It’s just good to have a whole bunch of the kids together and it makes it a little bit easier, you lighten the load on one person when there’s two of you organising it, but it wouldn’t have changed what I do would do next time or have done before, it’s just a little bit less time to prepare it when there’s two. *Dean – Interview 2 (DI-2)*

Chris and Dean both demonstrated similarly high expectations for student behaviour, with any inappropriate talk or disruption being quickly addressed in a firm but calm manner. In one incident during a whole-group discussion, a student who had made a series of inappropriate comments was promptly led out to the hallway for a private discussion with one teacher while the other took over and proceeded with the lesson. This again matches Tobin’s description of a typical coteaching scenario, that when questions or issues arise “they can be resolved non-obtrusively by a coteacher while the central teacher continues to teach, not disrupted by the quiet interaction between a needy student and a coteacher” (Tobin, 2006, p. 138). The teachers were both comfortable with a degree of noise and disruption when students were engaged in small group investigations, and had effective strategies for quickly regaining the attention of the whole group when necessary. Both teachers demonstrated highly skilled questioning strategies (as detailed later in Section 4.5) in whole class and individual exchanges. Students contributed confidently to discussions, and their ideas were clearly valued by teachers and their peers.

The STEBI-A survey (Riggs & Enochs, 1990), discussed in Sections 2.6.3 and 3.4.1, was administered to the whole staff after the second PD session. This one-off test added to the contextual data, providing an indication of the staff profile relating self-efficacy; there was no intention to use this data to quantify change. The resultant data are presented in Table 4.1, compared to data gathered by an earlier study (de Laat & Watters, 1995) using the same instrument at a school in the same city. The comparison shows data in a similar range, although both are lower than those obtained in a larger study (n = 288) by Riggs and Enochs (1990) who obtained values of 57 (PSTE) and 48 (STOE).

Table 4.1

Comparison of STEBI-A Scores

Data source:	De Laat & Watters, 1995 (n=37)		Present study (n=21)	
	PSTE	STOE	PSTE	STOE
Mean	50	34	48	35
Range	33-62	20-44	35-61	24-45
Standard deviation	5.9	5.6	7.4	4.1

While most of the responses to the survey were anonymous, Dean was one teacher who identified himself. This was interesting because his survey response indicated he was a significant outlier, with the highest scores in both PSTE and STOE scales of all the teachers surveyed in the school. This indicated that he had a high expectancy that science teaching could produce desirable outcomes (outcome expectancy), as well as a solid belief in his own ability to provide that teaching (self-efficacy). In my initial meetings with them, both teachers made comments about their confidence with teaching science. This exchange took place in Dean's initial interview:

How well prepared do you feel to guide student learning in science?

I feel well prepared. Science was something that I enjoyed at school and it's something that I'm generally interested in. I'll read about it when I see it in the paper or watch a documentary on TV, so it's something that I feel that I can speak to the class about just from my knowledge and be confident. Science isn't something that I feel I need to go and do a whole lot of reading for before I teach a lesson, and I think that's really important. (DI-1)

Chris's STEBI-A scores are not known, but initial discussions with him suggested that his beliefs and attitudes were similarly positive about science, although he expressed some concern about presenting science in an authentic way, as indicated in this extract from the first interview:

How do you feel about teaching science?

I love the idea, it's just hard to find the time. It's definitely something that interests me... I feel pretty well prepared... I have a B.Sc... I did take science in university and it does interest me. *Chris – Interview 1 (CI-1)*

Change occurs when people expect new behaviours to produce desirable outcomes (outcome expectancy), as well as believing in their own ability to perform those behaviours (self-efficacy) (Riggs & Enochs, 1990). The pre-existing high outcome expectancy and self-efficacy of these two participants may have been a factor in the change that was later observed.

The selection of the teachers was organised by the Deputy Principal at the school. Both Chris and Dean had readily volunteered after seeing what the program had to offer during the PD sessions. In the first meeting, the pair was very positive about using *Primary Connections*, based on what they had learnt in the PD sessions, but communicated their wariness of some aspects. Dean explained how he liked using “scientific method” and thoroughly exploring the background to concepts in experiments. Both teachers expressed a preference for teaching within a wider, integrated context and talked about developing links to other learning areas from the science unit. Chris and Dean expressed concern about whether the *Primary Connections* unit would have sufficient intellectual rigour and “content”. Another concern was that the *Primary Connections* model might be confusing for children, and that the science might need to be taught in isolation. This could indicate that they themselves were still somewhat confused by the unit structure. Despite their concerns, they readily engaged with the intervention, committing substantial time to planning and implementing the *Primary Connections* unit.

Although the data indicate occasional differences between Chris and Dean in their beliefs and pedagogy, such differences were minimal when compared to the strong commonalities identified. The seamless role-sharing demonstrated in their coteaching, and the close alignment of pedagogy and teaching content, provided a consistent science learning environment for their students. Because the data give no

compelling reason to compare or contrast the two teachers, it was decided that the clarity of the study would be best served by considering Chris, Dean and their classes as a single case.

4.1.2 THE STUDENTS

As discussed in Section 3.5, both classes had students with a wide range of abilities, but general behaviour and level of engagement appeared to be excellent. The first lesson, which provided extended time for small groups to work with minimal supervision, showed that virtually all students were comfortable working in this mode. Students responded well to the combined class format, with one commenting, “Doing science with (the neighbouring class) made it a lot easier to learn” (*Student 4*). In whole-class discussions and in the group tasks students showed initiative in the way they addressed science concepts throughout the lessons I observed.

4.2 INTERVENTION FRAMEWORK

The proposed intervention was described fully in Chapter 3 (see Figure 3.1 for the outline), however various circumstances impacted on the way it was enacted so it will be revisited to provide further context for the findings. The timing of key elements of the intervention and data collection is presented in Appendix D.

As noted earlier, the intervention was loosely structured around the same 5Es model that *Primary Connections* units employ, so the description follows that framework. A condensed outline is presented in Figure 4.1.

Engage	Explore	Explain	Elaborate	Evaluate
Orienting →	Planning →	Implementing →	Designing →	Reflecting
Introduce constructivist models and pedagogies	Select and prepare to implement unit	Classroom use of model unit	Write or adapt and implement subsequent units	Reflect on the process and the learning journey

Figure 4.1. Intervention outline.

4.2.1 ENGAGE PHASE

This phase began with the teacher PD sessions, and continued with planning meetings involving the two subjects. During the first planning meeting, both teachers told how they had subsequently replicated the “stretchy snakes” and “water drop” activities from the PD sessions in their classes, with follow-up discussion about

surface tension prompting Chris to do some Internet research into water tension for his own background knowledge.

In the PD sessions, the teachers had an opportunity to examine all the published Primary Connections units available at that time. Both participants commented that this aspect of the sessions was a valuable learning opportunity, and was also the time when they were able to discuss units appropriate to their class context. This is consistent with the CBAM model of change (Hall & Hord, 1987), where the first area of concern is not knowing about the initiative (see Table 2.16). Dean explained that the sessions had allayed some of his initial concerns:

Yeah, I don't think that it made me concerned at all, it probably made me feel more confident in teaching science. Not just saying it to give you a rap... *DI-1*

In a later interview, Dean indicated that his positive response to the sessions had extended to replicating some of the activities with his class: "I used those (activities) with my class. We did all of those afterwards and again, they were so simple." *DI-2*

Chris identified elements of the 5Es structure and the content of the sessions that could relate to his teaching practice:

It was good. I liked the stand-alone activities because it showed how easy it can be to teach science. I liked those little things that we did, and I also liked the showing of the structure that we did, and the structure of *Primary Connections*. You showed how easy it was to create these short little projects, and then you showed an actual written-out on paper unit – it was good. *CI-1*

4.2.2 EXPLORE PHASE

This phase included the teachers' selection and planning of *Primary Connections* units. With the 2008 Beijing Olympics being held at the time, Dean and Chris had previously talked about linking athletics to an "Energy and change" unit, so the appropriateness of using the Stage 1 "Push pull" unit with their Stage 2 students was discussed. *Primary Connections* units are organised in "stages", with Stage 1 designed for Year 2-3, and Stage 2 for Year 4-5. At this time, the teachers were reluctant to commit to using a *Primary Connections* unit "as is", because they

perceived this as relinquishing some of their control of the content and pedagogy agendas. Due to these concerns, they decided to go ahead with the unit's basic structure, but with some modifications to make it more age-appropriate. These included:

1. An expanded Explore phase with greater range of activities, including some related to sports
2. Adding a TWLH¹ component, a strategy used in Stage 2 and 3 *Primary Connections* units
3. Adding an extension to the Elaborate phase with an extra independent investigation related to athletics.

This discrepancy between the *Planned Curriculum, Implemented Curriculum* and *Experienced Curriculum* (Hardy, 1993) is a predictable result of the teachers' concerns about an innovation that it was imposed from outside (albeit with their consent) (Sikes, 1992). Cuban (1990) had observed how teachers alter the content, even when mandated, to conform to what they considered their students' best interest. In this case, however, the concerns were more with the detail of the implementation rather than broader concepts, and the discussions about modifications of the *Primary Connections* unit kept coming back to the 5Es, with both teachers demonstrating their awareness of the underlying importance of that model to the *Primary Connections* units.

4.2.3 EXPLAIN PHASE

The purpose of this phase was for teachers to further develop their understandings of constructivist pedagogies and accommodate these into their pedagogical content knowledge. The subjects' understanding of the Primary Connections model was developed more thoroughly when they implemented the unit with their classes. As they applied pedagogies that had been modelled in the initial PD sessions, they thought more deeply about how to use them and how well they worked. Both subjects reflected on the quality of the curriculum resources early in this phase. For example, after Lesson 1, Chris's opinion of the *Primary Connections* resource was that it was:

¹ TWLH is a variant of the commonly used KWL strategy (what we *Know*, what we *Want to learn*; what we *Learned*) adapted in *Primary Connections* units to be more specific to science learning: What we *Think* we know; what we *Want to learn*; what we *Learned*; *How* we know.

... easy to use, written in good, down to earth language, it's not written for academics – which doesn't mean it's dumbed down, it just means that it is a useful tool, it's not an "elite" sort of item. *CI-1*

Dean expressed a similar view of the clarity and efficacy of the published resource:

Looking at the *Primary Connections* units and the fact that they're set out really clearly and you don't need too many resources I think was a good thing... I can't bag it. I really only had a close look at this Push Pull unit that we're doing, but it's simple and to the point and fun, so that's fine. *DI-1*

The Explain phase provided evidence of the effectiveness of the PD sessions in bringing about pedagogical change when strategies modelled in those sessions were observed being explicitly replicated in the classroom. For example, the cooperative learning strategy modelled by *Primary Connection*, which was new to the teachers, was readily adopted as a regular part of their science lessons, as evidenced by the following transcript from a lesson observation:

Dean: You're going to get into small groups in a moment. There's going to be a Manager, a Speaker, a Director. Now remember the roles are up there (*reads wall chart*).

Lesson Observation 4 (LO-4)

Another strategy modelled in the PD was "Think, Pair, Share", which was used effectively to provide reflective time for students, before discussing ideas with a partner and then bringing refined ideas to the whole group. The following passage is an example of its use in Lesson 3:

Dean: I'm going to get you to do with a partner something called Think Pair Share. You're going to think about where you find air. You're going to find a partner and share with them. You might say "I don't think there's any air in my cupboard at home" You're talking about where air is found and where it's not. *LO-3*

A further strategy implemented by the teachers was "Predict, Observe, Explain". This was modelled in the PD sessions and is also explicitly included in one of the *Primary Connections* lessons, as indicated by this extract from the Lesson 3 transcript:

We're going to do a little experiment now. You're going to make a prediction, then you're going to make an observation, seeing what happens, and you're going to be explaining why you think it happened. *LO-3*

These brief comments and vignettes above illustrate how strategies that had been modelled in the PD sessions were transferred into the teachers' classroom practice.

4.2.4 ELABORATE PHASE

In this phase, teachers innovate on the models and pedagogies they have been using. The original expectation was that this phase would involve using the *Primary Connections* template to develop a new science unit to follow up the first one. However, because there was a large element of redesigning the initial unit before implementation, this phase overlapped somewhat with the earlier two. Also, the participants had by now developed a more detailed understanding and appreciation of the published units. The idea of developing their own, which had some appeal when discussed in the early planning meetings, was now not as attractive as immediately using another published *Primary Connections* unit, "Material world", with their classes. Because the second unit they selected was appropriate for their age juncture, planning it was much less complex. Dean identified the value of the *Primary Connections* model, including the 5Es structure and the use of simple investigations:

(The unit) was broken down into simple steps and it wasn't resource intensive. It was so easy to do it with a variety of things. *DI-2*

The teachers by now were both demonstrating confident mastery of the *Primary Connections* model, and were readily including further units in their planning, as well as coherently linking them to related activities from other sources. For example, the teachers reported that their follow-up unit on materials was used to lead in to a Technology challenge from the QSA Assessment Bank (Queensland Studies Authority, 2009a).

4.2.5 EVALUATE PHASE

The intention of this phase is for teachers to consolidate the change process by reflecting on their learning journey. It was in this stage that Dean identified the value of the 5Es model:

Yes. It was a good way of keeping on track... with that model it's easier to break down each step, and to allow them to keep on their own track without having to do everything at exactly the same time. *DI-3*

Much of the teachers' reflective thinking was documented in interviews, and in their aside comments to me during lessons, and will be presented later in this chapter.

4.2.6 SUMMARY OF INTERVENTION FINDINGS

Prior to the data gathering, it had been assumed that particular aspects of the intervention would emerge as being dominant in facilitating change. However, this initial overview of data has indicated that this was not the case; rather, it is apparent that each element of the process was important in promoting change in the subjects' beliefs and practices. This confirmation of the efficacy of the *Primary Connections* multi-stranded professional learning model was one of the key findings of the study, as noted at the start of this chapter.

The two subjects were competent and confident teachers who were prepared to explore and adapt an alternative approach to teaching science and add it to their repertoire of practice. The next section will take a more detailed look at the findings in relation to the intervention's impact on their beliefs and practices. An initial summary of observed changes is referenced to a list of classroom behaviours expected to be changed by a constructivist reform, followed by a more detailed analysis of the findings mapped to each research question.

4.3 CHANGED TEACHER BEHAVIOURS

The changes confronting teachers when they implement constructivist reforms were discussed in Chapter 2 (Section 2.4), and a range of issues and lists of changed practices were presented (Goodrum et al., 2001; Goodrum, 2006; Jones & Eick, 2007; McKenzie & Turbill, 1999; Taber, 2006). One of these examples, Goodrum's 2006 study, was based on an intervention with similar constructivist principles to the current one. The changes he observed in teachers' practice (previously discussed in Chapter 2, including Table 2.11) bear striking similarity to the findings of the current study. Consequently, it will be used as an initial framework (Table 4.2) to introduce the data showing changes in teachers' behaviours during this case study. The evidence for change will be presented sequentially, sorted according to the nine examples in Goodrum's list of classroom behaviours that changed in a constructivist

reform. Additional changes not included in this list are included in the following discussion of the research questions.

Table 4.2

Classroom Behaviours Changed in a Constructivist Reform (Goodrum, 2006)

Changes	Examples of changed behaviours
Reduced “teacher-directed” teaching evidenced by less:	Notes copied from the board Teacher explanation
Increased “student-centred learning” evidenced by more:	Small group discussion Cooperative learning groups Open-ended questions with wait time Conceptual explanation after activity and experience Investigations Heightened exposure to fewer concepts Diagnostic and formative assessment

4.3.1 NOTES COPIED FROM THE BOARD

Both Chris and Dean discussed how this aspect of “teacher as presenter” had changed. For example in his third interview, conducted in Week 21 of the 22-week intervention, Dean reflected on how he would do things differently, compared to his practice prior to using *Primary Connections*: “I’d make sure they (students) were much more part of doing things themselves or in small groups, writing down their own conclusions instead of a ‘mass’ conclusion that is up on the board.” *DI-3*

Further evidence presented later makes it clear that the teachers were placing more value on students’ ideas and findings rather than their own established beliefs about what should happen. The result of this attitude being communicated to the students is that the notes students were writing in their science journals were almost entirely their own words. A typical example of open-ended note-taking is this student’s ‘predict, observe, explain’ response in Lesson 5 of Push-pull:

Predict: The cup is going to float. It will also turn.

Observe: The cup is floating and the tissue is not getting wet at all even when you push it right to the bottom.

Explain: There was still air in the cup. LO-3

4.3.2 TEACHER EXPLANATION

One of the key elements of change identified by both teachers was the degree of “teacher talk” and direction in lessons. In the first *Primary Connections* lesson, observed in Week 4 of the intervention, the tasks were all set up in place before the class arrived in the room, so the students were highly motivated to start work, but the teachers felt it necessary to give a lengthy introduction (25 minutes) before students were allowed to begin working independently. When reflecting after Lesson 1 about what he would have done differently, Dean said, in his first interview,

I think that I would have thrown them straight into it... I would have made the intro a lot shorter and I would have chunked the kids in there just to see what they do and then bring them back (to discuss it). *DI-1*

Dean identified the importance of allowing children to develop their own understandings, a view that was confirmed by his observation of the quality engagement in the activities and the subsequent discussions. This is in line with the findings of Diezmann and Watters (2002) that if a teacher provides unnecessary support for students who have the ability to accomplish a task unaided, the cognitive value of a task is reduced. Dean recognised that the unnecessary scaffolding he and Chris provided may have inhibited rather than enhanced students’ learning. He returned to this topic in a subsequent interview:

I’d cut down the amount that I spoke, more again. That’s a big point. I was really happy with how we did everything, but sometimes by talking that little bit more you can give out a weaker message. You just dilute what you really want them to hear if you talk too much. *DI-2*

Chris made similar comments when asked how he felt about Lesson 1:

It was student-focussed and student-led. I like that we didn’t do the work and that they had to work it out for themselves *CI-1*

However, when asked in the first interview what he’d like to do next, Chris’s response indicated that he still lacked confidence that student investigations were able to consolidate learning without teacher-directed input:

I’d definitely introduce direct instruction, a little bit of direct instruction, just a quick “this is what we’re talking about”, and reference what they had done, and then do some more exploring from there. *CI-1*

Dean returned to this theme in an interview later in the study, when asked to discuss changes in his teaching:

I think that my science lessons before were too teacher-directed, me standing up there just taking them through each step whereas now I'd be inclined to give them a few things and get them to create a lot of the steps themselves, being a lot more laissez fair with I how I do it now compared to what I used to – that's the big change. *DI-2*

When asked what had changed in his view of the way students learn science, Dean explained how the autonomy he was giving the students now was quite different to his prior practice:

Not that they don't learn when they're being directed by the teacher as well, but they enjoy being left alone and playing around with things... The way I taught before, they didn't really get to talk between themselves about what they'd learnt, they really just listened and used what they heard to put an idea down on paper... *DI-2*

The lesson observation transcripts confirm the extensive amounts of time the teachers allowed for students' independent and group investigations. This particular aspect of change was the one both teachers most often referred to, as it clearly had a profound effect on their approach to teaching science.

4.3.3 SMALL GROUP DISCUSSION (SOCIAL LEARNING)

All of the lessons observed included a strong focus on students talking to each other to construct shared understandings. However, the teachers indicated that these discussions were more open-ended than in their usual practice and they repeatedly commented on the quality of the students' conversations. This aligns with the findings of cognition and brain function research compiled by Bransford et al. (1999), that learning is mediated by the social environment in which learners interact with others, and that effective learning requires that students take control of their own learning. Goodrum et al. (2001) detailed the necessary changes in classroom practice required to support such learning, including more opportunities for scientific discussion among students, and more groups working cooperatively to investigate problems or issues.

The data show that social learning was accepted and encouraged. Increased group discussion was a logical outcome of the previously-discussed change in the amount of teacher explanation, with the focus turned from teacher input to student investigation. The focussed engagement observed in students' discussions was possibly prompted by implementation of the *Primary Connections* model for cooperative learning, which is the next element of teacher change to be discussed.

The evidence of both teachers giving students “power” and “responsibility” for their own learning identifies that they have adopted an essential aspect of unstructured inquiry approaches; it possibly also represents a more authentic view of the nature of science in that there is an acceptance of a process in which different answers might need to be considered, debated and reconciled with evidence gained by the students through experiment. This is in line with the advice that “all students are given multiple and varied opportunities to pose questions, design investigations, dialogue/collaborate with peers and teacher, collect and evaluate evidence, justify conclusions, and demonstrate their understanding” (Fletcher et al., 2004, p. 2).

4.3.4 COOPERATIVE LEARNING GROUPS

Good's (1996) summary of the research into what it means to “teach for understanding” presented a number of key points (presented earlier in Section 2.4) of which three are particularly relevant in this context: (a) knowledge is socially constructed; (b) learning needs to be tied to authentic tasks; and (c) teachers should progressively transfer responsibility for managing learning from themselves to learners. These aspects were embodied in the cooperative learning strategies used in the lessons observed. In Lesson 1, the teachers explicitly modelled the “Speaker, Manager, Director” cooperative learning strategy used in *Primary Connections*, and then continued to use this strategy as a key element of each subsequent lesson. While the strategy is not unique to *Primary Connections*, it had not been used previously by these teachers or students. They also used a “Think, Pair, Share” strategy in Lesson 3 to encourage diversity of ideas as noted above in Section 4.2.3. A typical student response is the following extract from a science journal:

Predict: The cup is going to float. It will also turn.

Observe: The cup is floating and tissue is not getting wet at all even when you push it right to the bottom.

Explain: There was still air in the cup.

The students were observed to respond well to both the strategies mentioned above, demonstrating a high level of engagement and providing a rich diversity of ideas in subsequent discussions.

4.3.5 OPEN-ENDED QUESTIONS WITH WAIT TIME

There were many examples of open-ended questioning throughout the lessons, both in whole-class discussions and in conversations with individuals and groups during investigations. Wait time was a regular feature of class discussions, with the teachers often encouraging students to take time to consider an answer, or to think about whether there were alternative answers, before asking for responses to questions. One very structured example of open-ended questioning with wait time occurred in Lesson 2 with a Think, Pair, Share exercise being organised by Chris, as detailed in this extract from the Lesson Observation log:

I'm going to give you one minute to think about where we find air and where we don't.

(A minute later) Now share what you thought with your partner.

(partner discussions)

(Two minutes later) Now you're going to write in your science journal. LO-3

Students were given ample time to consider their personal ideas, before discussing with a partner, and then writing some notes. The strategy fostered deeper learning by encouraging individual reflection, followed by focussed dialogue in which students could co-construct shared understandings, and culminating in reflective writing. The observation indicated that students engaged with this extremely well, as evidenced by the subsequent class discussion which had a wide range of divergent ideas. This strategy not only broadened the scope of discussions, but demonstrated the value of the students' voice in the development of ideas and investigations.

4.3.6 CONCEPTUAL EXPLANATION AFTER ACTIVITY AND EXPERIENCE

The observed lessons featured open-ended investigations of phenomena *before* more structured discussions and explanation, consistent with the constructivist learning models discussed in Chapter 2 (Bybee, 2006; Dewey, 1938; Kober, 1993; Nussbaum & Novick, 1982). In the first lesson, both teachers deviated from their lesson plan by engaging in discussion of the concepts before allowing the students to

begin the activities, but both later commented that it would have been better if they had not done this. For example, Dean clearly reiterated the “Explore before Explain” principle which had been presented in the PD session:

I think I had a little bit of an influence over their understanding before they had a chance to get in and do it themselves, which I would prefer not to do. I would have preferred to have them find out more for themselves as opposed to laying it out for them. *DI-1*

4.3.7 INVESTIGATIONS

In the lessons observed, the teachers used the published lesson plans, as well as their own questioning strategies, to encourage investigation and active inquiry, aiming to achieve experiences which would enable discussion of science concepts. When asked what had changed in his view of the ways students learn science, Chris said that his approach now included “a lot more open-ended experiments without an expected outcome” because he had become more convinced that “They learn by doing.” *CI-2*

Such statements indicated that earlier teacher concerns about the apparently limited content and rigour in the *Primary Connections* lessons had been over-ridden by their observations of student learning.

4.3.8 HEIGHTENED EXPOSURE TO FEWER CONCEPTS

In the initial planning meetings, both teachers expressed concern about the lack of content in the unit, and felt that they were going to need to “pack it out” with more direct teaching. The first lesson they planned, though, consisted largely of individual activities and group investigations, as shown in Table 4.3. However, note that in this lesson the students’ independent activity did not start until twenty-seven minutes into the lesson – a point that the teachers noted as significant and will be addressed in later discussion.

Table 4.3

Outline to Lesson 1 (as implemented)

Time (min)	Description of events
0	Outline of topic – Push/pull
2	Groups of three formed
4	Explanation of roles (Manager, Speaker, Director); hand out badges
9	Show “Push and pull pictures” sheet, explain activities (draw arrows to show pushes & pulls); student questions & discussion
14	Distribute sheets; students complete individually.
25	Explain six activity stations
27	Rotation through six activities, document findings on retrieval sheet (see Figure 4.2)
63	Debrief – “Speakers” asked to describe their group’s findings for a particular activity
69	Introduce “Word wall” and add words from discussion
74	TWLH – notes of discussion on whiteboard (see example in Figure 4.4)
95	Students given “Science journals” and glue in both sheets.

When asked to reflect on how the first lesson had gone, Dean explained how he had changed his opinion on this:

You mentioned previously that you felt there wasn’t enough substance in some of the activities...

Yeah well I thought that about the activity we did the other day and that erases that concern. I thought that getting the kids to go around those six little stations was going to be something that we couldn’t get too much from; that it was going to be 5 or 6 minutes at each and the kids getting bored quite quickly and waiting to move on to the next thing, but that didn’t happen. It played out better than I thought because with the ping pong ball and the straw and the counters, I felt as if the kids were going to come along and just use each of the items just as toys and I didn’t think that they were going to talk about the pushing and pulling aspects of it, I thought they just going to think of it as a bit of a play task. *DI-1*

The teacher was encouraged by the extent to which the students engaged in discussion and argumentation, which challenged his original expectations. He had predicted that the simple activities would produce simple responses, but the students built in more complexity and found creative ways to extend the challenges, effectively neutralising Dean’s concerns about the lack of substance in the activities.

4.3.9 DIAGNOSTIC AND FORMATIVE ASSESSMENT:

The first lesson began with a diagnostic assessment activity, with students drawing arrows on a diagram to explain their pre-existing understandings of forces. Chris explained to the students: “This will show us whether you have a good understanding of these things.” Later, Dean reflected that, “For a long time in the past when I’ve done science, the assessment has been an experiment, like a full write-up of an experiment and not testing their ideas.” *DI-3*

The assessment in both classes was ongoing, based mainly on the students’ documentation in their “science journals” of their thinking at each stage of the unit. There were also numerous examples of the teachers making judgements of student progress during the lessons, for example, this aside comment to me during the first lesson: “The reporting (recording activity findings) – the first one they were a bit rusty, but after that they’ve really picked it up and figured out how to best get their results down.” *LO-1*

4.3.10 SUMMARY

The nine changed classroom behaviours identified by Goodrum (2006) have provided an outline for an initial consideration of the data, showing how the subjects changed their science teaching practice: they encouraged student voice and autonomy by reducing formal note-taking and using open-ended questioning; they facilitated shared learning experiences by encouraging open-ended investigations in social learning groups; they enhanced the degree of challenge by reducing the scaffolding; they supported conceptual development with discussions that took place *after* investigations, using questions and wait-time that valued student input; and they effectively used diagnostic and formative evaluation to guide their planning. While each of the elements from Goodrum’s list was clearly evident in the data, the participants placed particular emphasis on a reduction in their amount of explanation (Section 4.3.2), and in a new focus on exploring before explaining (Section 4.3.6), in line with the *Primary Connections* model.

Before concluding this section on changed teacher behaviours, it is worth considering the evidence for causality of these changes, that is, the extent to which the subjects attribute their changed practice to the PD program and the implementation of *Primary Connections*. Both Chris and Dean had described significant changes in their approach to teaching science, and were explicit in saying

repeatedly that elements of the intervention had initiated that change. For example, Chris identified both the teaching resources and the PD sessions as influential in this interview exchange:

We've talked about change. Can you comment on how influential the Primary Connections unit & teaching resource were in that change?

I think it's been central, that modelling of good science teaching.

Were the initial PD sessions influential?

Absolutely, I think they were a good spark. They got me thinking in different directions in how I could implement that in the classroom immediately. So just doing simple tests, getting the kids to do some of those simple exercises that we did in the PD. CI-2

Dean had adopted the strategy modelled in the PD sessions of identifying variables and using them to develop a range of investigations, and attributed this new approach directly to *Primary Connections*:

I didn't really think about variables closely in science, not to the extent that I do now, and it's something that has carried over into my teaching. I think that I focus on that a lot more now when we do science in the classroom and I've done a lot more of it since we've done the Primary Connections stuff.
DI-2

Thus far in the chapter, the intervention and the general themes of the data have been introduced. The focus of the rest of this chapter will be a more detailed presentation of the findings in relation to each of the four research questions.

4.4 FINDINGS ALIGNED TO RESEARCH QUESTIONS

The key research question for this case study is "*What are the changes in teachers' beliefs and practices associated with implementing a constructivist-inspired learning program?*" Many of those changes have already been discussed but to provide more detail in answering the question, the four supporting questions will be addressed in turn, with discussion of the findings relating to each.

4.5 RESEARCH QUESTION 1: STRUCTURED CONSTRUCTIVISM

In what ways do the PD program and the published curriculum units foster the development of inquiry-based science in a constructivist learning environment?

The answer to this question depends on evidence of open-ended inquiry-based learning with students making key decisions about their learning. The majority of practical activities in the *Primary Connections* units are relatively closed because the curriculum was written for teachers who lacked confidence in teaching science and therefore was highly structured (Hackling, 2005). Consequently, there is a degree of tension in a resource that promotes student-led inquiry but models it in a structured manner. This may be an intrinsic limitation to the degree of open-endedness in *Primary Connections* investigations and will be considered in the following discussion.

Constructivist pedagogies were discussed in Section 2.4, with models from a number of different researchers presented to help identify appropriate classroom practices (Bransford et al., 1999; Fletcher et al., 2004; Hackling & Prain, 2005; Magnuson et al., 1999). The study by Fletcher et al. (2004) investigated which constructivist pedagogies best fostered science literacy for all students, and presented a list of nine easily identifiable practices. The list, presented earlier in Table 2.5, will be used in this section as a guide to identifying such practices in the case study data, so is included again as Table 4.4. In this section, the table is referred to as *Fletcher's list* (FL) and items from it referred to numerically, for example *FL-2*.

Table 4.4

Constructivist Pedagogies That Foster Scientific Literacy (Fletcher et al., 2004)

FL-1. Student inquiry is the foundation for concept development.

FL-2. All students are given multiple and varied opportunities to pose questions, design investigations, dialogue/collaborate with peers and teacher, collect and evaluate evidence, justify conclusions, and demonstrate their understanding.

FL-3. Students take an active role in directing inquiry activities, explaining concepts to one another, and evaluating themselves.

FL-4. All students participate equally in the learning process.

FL-5. Teachers use assessment and questioning to guide instruction.

FL-6. Students take responsibility for their own learning.

FL-7. Teachers employ multiple and varied instructional and assessment strategies to facilitate conceptual understanding.

FL-8. Students see personal value and relevance in the science they learn.

FL-9. Science literacy for all students is the goal of instruction.

4.5.1 STUDENT INQUIRY FL-1

Students' science activities can be considered on a continuum, ranging from open-ended, student-instigated inquiries at one extreme, to closed, teacher-directed activities at the other. As mentioned in Chapter 2, it is common for teachers of science to operate at the 'closed' end, treating experiments as simple exercises in verifying theories that explain known phenomena (Coble & Koballa, 1996), and this was identified by both subjects as typical of their previous practice. Jones and Eick (2007) identified open-ended inquiry-based science teaching as a particular challenge for teachers because it requires them to suspend planned instruction to explore students' questions. Dean and Chris approached such pedagogies tentatively at first because, as Jones and Eick explained, teachers may perceive this approach as relinquishing control of their teaching. However, they became much more comfortable with moving along the continuum towards open-ended and student-led inquiries after seeing evidence of success.

The initial activities in the *Primary Connections* unit were considered too simplistic for the age of the students, as explained by Dean:

The unit that we're doing is a Level 1 (Year 2/3) and obviously we're doing it with a Year 4 & 5 class so it's going to be below them, so we've taken everything that's in the unit and built upon it, so that there are some outcomes that are more challenging for the kids that we've got. We haven't had to change too much – not as much as I thought. DI-1

Chris explained this further:

We're modifying it by trying to bring in some more complex questions, maybe some questions that involve a 2- or 3-step process of linear thinking rather than just asking them a very simple "What is this force".

Consequently, the teachers developed a more complex Engage lesson that aimed to extend the students' thinking while keeping true to the original unit design. It was planned around a series of six relatively open-ended activities, each involving two simple objects, with instructions such as these:

Task 1: Ping Pong Ball and Straw

- Push or pull the ping pong ball as many ways as possible using only the straw.

- Make sure you make a note of each of the push and pull methods you use on your results sheet. Don't forget to write whether the force is pushing or pulling!

Students were given a retrieval sheet to document their findings. The example provided (Figure 4.2) is typical of the way students used words or pictures for recording. The teachers had very little input once the rotation of activities began, other than encouraging students to explore more diverse responses to the challenges.

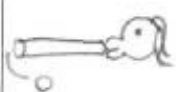
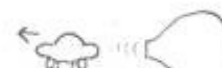
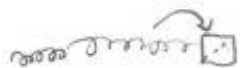
Activity	Push	Pull
¹ Ping Pong ball and Straw		
² 2 counters!	flick, by putting 1 counter over the other and push down	pull by grabbing 1 counter in 2 hands and pull towards you
³ Bottle top and rubber bands!		
⁴ Toy car and balloon		
⁵ Soft ball and Skipping rope		
⁶ dice and spring		

Figure 4.2. A student's "Push-pull" recording sheet.

The following exchange between Dean and a student occurred during Lesson 1, with a student who was exploring ways to use a pair of plastic counters:

Student: You can also play tiddlywinks on the carpet. If you use the carpet it goes higher. If you do it on the table it goes forwards. If you put pressure on it goes up.

Dean: That's on the carpet. What's the difference when you've got it on the table?

Student: You can't push it down on a hard surface (tries soft chair)

Dean: What do you think, is this going to be higher or flatter?

Student: It'll go flatter because it goes too...

Dean: So you get to a point where you don't want it to be so soft? So it's like a Goldilocks thing – too hard, just right, too soft?

Student: Yeah

Dean: What's another way we could make the counter move? *LO-1*

This line of questioning sought to value the student's discovery and initiative, but also to extend it and try further open-ended options. Another sample, from 'Push-pull' Lesson 8, is an example of the way the teachers regularly used student ideas as the basis for discussion. In this case, students had been modifying pieces of paper and testing the effect on their rate of fall:

Dean: We're going to do one more little experiment. Someone over here has been turning a piece of paper into just about confetti (*holds up shredded sheet*). Let's see if this piece of paper has enough air or wind resistance to hold up. Who thinks this piece of paper is going to fall faster than it has the last two times? Who thinks it's going to fall the same time as this piece (*scrunched ball*)? *LO-3*

Inquiry-based teaching puts increased demands on teachers' content knowledge, which must be deeper and broader than in traditional teaching in order to cope with the range of students' questions and investigations (Fishman et al., 2003). This quickly became apparent during the lessons I observed, despite the subjects' relatively strong background in science content knowledge. Chris mentioned to me that after repeating the "water drop" activity from the PD session with his class, he had done some internet research on surface tension so he could more confidently explain the phenomenon the students had been exploring. During Lesson 3, Dean admitted to me that he was out of his depth with the content being discussed:

Dean: Now you're going to write in your science journal. Your heading is going to be "Air is found..." and underneath that you can just list places where you find air. Beneath that, if you think that you can find places where there is none, "Air is *not* found..." – I want you to list places where there is

not air.

(students discuss & write)

Dean (to me): I don't know that much about air myself. It's not found everywhere, but I don't know exactly where it's not found. I don't think it's found in water – water is oxygenated, but does that mean it has air in it? I don't know *(laughs)* *LO-3*

Both teachers made it clear that they were sometimes out of their comfort zone, but they clearly saw this as a stimulating challenge rather than something to avoid. Perhaps this is where their high self efficacy and outcome expectancy, supported by their science content knowledge, enabled them to persevere with the new pedagogies and embed them in their practice (Bandura, 1986), whereas a teacher with less confidence in their science content knowledge may at this point have shied away from the challenge.

4.5.2 STUDENTS INFLUENCING PLANNING FL-2

As students neared the end of the activity rotation in Lesson 1 (see Figure 4.2), Dean was already sufficiently impressed with the outcomes that he was planning a repeat of the open-ended inquiry strategy, as he mentioned in an aside recorded during the lesson:

I'm thinking when we get to the part where we use water and its effect on push & pull, doing another rotation of activities like this in water-based activities. Like how could you move a ping pong ball in a bucket of water, or using an eye-dropper? I'm thinking of saying to Chris we should give this another spin but all water-based and the water must be the thing used to push or pull. *LO-1*

This thought was at least partially in response to a student's suggestion, although as Dean admits, it was already planned to some extent:

The next step I think will be what one of the kids suggested and that's to look at how pushing and pulling works when we use water. We did all those activities the other day without the use of water and that's where one of the kids suggested we should go next... and that's what we've had written into our planning anyway... *DI-1*

However, there was a clear acknowledgement of the students' role in the direction the unit takes, and of their responsibility for their own learning (FL-6). Also evident is the capacity of students to link new experiences with earlier learning.

The aim of lessons was clearly articulated, and linked to a focus on assessment (FL-5), as shown in the following example where a clear performance-based outcome of the lesson was described.

I just want them to understand that, as one of the kids said, for every action there is a reaction, and I want them to be able to tell me that when somebody does something day to day whether it is involving pushing or pulling...*DI-1*

There was clear intent to allow students to take an active role in developing inquiries (FL-3), as indicated by this quote from Dean in the initial interview:

The only other thing that we're changing is what we're going to do at the end, the culminating activity, where we're going to get some children to set up a little station for themselves. *DI-1*

Further elements of FL-3, students "explaining concepts to one another, and evaluating themselves", was supported by the teachers, as evidenced by this exchange in 'Push-pull' Lesson 8:

Dean: Who thinks that they're either going to either fall at the same speed and land at the same time, or that one's going to hit the ground before the other? What do you think?

Student 1: I think the ball (of paper) is going to hit the ground first.

Dean: Does anyone disagree with her?

Student 2: I do: If you drop an apple and a banana down from a height at the exact same time, they will hit the ground at the same time. The crumpled paper and the normal paper weigh the same so I think they will hit the ground at the same time. *LO-3*

The second student's prediction was clearly wrong, but Dean resisted correcting the flawed thinking and left it to the students to investigate the phenomena independently. He was able to later reflect on the autonomy he was now allowing students (FL6):

What's changed in your view of the way students learn science? What's changed is that they learn about it by doing it, by being left alone.... leaving them to their own devices. DI-2

Chris was able to make similar comments about students taking responsibility for their own learning (FL-6):

I think that they were able to explore things in their own way. CI-1

Assessment and questioning were used effectively to guide instruction (FL5), from structured, written diagnostic activities to incidental questioning throughout lessons, as indicated by this quote from Chris in the first lesson:

I'm just trying to get you to think about... there could be more than two forces at work here... I had a good comment – what was it? LO-1

In the initial PD sessions, teachers were introduced to the POE inquiry model – *predict* what you think will happen; *observe* the phenomenon; and *explain* what happened. Such an activity was the focus of ‘Push-pull’ Lesson 4, although the teachers adapted the published lesson plan by increasing the complexity of the task by doubling the number of trials to be documented from three to six as shown in Figure 4.3. The students’ active role in posing questions, designing investigations, compiling evidence and justifying conclusions (FL-2, -3) is demonstrated in this “sink or float” investigation. The task was relatively structured, in that the inquiry itself was decided by the teachers, but there was a degree of open-endedness for students who were able to select the materials to test and the way they recorded their findings.

1. Choose six objects
2. Predict whether they will sink or float by circling the word.
3. Circle what you observed – did they sink or float?
4. Explain why you think these objects sink or float.

Object	Predict	Observe	Explain – why?
1 rock	sink OR float	sink OR float	the rock is so heavy that the water can't hold it up.
2 steel	sink OR float	sink OR float	the water is more dense than the steel so it holds it up.
3 Plasticene	sink OR float	sink OR float	Plasticene sinks because it is more dense than the water.
4 tin	sink OR float	sink OR float	the tin will float but if you turn it upside down it will let water in and sink
5 tennis ball	sink OR float	sink OR float	the tennis ball floated because it is less dense than the water
6 crayon	sink OR float	sink OR float	the crayon sunk because it was more dense than the water.

Figure 4.3. A student's Predict, Observe, Explain chart.

Further elements of Fletcher's list were demonstrated as the unit progressed, with all students engaging in the learning process (FL-4) and taking increasing responsibility for their own learning (FL-6). By 'Push-pull' Lesson 8, students were engaged in more complex design of investigations and developing their thinking about phenomena, as indicated in the following quote from a student book:

Researchable question: What happens to the paper helicopter when we change the wings, cut off at the second line?

Hypothesis: It just spins normally.

Results: It was faster.

Discussion: The changed helicopter went down first. It happened because the changed one has less weight to carry.

Conclusion: It spun faster. So our hypothesis was wrong. LO-4

Examples such as this, which document misconceptions or flawed reasoning, created a tension for the teachers who would prefer only "accurate" statements to be recorded in books, however they recognised the need for students to develop conceptual understandings at their own pace.

4.5.3 UNIT PLANNING

A particular concern for Dean in the early stages of the intervention had been planning cohesive science units. He identified *Primary Connections* as integral to supporting a changed view:

With the *Primary Connections* units I think that (planning a whole unit) is going to be a lot easier.

Chris explained that significant change was that he was now teaching more science because he found it easier, requiring less time and resources than his previous science practice. In his second interview he gave the following response:

Reflecting on your view of the way students learn science, how would that influence the way you plan a unit differently now than you might have six months ago?

Number one, we'd see a big difference because I'd be more comfortable actually *doing* a science unit – that's a difference, but definitely also having a lot more time for exploration, a lot less time with me talking, which is always a good thing.

What has been the most useful outcome for you as a teacher? Just demystifying the whole idea of teaching science. Making it much more accessible, so that it doesn't seem like this subject that I'm missing out on because I don't have the time to do it. Making it seem like something we can do in the classroom with a limited amount of materials. *CI-2*

In the final interview he again commented on the practicality of the curriculum resources:

Having used Primary Connections, do you feel more confident to plan your own science unit? Definitely. I'm a lot more able to develop practical activities and link them to the curriculum. *CI-3*

4.5.4 SCIENTIFIC LITERACY

This research question is supported in part by observation of classroom practices that support an enhanced understanding of scientific literacy and the Nature of Science (NOS), particularly those aspects related to open investigations. Australia's *National Assessment Program: Science Literacy* (Curriculum Corporation, 2006) developed a concise definition of scientific literacy which encompasses three domains, listed in Table 4.5. As mentioned earlier, there are alternate definitions, but since the Curriculum Corporation model of scientific literacy forms the basis of content for the *Primary Connections* program, it has been used to guide the PD program developed by this study. This section will align the findings of the study to these three domains.

Table 4.5

Three Domains of Knowledge in Scientific Literacy (Curriculum Corporation, 2006)

A	Formulating or identifying investigable questions and hypotheses, planning investigations and collecting evidence.
B	Interpreting evidence and drawing conclusions, critiquing the trustworthiness of evidence and claims made by others, and communicating findings.
C	Using science understandings for describing and explaining natural phenomena.

Understanding NOS is a foundational element of scientific literacy; in Section 2.1.2, several outlines of NOS were discussed, including one devised by Bell et al. (2000) listing seven interrelated aspects of scientific knowledge, which is said to be (a) tentative, (b) subjective, (c) empirically based, (d) socially embedded and (e) dependent on human imagination and creativity. It also distinguishes between (f) observation and inference and (g) theories and laws.

The initial interview with Chris identified a number of elements of his understanding of the nature of science:

I would love to show them something and have them do something but I guess it was that lack of... It was that big jump between showing them something cool and then letting them do some science behind that...
...what concerns me the most, is showing them just a phenomena [sic] and not being able to reproduce it. My big concern is going off on a tangent and doing things that are not necessarily scientific, not able to be reproduced.

CI-1

One key element Chris identifies as important is reproducible demonstration of phenomena, aligning with the idea that science is empirically based (Bell et al., 2000) as well as Domain C of scientific literacy from Table 4.5. In the following statement, it is clear that his view of scientific literacy also includes elements of Domains A and B when he states his aim for students to develop investigations and communicate their finding with subject-specific terminology.

I'd like them to be able to design their own experiment, and to use the language that we've gone over. *CI-1*

As described in Section 3.6.1, both PD sessions included modelling of the way each variable in a phenomenon could be used to develop a further investigation. This

strategy for extending simple activities by developing subsequent investigations was taken on board as a key element of classroom science practice by both teachers. Dean reflected on how the PD sessions had impacted his view of science. In particular, he had become interested in the way variables could be used to initiate and extend investigations, a key element of Domain A. In the following excerpt, he explains how this new understanding helped him to turn a potential problem (two students doing the same science demonstration) into a richer learning experience for the class:

Thinking back to the PD sessions that we did; did they present anything new or unexpected?

Yeah they did. I thought about using variables before when we've done experiments, but I haven't looked deeply enough at them, and it's changed the way that I've taught science because outside the lesson that we did the other day I've had kids doing their own science experiments in front of the class. The other day there was a bit of a mix-up and two of the kids did the same experiment on the same day using detergent and milk and food colouring. I think I would have otherwise thought "Oh well, they're going to do the same experiment, this isn't going to go well" but it ended up being a lot more worthwhile because we were able to look at the difference between the two. They used different milk, different amount of detergent, different type of detergent. I don't think I would have covered that as well if I hadn't done what I did in those workshops looking at variables.

That turns it into a much stronger activity, doesn't it...

Yeah, it went really well; before then I would have thought "These two are the same and the kids are going to get bored and this is going to just bite the dust" – but I didn't. *DI-1*

The initial PD sessions of the intervention modelled a strategy for identifying the variables in a phenomenon and using each of them as a potential new investigation. The above quote indicates how Dean had embedded this idea into his classroom practice.

The following statement from Lesson 3 provides evidence that the fair test terminology had become a standard part of science lessons:

Dean: I want to talk about a fair test; that means we have to make things the same. What things must we do the same to make it fair? *LO-3*

Another aspect of change in the teachers' view of scientific literacy aligns with Domain C, explaining natural phenomena, with Dean identifying the way scientific understandings can be used to explore everyday situations and objects.

I think that just playing around with objects that aren't necessarily associated with science has been something that I've changed my mind about. Usually when I've done science I thought about scientific instruments like microscopes and that sort of thing, whereas what we did in the lessons here used a whole lot of ordinary, everyday objects that could be sourced from anywhere, not just a science resource room. *DI-2*

Dean had expressed the common misconception that scientific processes are associated with complex apparatus, but his focus had changed to science as a *process*. A positive outcome of this change in thinking and practice is that Dean is now likely to teach science more often because he is not constrained by the need for special resources, as he explains in the following quotes.

...just using ordinary objects in science. I would have only thought about teaching science before if I had specific science objects to work with, if I had charts, or microscopes, or powder. Now I'd be able to teach science just using... silly things, just talking about forces like we did in the unit last term, it's so easy to do without the resources that I would have associated with teaching force before. *DI-2*

...just how I go about teaching science by not thinking that I need these resources when I don't. *DI-2*

Chris described a change in his view of science similar to Dean's; that it was not necessarily as complex to understand as he had previously thought, and that designing an investigation was much more achievable for students. In his written reflection following Lesson 1, he wrote:

It is amazing how much science there is to be taught to explain how very simple things work. *CR-2*

The significance of this change in view was emphasised when Chris returned to it in each of the next two interviews held in Weeks 5 and 10.

I liked the structure [of the *Primary Connections* units] and I liked... it was just a spark to me really, because there is science in just about anything and you can explore that using simple objects. *CI-1*

What has changed in your view of the nature of science? It's focussed it and made it a little bit clearer as to encouraging scientific questioning in the classroom, and just how simple it can be to set up an exercise. CI-2

The examples provided in this section have shown that, while there was considerable structure in the *Primary Connections* teaching resources, implementing them fostered elements of change in the teachers' practice. The lessons observed included many elements of open-ended inquiry-based learning, and these closely aligned with the list of constructivist pedagogies identified by Fletcher et al. (2004) as well as with the elements of scientific literacy identified by the Curriculum Corporation (2006).

On that basis, the evidence suggests a response to the first research question that *the PD program and published curriculum units supported the development of an authentic constructivist learning environment.*

4.6 RESEARCH QUESTION 2: EXPRESSED BELIEFS VS. ENACTED BELIEFS

To what extent are teachers' expressed beliefs about constructivist learning aligned with their enacted beliefs?

This research question requires supporting evidence showing that expressed aims align with classroom practices, which in turn demonstrate constructivism-inspired pedagogies. The question focuses on the tensions created by the change to new practices, as indicated by Dean when he said, "...that's where one of the kids suggested we should go next... and that's what we've had written into our planning anyway..." *DI-1*

Dean indicates that he clearly understands the "ideal" of students directing their own learning, however, the fact that the student's idea conveniently aligns with the teachers' prior planning suggests there may be an element of tokenism. A further quote from Dean's first interview implies that there is tension between the "fun" elements of science and clearly expressed learning outcomes.

I think (the *Primary Connections* unit) gives me enough structure to make some changes so it suits the kids that I've got but also feel as if I'm doing it for a reason and it's going to culminate in something that's going to stick with them, as opposed to something that they do for fun one afternoon. *DI-1*

Tension around the idea of fun also appears in a comment to the class by Chris during Lesson 4.

I'm glad that we're going to do this (practical investigation) because it shows that we're doing things that are not only fun but they can teach us things as well. However, there is going to be a bit of thought put into this.

LO-4

Clearly “fun” does not completely align with the teachers’ views of learning, and they feel students need some extra focussing statements to engage their scientific thinking. Chris demonstrated similar tensions between teacher-centred “direct instruction” and “activities for the sake of doing activities”, implying that conceptual learning only occurs when direct instruction is linked to investigations: “Just to solidify some concepts so that they’re not doing activities for the sake of doing activities.” *CI-1*

The observations showed that what the teachers identified as direct instruction was not a completely didactic or transmissive model incorporating lectures or other teacher-centric practices, but involved active class discussion and targeted questioning. However, the distinction the teachers were making is that it did not value or allow student direction or initiative.

While the focus on direct instruction seems to be at odds with the constructivist model being implemented in the *Primary Connections* unit, Bybee (1997) suggests that it may be essential. While a structured sequence of activities such as his 5Es model *enhances* the possibilities of learning, it does not *ensure* learning as this is too great a demand to place on an instructional model. It is the teacher’s role to manage and complete the process of change. Teachers are facilitators of students’ conceptual change (Goodrum & Rennie, 2007).

Early in the intervention when the above quote was recorded (Week 4, soon after the first lesson), the idea of *structure* was identified as an issue. Both teachers had explained how their prior practice in science was based on one-off disconnected demonstrations of phenomena, and developing a formal unit was a new challenge.

I feel confident teaching science, but I don't feel confident teaching science as a unit. In the past I'd do science lesson, but they'd really just be one-off.

I'd say "Today we're going to do this" and we really just looked at without talking enough about "why" it happened. *DI-1*

By the second interview in Week 14, Dean was indicating that there was a change in his views, and that using the *Primary Connections* model had helped him to view science teaching as less of a challenge than he previously thought.

The fact that it's a lot more simple than what I used to think, and it's a lot more simple than I think a lot of teachers find science... I think there's a lot of people, well, me myself, just daunted by it, getting a lesson prepared. *DI-2*

There was also evidence of changes in the teachers' attitude to the autonomy of students. In the first interview, after the first lesson, Dean reflected on how he would have preferred to make it more student directed:

I would have preferred to have them find out more for themselves as opposed to laying it out for them. *DI-1*

When the final interview was recorded in Week 21, he returned to the same theme, indicating that a sustained change had taken place:

I wouldn't make it as teacher-directed as I have in the past – me standing up there doing things and getting the kids just to watch. *DI-3*

In a written reflection following Lesson 1, Chris is beginning to indicate a view that students are capable of managing their own learning.

I would have prepared more for the session, although the kids seemed to work things out for themselves. *Chris's Reflection 1 (CR-1)*

Both teachers continually encouraged students to think laterally and develop more open-ended responses, as shown by these quotes from the transcript of Lesson Observation 1:

Chris: When you're looking at that sheet, there might be more than one push or pull... *LO-1*

Dean: Remember it doesn't have to be just one way (to move the object), maybe there's three ways. *LO-1*

The lesson transcript below, however, provides an example of the teacher imposing a content agenda on a relatively open student inquiry. A group of students

had ping pong balls and drinking straws, and were trying to keep the balls in the air by blowing through straws.

Chris: Your air is keeping it up, but why doesn't it just fly off into the sky?

My question is, you're making a pretty good effort by pushing it...

Student 1: You have to blow really hard.

Chris: Why do you have to blow hard? Why don't you just go "Shoo" and it goes through the ceiling and keeps going up into outer space?

Student 1: If you blow soft...

Student 2: Gravity, gravity, GRAVITY!

Student 1: yeah, and gravity too.

Chris: I figured one of you'd figure it out. *LO-1*

The teacher was keen to foster further learning by adding a concept, "gravity", to the students' thinking. However the students were actively engaged in a practical inquiry and the response the teacher was looking for did not logically follow from their explorations. In this instance, the teacher's intervention with a pre-determined agenda actually stifled further inquiry rather than expanding it.

Another example of that practice is shown below, where Dean has a particular idea in mind which he's hoping a student will state. Although some aspects of the inquiry (experimenting with the effects of wind resistance on a dropped piece of paper) are open-ended, the teacher is keen to build in some specific terminology:

Student: Because that one, when it was falling, had more air underneath it. The scrunched up one, all the air was just going out there and this one it was staying under there, so it had like a parachute.

Dean: So we call that is two words, what are the two words I'd use? One starts with W and the other starts with R.

Student: Umm...

Dean: We call it air resistance or wind resistance. So it's like a parachute – air made it float. Now if I got a parachute and I crumpled up all of the material and threw it out of the plane, it would hit the ground faster than a parachute that opens up and catches the air. *LO-4*

The students had been engaged in their own inquiries and constructing their own meanings up to this point, but once the teacher intervenes, the student is thwarted and unable to provide the required response, despite having been fully engaged in independently making and trialling different variations of the

phenomenon. As noted earlier in the discussion of *teacher explanation* (Section 4.3.2), Diezmann and Watters (2002) showed that unnecessary support for students who have the ability to work independently will reduce the cognitive value of the task. Findings presented elsewhere indicate the teachers became more aware of this issue as the intervention progressed.

The second research question sought evidence of alignment between teachers' expressed and enacted beliefs about constructivist learning. Some elements of tension were identified, particularly in the idea of fun and how it could fit with rigorous learning activities. Structure was another element of concern identified early in the intervention, but, like other teacher concerns, was mitigated as the term progressed. The conflict between expressed and enacted beliefs can be seen in the data as a logical outcome of the change process, and seemed to be minimised as the teachers became more prepared to relinquish control of lesson agendas and allow students greater autonomy.

4.7 RESEARCH QUESTION 3: TEACHERS' PERCEPTION OF STUDENT OUTCOMES

How does implementation of the PD intervention change teacher perceptions of student learning in science?

This research question is supported if the teachers find evidence of improved science learning outcomes which they attribute to *Primary Connections*. Keys (2006, p. 43) said that "changing curriculum and pedagogy is to change a teacher's beliefs on educating a child". Guskey's work on change (1986, 2002) found that significant change in teachers' beliefs and attitudes is likely to take place only *after* changes in student learning outcomes are evidenced. His model of the process of teacher change takes the following sequence:

Staff development (*followed by...*)

1. Change in teachers' classroom practices
2. Change in student learning outcomes
3. Change in teachers' beliefs and attitudes

If that three-stage model is applied to this study, the change in teachers' classroom practices (Stage 1) can be taken to be implicit in their implementation of

Primary Connections units, and the details of such changes have been described in previous sections of this chapter. This section will complete the mapping of findings to Guskey's (2002) change model by presenting evidence of (Stage 2) the teachers' perception of change in student learning outcomes, followed by (Stage 3) evidence of change in their beliefs and attitudes.

4.7.1 "THEY'RE HAVING FUN, AND I THINK THEY'RE LEARNING SOMETHING"

The teachers recognised the potential for improved learning outcomes from their initial contact with the intervention. The first opportunity they had to observe participants' response to open-ended science investigations was when teachers engaged with them in the PD sessions. Dean made this comment about the hands-on inquiry focus of the PD program:

When you see adults getting right into it, it was always going to be a winner with the kids, using the snakes and the coin and the eyedroppers. DI-2

After observing the high engagement levels of their colleagues with these simple inquiries, both subjects replicated them in their classrooms prior to actually beginning the *Primary Connections* unit. This consequential "critical incident" had a substantial impact on the teachers:

4.7.2 CRITICAL INCIDENT: UNEXPECTED CONSEQUENCE OF TEACHER PD SESSIONS

In the initial planning meeting with the two teachers, they expressed concern that there didn't seem to be enough substance in some of the activities. However, these concerns were allayed in a somewhat unexpected way. The initial teacher PD sessions included simple investigations ("How many drops of water can you fit on a 5¢ coin?", "How stretchy is your lolly snake?") which modelled the way each variable in an activity can be used to develop another experiment. For example, when variables in the "water drop" activity were listed, each small group was able to develop a different follow-up inquiry, testing the effect of changing the height of the dropper, the type of liquid, the drop rate, the type of liquid used, its temperature, the side of the coin used and so on. While it was assumed that these were just illustrations for teachers, they were repeated as class activities by both subjects, and the engagement of students provided the first evidence to them that this model of science inquiry was effective:

When we did those things with you in the workshops, the 5c coin and the snake stretching, it showed me that simple things like that, that you think would only get ten minutes use in the classroom can really be stretched out, because I did both those things back here in class after we did them with the teachers that day, so that eased my concerns about that. *DI-1*

The students' response to the first *Primary Connections* lesson had a profound effect on the teachers, and numerous extracts from the transcript as well as teachers' reflections on it have been included throughout this chapter. A typical response is this comment Dean made to me during the lesson:

It's good to see the differences in how they record their results. The kids who find one way and that's it, and the other ones who delve more deeply and find multiple ways, I think is really interesting. They're having fun and I think they're learning something – and they've only got a couple of minutes at each. *LO-1*

Chris made a similar comment to me during the same lesson:

It's great stuff and I was so pleased at the way the kids took to it and how attentive they were when you engage them like that. *LO-1*

The following incident from Lesson 1 was typical of several one-to-one exchanges that impacted on the teachers, with this one involving both of the teachers and the whole class.

4.7.3 CRITICAL INCIDENT: A STUDENT'S EXPLANATION

In Lesson 1, one of the activities was "Push or pull the ping-pong ball as many ways as possible, using only the straw." One student found that he could suspend the ball in the air by blowing under it through the straw. This exchange between the student and the two teachers took place in the subsequent whole-class discussion, when the student was invited to explain his findings:

Student: (drawing on whiteboard) Blowing in the straw, the wind blows up onto the ball which makes it go up (*draws arrow*). Gravity is going down, right (*draws down arrow*), so that might be +1, and if you're blowing up, that's +1 as well so this would be 2.

Chris: Do you mean -1, and then you'd get 0 because you're equal?

*Student: (pause)...*It's gravity and force...(*seems confused*)

Chris: But you're trying to describe something that's floating and staying at rest, right? Or just staying still. So I think you're thinking that gravity is pushing down, that's -1, and that your result is zero.

Student: (rubs out +1 and changes to -1)

Dean: That's brilliant! What they did just there, that's enough for me to think today went as well as it could. What do they pay me for? That picture is the best thing on that board, I reckon.

(Student adds spiky hair to drawing; all laugh) LO-1

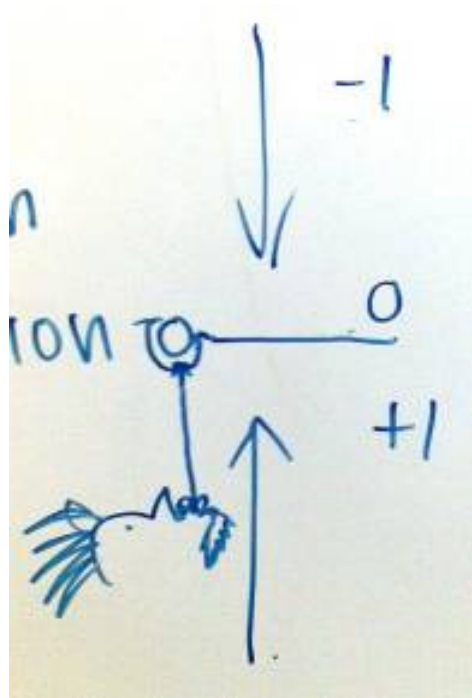


Figure 4.4. Student drawing to explain forces.

Figure 4.4 shows the student's final sketch on the whiteboard. In this exchange, the student had an understanding of the phenomenon that was keeping the ball suspended, but made an error when using numbers to explain the forces. Chris immediately corrected this, but the student's next response indicated confusion ("It's gravity and force..."). It was not clear that the student fully understood the explanation, but quickly changed the numbers on the board as suggested by the teacher. Chris was perhaps too quick in providing the correct answer, rather than supporting the students in constructing their own understanding. However this was quite a significant exchange in the context of the lesson. It neatly summed up the way relatively complex thinking could come from a simple activity, and led Dean to state that student learning had exceeded his expectations, and suggesting ("What do

they pay me for?’’) that in this situation, the teachers’ input was redundant as students were working so well as independent learners.

This incident, during the conclusion to Lesson 1, provided the teachers with substantial evidence of student learning and engaging with concepts at a much deeper level than they had expected, and thus was influential in the ongoing change of their attitudes and belief towards teaching science. The following reflections are from an interview with Dean soon after that lesson:

... the language that they used and the way that they tried to vary what they were doing to improve their results made me a lot happier with the lesson than I thought I was going to be. *DI-1*

I reckon that they realise that there are forces at work, such as pushing and pulling that they wouldn’t have thought about before when it comes to just their day to day activities. I think they were able to understand that you push and pull things all of the time. And just the terms that we discussed, I don’t think they would have been familiar with too many of those terms before.

DI-1

As indicated by the above extracts, an initial, clear outcome of the first *Primary Connections* lesson noted by the teachers was the shared vocabulary that developed. This is an aspect of student learning that was noted throughout the intervention. The third interview with Chris (Week 22) occurred after his class had completed the state-wide Queensland Comparable Assessment Task (QCAT) in science (Queensland Studies Authority, 2009b). He identified a transfer of learning from the *Primary Connections* lessons to the differing context of the assessment:

I know that after doing the unit they were a lot more open to these questions (in the QCAT assessment), the reflective questions that we don’t normally go over in class necessarily. If they hadn’t done the Primary Connections unit they wouldn’t have been as comfortable with these sorts of things. *CI-3*

Both teachers linked student engagement and enjoyment to learning outcomes, as shown in this quote:

...they enjoy being left alone and playing around with things. Even if it’s not always as easy to track, I could just tell in their own conversation they need to be left to their own devices, to experiment, and they enjoy it more and therefore they learn more. *DI-2*

The above comment from Dean does mention a point of concern (“...it’s not always as easy to track”) that aligns with Jones and Eick’s (2007) finding that open-ended inquiry can be a challenge for teachers if they perceive it as relinquishing control of their teaching. In this instance, the observed positive learning outcomes mitigated such concerns. Chris had expressed similar concerns about potentially reducing his control of the learning process as students “played” with materials, but by mid-way through the unit he could see the value in the new pedagogies, not just in learning outcomes, but also in reducing behaviour issues:

What has been the most interesting observation for you in this process?

Seeing how engaged some of those behaviour “problems” (students) in the classroom, seeing how engaged they were; how a lot of what looked like playing was actually them exploring scientific methods or scientific inquiry, how their playing around with different things was actually productive and it engaged them as a result. *CI-2*

4.7.4 “I THINK THAT THEY NOW KNOW THAT SCIENCE ISN’T JUST EXPLOSIONS”

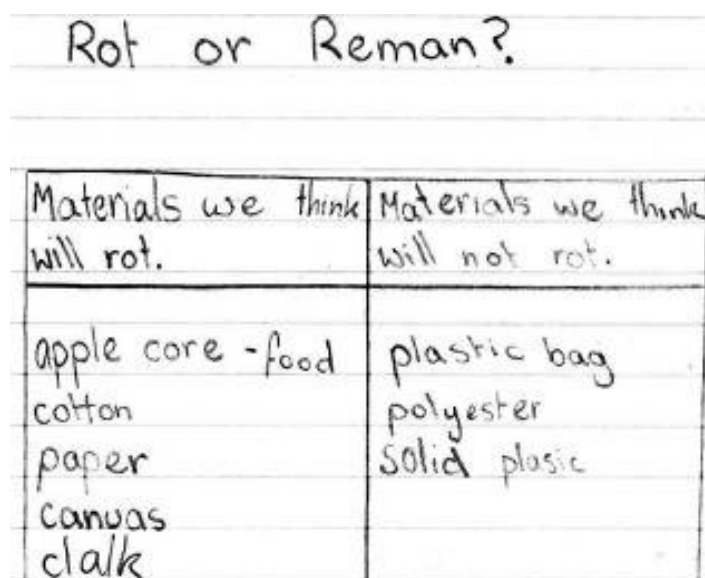
The teachers identified changes in students’ views of the nature of science. In his third interview, Dean reflected on the change and a possible cause:

They had that traditional view of science – I reckon kids do – of someone sitting in a lab in front of a Bunsen burner but now they see that science is just an everyday thing and that anything you do has scientific reason behind it. I think that because of the simplicity of the experiments that we did with the balls and paper clips and that sort of stuff, it allowed them to see that science isn’t just wham bam, space and explosions and that sort of thing. *DI-3*

In referring to the second *Primary Connections* unit, ‘Material world’, which the teachers used in Term 4, a change in students’ understanding of the everyday relevance of science was identified. The students were now looking at phenomena through a “window” of science, as evidenced by the following quote:

Looking at materials – I don’t think the kids realised that was science either. I think they probably thought that was art or sewing before, but now we’ve done that, looked at the different qualities of a whole list of materials, and what makes a material useful for this purpose but not for that purpose, again expands what they think science is about. *DI-3*

In the 'Material world' unit, students developed a fair test of decay in materials. They predicted which materials were more likely to rot, as shown by the science journal excerpt in Figure 4.5.



Rot or Reman?

Materials we think will rot.	Materials we think will not rot.
apple core - food	plastic bag
cotton	polyester
paper	solid plastic
canvas	
chalk	

Figure 4.5. Student book excerpt – “Rot or remain?”

Further evidence of the students' application of fair test concepts is demonstrated in the following extract from another science journal (Figure 4.6). The first section outlines the students' predictions prior to the test, followed by a list of variables that will be controlled in the test.

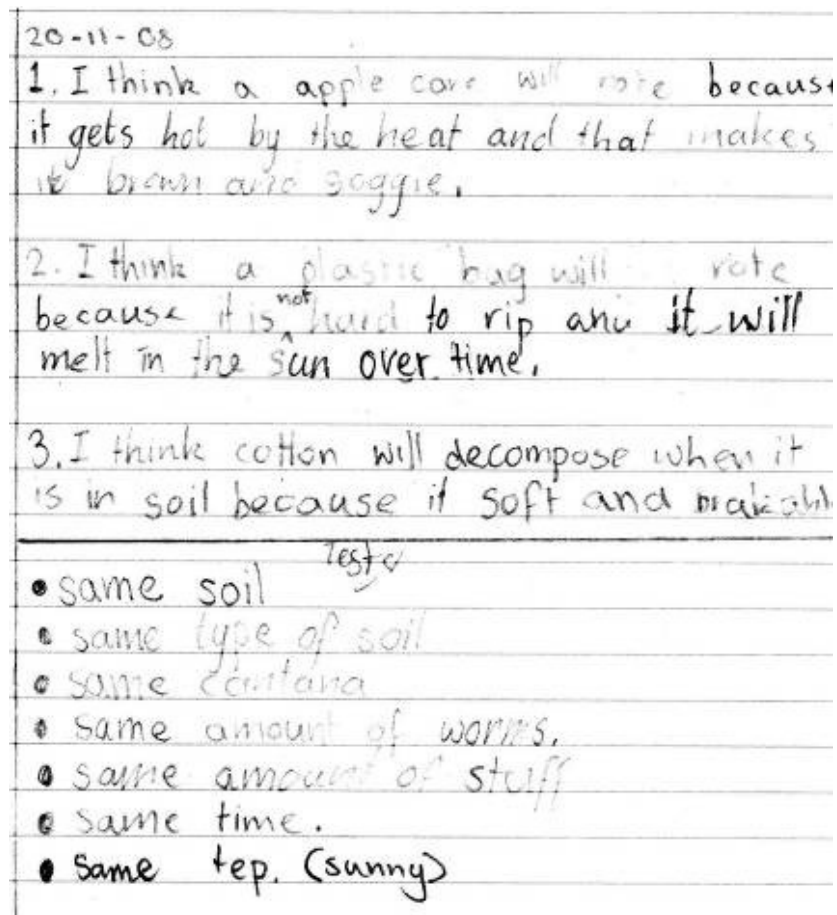


Figure 4.6. Student's investigation planning.

After the eight lessons of the first Primary Connections unit were completed, the teachers asked students to reflect on their learning journey by providing written answers to two questions, (a) “What do you think science is?” and (b) “Has your idea of what science is changed this year? If you said ‘yes’, what changed? What made you change your ideas?” Here is a sample of the responses indicating changed ideas:

What do you think science is?

Science is a fun activity that we do at school. Science is about guessing and observing things. Such as giving a definition like “will a ball float or sink?”

Experiments and trying different stuff.

Science is scientifically finding out questions or experimenting ideas or minerals.

Science is something that teaches you things like “why does it do that? How does it do that?”

What stuff can do with other stuff.

Has your idea of what science is changed this year? If you said “yes”, what changed? What made you change your ideas?

Yes. Now I know that science isn’t just testing. It means hard work.

Yes it has changed because we do experiments.

Yes, my knowledge of science and how to do a test scientifically.

4.7.5 DEVELOPING SCIENTIFIC LANGUAGE

The *Primary Connections* units have a strong literacy component, although this aspect of the program was outside the scope of this research. However, scientific language was specifically addressed in the lessons observed. In the lesson extract, a student was reporting to the class about his group’s experimentation with counters:

Student: When we put a counter on the carpet and pressure it with another one, it goes up high; when we do it on a table it goes forward.

Dean: That’s really important what he just said – he used a “variable” there – he changed things.

Chris: Tell you what I liked in what he said: he used the word “pressure” – that was a really good word. We’ll use it to introduce our Word Wall. *LO-1*

In that exchange, each teacher identified a different piece of relevant vocabulary that had been developed during the lesson, and these were added to the class “Word wall” collection of scientific vocabulary. Over time, this collection grew, as did students’ fluency in describing scientific phenomena. For example, a few weeks later during ‘Push-pull’ Lesson 8, Dean made the following aside comment to me:

We do science experiments in class every week where they have to conduct them and you can see, just the way they talk about what other kids do, so much more improvement... like, a kid did a “come-back tin” where the coil winds up inside the tin, and the words they were using to describe that were really good. “Force was building up inside the tin and the force was released when it got to the other end.” Before they would have said, “The tin wound up until it couldn’t then it just went back.” *LO-3*

In his third interview, Dean reflected on the students’ development of scientific language, in the context of written assessment:

(Testing students’ ideas) is something I’ve done a lot more since this unit’s been and gone, and it’s good to see kids writing their ideas down in a

different way now, using more scientific language. There's a difference in the way they explain the processes. *DI-3*

4.7.6 REFLECTION

Further evidence of enhanced communication by students was reported by Chris in the final interview where he links it to reflection, which is a key assessable element of the syllabus that had been recently introduced:

What changes have you observed in student learning that you can attribute to Primary Connections?

A big improvement in reflections. Students are much more able to reflect on what they've learnt. I noted several examples of students who were much more able to verbalise their thinking. *CI-3*

Students' reflection was a relatively new concept for teachers, at least in terms of assessment, having been recently introduced as a key assessable element of the *Essential Learnings* (Queensland Studies Authority, 2007b) which form the basis of the state curriculum. Consequently, this outcome of the *Primary Connections* unit was valued by the teachers.

This section has presented a variety of evidence showing how the intervention resulted in teacher perceptions of improved student learning outcomes. Guskey's (2002) change model predicts that such evidence will result in change in teachers' beliefs and attitudes. This chapter's discussion of the evidence as it relates to the research questions will conclude with a presentation of findings that indicate such change has occurred.

4.7.7 STUDENT OUTCOMES IMPACTING ON TEACHER BELIEFS AND ATTITUDES

A substantial change in the teachers' thinking about science occurred during, and subsequent to, the first *Primary Connections* lesson. Both teachers independently commented that student learning covered much more breadth and complexity than they expected; as Dean said, "...things that I wouldn't have thought about."

Just to wander around when we had those small-group stations set up over those few weeks was really interesting. Just listening to them talk was really interesting because they thought about things that I wouldn't have thought about. That probably showed me more than anything why it's good to let them experiment for themselves.

What has been the most interesting observation for you in this process?

Listening to the kids talk, yeah, just as they did those little activities,
listening to what they said. *DI-2*

The above comments from Dean are interesting in what they show about his assessment strategy. The informal discussions as students engaged with activities were informing his judgement of learning. This evidence of learning, and the consequent impact of such observations on Dean's beliefs, may not have been apparent if he had relied on more formal modes of assessment such as written tests.

Chris had previously said that he felt quite confident teaching science and thought he did it quite well, but his experience in this lesson radically changed his thinking:

I like that it was open and some of them got so much more out of it than if
I'd just told them to do Step A and then Step B and Step C. *CI-1*

Throughout the series of interviews, both teachers provided descriptions of their practice prior to the intervention. Chris described a teacher-centred didactic approach: "Probably more focused on telling them, 'This is what should happen'." *CI-2*

Dean made similar statements in each of the three interviews. For example, in the first interview, even though he emphasised fun aspects of science, he identified a rigid, content-focussed approach.

In the past I did science as a way of just showing kids that some cool things happen when you make something react with something else, as opposed to telling them why it happens. I never planned science units, I just did science lessons as one-off "things" for an hour in the afternoon or something like that, whether it was making slime, or a cork rocket, but it didn't have an aim... my concern before was that it wasn't something that I felt comfortable planning myself as a whole unit. *DI-1*

In the third interview, he again commented on past practice that was more teacher directed and didactic:

...me standing up there doing things and getting the kids just to watch.
Before I would just do an experiment and the kids would just write down a conclusion based on what we all thought. *DI-3*

When reflecting in the final interview on how his science teaching practice had changed, Dean made this statement:

I wouldn't make it as teacher-directed as I have in the past. I'd make sure that they were much more a part of doing things themselves or in small groups, writing down their own conclusions instead of a "mass" conclusion that is up on the board. *DI-3*

Despite some early reluctance and, at times, contradictory practices, by the time I conducted the second interview, Chris was speaking enthusiastically about a new-found focus on student-led inquiry-based science:

What has changed in your approach to teaching science?

A lot more open-ended questions, open-ended experiments without an expected outcome.

(What has changed) in your view of the way students learn science?

They learn by doing. Before, I had the idea that you had to teach them scientific facts and scientific theory; now I let them learn by doing; give them material and let them set up their own experiments.

That sounds like a big change to me. Would you say that change was influenced by this process (the Primary Connections implementation)?

Yes, absolutely. *CI-2*

The fourth research question sought evidence that the implementation of the PD intervention resulted in changed teacher perceptions of student learning in science which the teachers could attribute to *Primary Connections*. Such evidence was clearly apparent, from the first lesson where student engagement and learning was a key feature of the participants' comments, with further aspects detailed as the unit progressed, including transfer of learning to wider contexts such as a state-wide assessment.

4.8 SUMMARY

In this chapter, the findings of the study were presented and analysed. The introduction consisted of contextual information about the two subjects and their classes, followed by an outline of the sequence of the intervention. In the body of the chapter, an analysis of the data was developed by aligning it to the three research questions. This analysis can be condensed into the following set of assertions drawn from the data: (a) the *Primary Connections* professional learning strategy supported

the development of inquiry-based science in a constructivist learning environment; (b) changing teachers' beliefs and practices requires extended time; (c) promoting student autonomy enhanced science learning; and (d) authentic science investigations promoted enhanced scientific literacy and understanding of the nature of science.

These assertions will be explained in the next chapter, leading to discussion of their implications for the design of teacher development programs and suggested directions for future investigation.

Chapter 5: Conclusions

The purpose of the study was to examine the changes in teacher beliefs and practices during implementation of a constructivist science learning program, based on the *Primary Connections* professional learning model.

The case study findings (detailed in the previous chapter) documented progressive changes in teachers' beliefs and practices relating to teaching science, helping to address an identified need to understand teachers' interaction with the various elements of a multi-mode professional learning program and the way these influence change. In this chapter, the reasons behind those changes will be considered, followed by proposals for further research and implications for practice, especially related to designing PD programs. Finally, there is discussion of the strengths and limitations of the study.

5.1 RESPONSE TO THE RESEARCH QUESTION

The review of the relevant literature (Chapter 2) analysed the theoretical foundations of the PD model and led to the development of a key research question and four related sub-questions. The key question is:

What are the changes in teachers' beliefs and practices associated with implementing a constructivist-inspired learning program?

The data surrounding each of the three supporting questions (Table 5.1) were discussed in detail in the previous chapter (Sections 4.5 – 4.7). This section provides a summary of the findings relating to each question.

Table 5.1

Supporting Research Questions

Topic	Question
1. “Structured constructivism”:	In what ways do the professional learning program and the published <i>Primary Connections</i> curriculum units foster the development of inquiry-based science in a constructivist learning environment?
2. Expressed beliefs vs. enacted beliefs:	To what extent are teachers’ expressed beliefs about constructivist learning aligned with their enacted beliefs?
3. Teachers’ perception of student outcomes:	How does implementation of the PD intervention enhance teachers’ perceptions of student learning in science?

5.1.1 RESEARCH QUESTION 1: STRUCTURED CONSTRUCTIVISM

In what ways do the PD program and the published curriculum units foster the development of inquiry-based science in a constructivist learning environment?

The lessons observed included many elements of open-ended inquiry-based learning, and these closely aligned with a list of constructivist pedagogies identified by Fletcher et al. (2004). The observations were supported by interview data that confirmed the teachers were applying strategies modelled in the PD sessions and were adopting pedagogies more consistent with constructivist models than in their previous practice (see Section 4.5 for more detail).

The *Primary Connections* teaching resources are relatively structured because they aim to support teachers who lack confidence in science; however the teachers implementing the resources in this case readily adopted them as the basis for more open-ended modes of science inquiry. Evidence has been provided to show that the PD program and published curriculum units successfully fostered the teachers’ development of authentic constructivist learning environments, although students’ experiences were not explored in depth.

5.1.2 RESEARCH QUESTION 2: EXPRESSED BELIEFS VS. ENACTED BELIEFS

To what extent are teachers’ expressed beliefs about constructivist learning aligned with their enacted beliefs?

In seeking evidence of alignment between teachers’ expressed and enacted beliefs about constructivist learning, some elements of tension were identified,

particularly with the idea of fun and how it could fit with rigorous learning activities. Structure was another element of concern identified early in the intervention, but, like other teacher concerns, was mitigated as the term progressed. The conflict between expressed and enacted beliefs can be seen in the data (see Section 4.6) as a logical outcome of the change process, as anticipated by Hall and Hord's (1987) Concerns-Based Adoption Model (CBAM). The data indicated that these tensions relaxed as the teachers became more prepared to relinquish control of lesson agendas and allow students greater autonomy.

In response to this second aspect of the research question, the data suggest that there were elements of misalignment between teachers' expressed beliefs and their actual practice regarding constructivist-inspired learning environments. Examples include a perceived tension between the idea of fun and academic rigour, as well as between direct instruction and student autonomy. However, these and other tensions were resolved over time and by the end of the intervention there was evidence of greater alignment of beliefs and practices.

5.1.3 RESEARCH QUESTION 3: TEACHERS' PERCEPTION OF STUDENT OUTCOMES

How does implementation of the PD intervention change teacher perceptions of student learning in science?

This element of the research question sought evidence that the teachers could identify changes in student learning in science and attribute it to the PD intervention and their implementation of *Primary Connections*. Such evidence (Section 4.7) was clearly apparent from the first lesson, where student engagement and learning was a key feature of the teachers' comments. Further aspects were documented as the unit progressed, including transfer of learning to wider contexts such as a state-wide assessment instrument. Guskey's (2002) assertion, that significant change in teachers' beliefs and attitudes only takes place *after* changes in student learning outcomes are evidenced, is clearly supported by the findings.

5.2 ANALYSIS

In addition to the assertions already presented, the findings included evidence of the effectiveness of the PD model in overcoming identified constraints.

The literature analysed in Chapter 2 identified a number of challenges for PD developers, with three issues emerging as key constraints to the effectiveness of

programs in facilitating change. These constraints are (a) *time* limitations resulting in one-off or short-term events; (b) failure to consider the *individual needs* of teachers; and (c) failure to link to *classroom context* (see Section 2.7.1 for details). Managing these constraints was central to the design of the intervention, and the data documented in Chapter 4 provide evidence for the efficacy of the intervention's PD model (described in Section 2.9) in mitigating their impact. Each of the three issues will be discussed in turn.

5.2.1 TIME

Successful PD is “a process, not an event” (Bahr et al., 2007) and one-off PD events seldom have any impact on teachers or their practice (Birman et al., 2000) because of the considerable time required to understand an innovation and to then reflect on and change teaching practice (Akerson & Hanuscin, 2007; Hall & Hord, 1987; Peers et al., 2003). The PD model used in this intervention demonstrates an effective, practical resolution to that issue.

The initial presentations were allocated two ninety-minute sessions for the whole staff. This is less than ideal, but for a relatively low-profile subject like science it was a substantial commitment by the school. It was sufficient for teachers to be immersed in a number of open-ended science investigations, experiencing learning themselves in the same ways that the program was proposing. There was also adequate time for teachers to experience and engage with the 5Es constructivist model, and to make a detailed examination of the curriculum resources.

Regardless of their effectiveness, it is unrealistic to expect that two such sessions could bring about sustained change in practice. However, following the PD sessions the teachers had agreed to use the provided curriculum resources, which provide a model structure and range of pedagogies, for a whole term. Thus, the influence of *Primary Connections* extended beyond the formal presentations to classroom practice, and this sustained engagement was where the data indicate that the real change occurred. The teachers explained how the initial presentations helped them understand the “big picture” of the program and become motivated to use it, but the data show that it was in subsequent weeks that they became convinced of the need to change their practices, and this was largely in response to seeing the success of the new pedagogies with their students. Consequently, a key finding of this study is that the intervention model, which used active, engaging PD sessions followed by

the implementation of educative curriculum materials (Schneider & Krajcik, 2002), provides a practical model for overcoming the constraints of time.

5.2.2 INDIVIDUAL NEEDS OF TEACHERS

Professionals consider that their time is wasted when sheep-dip seminars ignore prior expertise (Bahr et al., 2007), and individual needs are ignored by a production line approach to the mass rollout of an innovation (Guskey, 2002). The *Primary Connections* program provides teaching resources specifically designed to model innovative pedagogies, and thus referred to as educative curriculum materials by Schneider and Krajcik (2002). These provide opportunities for teachers to select a unit relevant to their needs.

The teachers in this study demonstrated that these resources are readily adaptable. While there was initial concern that the integrity of the study may be compromised if teachers substantially changed the unit outline, the durability of the 5Es model and the inquiry-based learning focus of the unit plan were demonstrated. When adapted to suit different-aged students, the selected curriculum unit engaged them in challenging learning experiences and the teachers reported positive outcomes. This supports the finding that professional learning was enhanced because teachers were able to readily adapt the *Primary Connections* units to suit their individual needs without compromising their efficacy. The teachers were able to use quality curriculum resources without losing their own sense of autonomy in planning and teaching.

5.2.3 LINKS TO CLASSROOM CONTEXT

Linking PD to the classroom context is essential because teachers come to PD programs seeking solutions to specific classroom needs, which is why programs undertaken in isolation from their ongoing classroom responsibilities have little impact on teaching practices or student learning (Collopy, 2003; Guskey, 2002; Rogers et al., 2007). This issue was effectively addressed by the PD workshops because they used the same 5Es model that teachers would apply in their classroom. Teachers in the role of learners also engaged with the program's cooperative learning strategies and a range of other pedagogies, so it was immediately obvious how these elements could transfer to their class contexts. This aligns with the call by Loucks-Horsley et al. (2003) for inquiry experiences grounded in the same pedagogical principles they are expected to implement with their own students because many

teachers have not experienced that kind of learning themselves. The teachers in this study referred to this experience, noting that observations of their colleagues' engagement in the PD sessions convinced them that these strategies would be equally engaging with their students (see Section 4.8.1).

The curriculum materials again played a role, as teachers were able to select a unit from a range of topics and adapt it for their current class. The *Primary Connections* model supports innovation by providing a planning template, empowering teachers to develop their own context-specific units once they are familiar with the model.

The evidence supports the proposition that the intervention provides a practical model for addressing the key constraints of time, individual needs of teachers, and links to classroom context in PD program design.

5.3 FURTHER ASSERTIONS

In addition to the three issues outlined in the previous section, further key themes emerged from the data analysis. They are presented here as assertions drawn from the evidence gathered. In summary, they are: (a) the intervention's PD model (based on the *Primary Connections* professional learning program) was effective in changing teachers' practice; (b) modelling proposed classroom strategies within PD presentations enhances teachers' confidence to adopt them; (c) it takes time to change teachers' beliefs and practices; and (d) promoting student autonomy enhances science learning.

The assertions are restated below, each with a set of supporting statements that emerged from the data.

5.3.1 CHANGED PRACTICE

The intervention's PD model (based on the *Primary Connections* professional learning program) was effective in changing teachers' practice. Findings supporting this assertion are that (a) prior science content knowledge and self-efficacy of the teachers did not ensure effective science teaching, (b) the combination of the PD program and published curriculum units fostered the development of student autonomy in constructivist learning environments, and (c) each aspect of the multi-faceted intervention contributed to changing teachers' beliefs and practice but no single element emerged as the dominant driver of change.

5.3.2 “PRACTISE WHAT YOU PREACH”

Modelling proposed classroom strategies within PD presentations enhances teachers’ confidence to adopt them. Supporting findings are that (a) teachers appreciated taking the role of students in developing fair tests, using a cooperative learning model, and experiencing a range of constructivist-inspired learning strategies, and (b) the teachers noted the effectiveness of the *Primary Connections* model of “explore before explain”, that is, allowing students to construct their own learning by engaging with phenomena before being given detailed explanations.

5.3.3 CHANGE TAKES TIME

It takes time to change teachers’ beliefs and practices. This assertion is supported by findings that (a) the initial PD sessions were influential, but changes were not embedded until teachers saw repeated evidence of enhanced student learning, and (b) initial conflicts between expressed and enacted beliefs were resolved over time as the teachers became more prepared to relinquish control of lesson agendas and allow greater student autonomy.

5.3.4 STUDENT AUTONOMY

Student autonomy enhances science learning. Findings supporting this assertion are that (a) teachers found that their students learnt more when they intervened less and that scaffolding open-ended learning opportunities for groups and individuals was a more effective pedagogy than reliance on teacher talk and teacher-led activities, (b) students and teachers identified student-led investigations as a valued practice that fostered positive learning outcomes, and (c) potential threats to teachers stemming from student autonomy (increased noise; reduced classroom control; apparent loss of authority; inadequate content knowledge) were counteracted by perceived enhancement of student engagement and learning.

5.4 DIRECTIONS FOR FUTURE RESEARCH

The findings of this study help to answer the research questions, but also suggest directions for further investigation, three of which are presented in this section.

5.4.1 ASSESSMENT

The evidence indicates that teachers’ observation of enhanced learning outcomes in their students, resulting from their changed pedagogies, was a key factor

in achieving change. The data do not include evidence of structured assessments, however the teachers clearly used effective informal assessment for learning (Curriculum Corporation, 2009) including discussion, observation and monitoring of students' science journals, enabling them to track progress in detail.

The state education authority currently has a major focus on assessment, particularly in science, including the following three elements.

1. Queensland Comparable Assessment Tasks (QCATs) (Queensland Studies Authority, 2009b) in English, Mathematics and Science mandated for students in Years 4, 6 and 9.
2. A Government-commissioned report (Masters, 2009) proposing state-wide testing of science at Years 4, 6, 8 and 10.
3. Development of the Assessment Bank (Queensland Studies Authority, 2009a) – an online teacher resource that models effective assessment strategies for all key learning areas, including science.

The observation of improved learning outcomes was a powerful motivator of change in this study. In line with the need to ensure that teachers receive regular feedback on their students' learning progress (Guskey, 2002), it would be valuable to investigate how the mandated systemic assessment programs can be used to aid professional learning, and to explore synergies between teacher PD and the state-wide assessment programs.

5.4.2 TEACHER REFLECTION

Reflection on practice is a key element of the *Primary Connections* professional learning model, so the initial research design included investigation of its use by teachers as a professional learning strategy. However, time constraints meant that this aspect of data collection did not occur as thoroughly as hoped. Further studies of *Primary Connections* implementations could provide valuable insights into the role of reflection, individually and in collaborative partnerships, in changing teachers' beliefs and practices.

5.4.3 SUSTAINABLE CHANGE

This study focussed on the implementation of a single *Primary Connections* unit in one school term, with follow-up interviews and collection of student work

samples in the following term. The data collection phase spread over about six months. The teachers initially agreed to implement just one unit, but following this they quite independently selected, adapted and implemented two successive *Primary Connections* units and talked of plans to use further units the following year, thus implying long-term adoption of the program. Since the current study has detailed evidence of substantial changes in their beliefs and practices across that six-month period, it would be valuable to obtain evidence over a longer time span to investigate the sustainability of those changes and the consequential impact on teaching practice.

5.5 IMPLICATIONS FOR PROFESSIONAL DEVELOPMENT

Primary teachers have considerable autonomy in the way they operate within their classrooms, and are expected to act professionally in developing their teaching skill or craft knowledge to motivate and manage classes, deal with disruptions and devise interesting, challenging learning environments. While much is expected of teachers, PD facilitators similarly need to respond to research that can inform their practice, and practice what they preach by embedding the strategies they are promoting within their learning design.

This study has demonstrated the effectiveness of a PD model that is efficient in terms of resourcing. There is ample evidence that one-off “talk and PowerPoint” PD presentations are ineffective or even counter-productive (Bahr et al., 2007; Loucks-Horsley & Matsumoto, 1999) but those who persist with this mode argue that time and resource constraints allow no other option. In this study’s intervention model, a suitably trained presenter was required initially to engage the participants and allow them to explore the strategies and resources. After that, the published teaching resources provided the means of long-term engagement (observed over six months, but likely to be much longer), with little or no on-going input from the facilitator.

The strategy aligns well with a constructivist model for professional learning proposed by Loucks-Horsley and Matsumoto (1999). Their three-step classroom-focussed learning model aims to (a) create sufficient cognitive dissonance to disturb the equilibrium between teachers’ existing beliefs and practices and their experience with content, student learning and teaching; (b) provide time, context and support to resolve that dissonance; and (c) ensure that the dissonance-creating and dissonance-resolving activities are connected to teachers’ own students and context.

The model used in the current study provokes cognitive dissonance in the PD sessions when teachers are placed in the role of students, resolving and then designing open-ended investigations. Repeating such activities in follow-up sessions provides opportunities to resolve the dissonance, as does the use of the teaching resources. This study has presented evidence that professional learning is sustainably transferred to changed practice once teachers implement the new strategies in their classrooms and observe enhanced student engagement and learning.

While the sample size of this study does not allow for broad generalisations, the alignment of the findings with major themes emerging from the associated PD literature justifies the presentation of some assertions. The key messages for designers of PD programs are that (a) effective presentations model the pedagogies being promoted; (b) teachers benefit from taking on the role of student and engaging in the proposed learning experiences; (c) related curriculum resources foster extended engagement with new concepts and strategies; (d) sustained change in beliefs and practices occurs after teachers implement the program or strategy and see positive outcomes in their students; and (e) implementing this study's PD model is efficient in terms of resources.

5.6 IMPLICATIONS FOR TEACHING

This study provided evidence confirming the effectiveness of the constructivist-inspired learning model used by *Primary Connections*. In particular, there is clear support for the following propositions about teaching practice:

Promoting student autonomy enhances science learning. Within an open-ended inquiry-based learning model, students learnt more when teachers intervened less. The teachers found that by scaffolding open-ended inquiries they achieved more diverse, complex and thorough learning outcomes than teacher-led discussions or demonstrations.

Student autonomy presents perceived threats to teachers but these are counteracted by enhanced student engagement and learning. Investigations devised by students may lead them to topics their teacher knows nothing about; student autonomy can imply an apparent loss of teacher authority; multiple independent investigation teams in the classroom can result in increased noise and apparently reduced control of behaviour. In practice, these threats were not as great as expected;

issues with classroom behaviour and teacher authority did not arise because students were fully engaged in their investigations; content knowledge issues arose, but resolving them became a stimulating part of the learning process for both students and teachers.

The structured constructivism of Primary Connections resources provides appropriate scaffolding for teachers and students to transition from didactic to inquiry-based learning modes. The practical activities in the *Primary Connections* units are relatively closed because they were written for teachers who lacked confidence in teaching science and would benefit from defined structures (Hackling, 2005). This study has shown that, while teachers appreciate and learn from that structure, they are able to quickly move on to developing more open-ended applications of the constructivist learning model.

Authentic science investigations promote understanding of the nature of science. Both teachers and their students developed an enhanced understanding of the nature of science through jointly constructing investigations and explaining their findings. This new understanding aligns well with the emphasis of contemporary science syllabuses on the processes or Ways of Working (Queensland Studies Authority, 2007b) of science.

5.7 STRENGTHS AND LIMITATIONS OF THE STUDY

This study aligns with Yin's (2006) contention that "the strength of the case study method is its ability to examine, in-depth, a 'case' within its 'real-life' context". The study's validity and reliability were discussed in Chapter 3 (see Section 3.10) but will be revisited briefly in this section.

Construct validity was supported by identifying a range of data collection modes (Table 3.3), and detailing in advance the specific evidence sought for each aspect of the research question (Table 3.1) while leaving open the question of the nature of the changes being observed. In Chapter 4, triangulation of the multiple sources of data (listed in Table 3.3), as well as seeking to identify common themes at different times in the study, were used to support key findings. As a result, "engaging multiple methods such as observations, interviews and recordings (led) to more valid, reliable and diverse construction of realities" (Golafshani, 2003, p. 604).

Internal validity is managed by concentrating on descriptive analysis. The case study design did not allow for prior baseline investigations or any form of pre-test. However the study's focus was on the nature of change and the processes involved rather than any form of quantified measure, so pre-test/post-test structures were not appropriate. The aim was to provide data and explanations consistent with the theoretical perspectives developed in Chapter 2 and detail the chain of evidence to link these together. The inference of causal relationships was generally avoided; on the few occasions that these were made, they were drawn from multiple, explicit elements of data.

External validity is a particular concern for a study such as this one with a small sample size and no explicit strategy for selecting "typical" setting and subjects. Care has been taken to avoid unsupported generalisations; however the detailed observations of change in teachers' beliefs and practices support *analytical* generalisations (Yin, 2003) that provide useful insights for professional learning designers and facilitators. Section 5.7.3 (below) presents further discussion of the suitability of the setting.

Reliability of a case study can be supported by developing a clear protocol prior to data collection (Tellis, 1997). Such a protocol was used in this case, with elements including (a) overview of the study describing objectives, issues and topics being investigated; (b) field procedures, including clearly defined data collection strategies and instruments; and (c) case study questions that were used to inform all elements of the data collection and analysis. See Section 5.7.2 below for further discussion of reliability.

5.7.1 SCOPE

Recent studies of the impact of *Primary Connections* have shown that the program enhances teachers' self-efficacy for teaching science, improves their pedagogy, and results in them teaching more science. Their students enjoy science learning and develop greater scientific conceptual understanding (Hackling et al., 2007; Hackling & Prain, 2005, 2008).

Those much larger studies provide general data from a large number of teachers about the impact of *Primary Connections*, but lack fine-grained detail of the stages of the change processes occurring inside individual classrooms as the program

is implemented. The sample size for the study was necessarily small, limited to two teachers; however the extended engagement with them (over six months) and the ability to observe their practice and interview them throughout that period has provided a window on the change process not previously available.

5.7.2 DATA QUALITY

The focus of a case study is on the quality and detail, rather than quantity, of the data. Because the study involved a single case of two teachers working together, it was possible to closely monitor their progress throughout the intervention. In the first unit they taught, it was possible to observe and document a majority of the lessons, interview the teachers at several junctures, and collect samples of student work.

The researcher's prior advocacy for the *Primary Connections* program, including facilitating the PD component of the current intervention, was recognised as a potential source of bias. That issue was intentionally addressed by a range of strategies, as described in detail in Section 3.10.

Data relating to the subsequent use of *Primary Connections* units in Term 4 were an unexpected addition as the subjects were at this stage working with the understanding that their voluntary participation had concluded in Term 3. Consequently these later data were less likely to be influenced by the presence of a researcher. Data relating to these subsequent activities were discussed in interviews and documented in students' science journals.

Both teachers were generous with their time and access to their classrooms, and provided frank and insightful reflections on their learning journey when interviewed. Many of their reflections were made as side comments to me while I was acting as a non-participating observer of their lessons; the immediacy of this data provided valuable insights into the teachers' thinking while they were actively engaged in implementing new pedagogies.

There was a high level of consistency between different data sources (interviews, lesson observations, student samples) and across subsequent interviews or observations. Extended engagement with the subjects over six months enabled opportunities to follow up issues and track changing ideas and practices over time. Key themes identified in the study relate to topics and ideas that could be

triangulated from multiple pieces of data gathered at different times, ensuring reliability in the findings.

5.7.3 SUITABILITY OF SETTING

In a state-wide education jurisdiction it is not realistic to find, or even define, a typical classroom setting for a study such as this so the school context is necessarily unique, and was described in detail in Chapter 3 (Section 3.4). The significant points for the current discussion are that the selected school was relatively typical of Queensland primary schools, or at least has no apparent features that would make it a deviant case. There had not been a whole-school focus on the *Primary Connections* program and the subjects were selected from those teachers with little or no previous exposure to it.

The school is located in a suburb with a relatively high socio-economic profile, and both teachers noted that their classes had a wide range of abilities, but few significant problems. The implication of this for the study is that the implementation was able to proceed with very little impact from behaviour or learning difficulties.

While it is not possible to assert that the findings would transfer to other contexts, there were no apparent factors in the setting that could be seen to compromise the validity of the study.

5.7.4 REPLICATING THE PD MODEL

A key aim of the study has been to examine the efficacy of a particular model of PD, as well as the underlying theoretical assumptions about facilitating change in teacher practice, so care has been taken to ensure that the model is practical in a wide range of contexts, particularly in terms of time and resources.

As implemented, the model is dependent on the availability of a trained *Primary Connections* professional learning facilitator to present one or more initial workshops. This is a reasonable expectation for most schools because many hundreds of such facilitators have been trained. Within the state of Queensland, a network of *Primary Connections* district coordinators is able to link schools with suitable facilitators.

In the model implemented for this study, I acted as the facilitator of the initial two workshops. Following the workshops, my role changed to that of non-participant observer. While I was present for some planning meetings and had informal

discussions with the subjects throughout the process, the level of support provided in these later stages was not greater than could be reasonably expected from a local facilitator supporting a school's implementation of *Primary Connections*.

The unit implementation requires the availability of the published curriculum resources. These are readily available for purchase from the *Primary Connections* program's website and are inexpensive. Specific lessons also require some apparatus for investigations, but this involves simple, readily available materials that have minimal cost.

In summary, the minimum resources required to replicate this PD model in a school include (a) a trained facilitator for one or more PD sessions; (b) time for teachers to attend sessions; (c) copies of published *Primary Connections* teaching resources; and (d) simple materials for investigations. This set of requirements is achievable for typical primary schools, and suggests that wider implementation of the proposed model is feasible.

5.8 CONCLUSION

Traditional facilitator-led presentation modes of PD have been shown to have little relevance or effectiveness, yet they still appear to be a predominant approach used by schools and education authorities. However, they are constrained by the availability of skilled presenters, of time for staff gatherings, and the presenter's limited understanding of the teachers' prior knowledge and the specific contexts in which they work. Given the ongoing decline in student enrolments in the sciences, and the limited impact to date of PD programs in addressing that trend, it is timely to explore alternate strategies. The literature provides clear guidance for a way forward, and programs such as *Primary Connections* offer practical support for teachers to apply contemporary theory in their classrooms.

The constructivist model implemented in this study brought together multiple modes of professional learning to address the major issues, including time, individual needs and classroom context, while focussing on strategies identified as most effective in facilitating change in teachers' practice. The findings of this case study provide descriptive detail of changes in the subjects' beliefs and practices which they attribute to the intervention.

Hackling and Prain (2008) found that “students from *Primary Connections* classes are more frequently curious in science and more frequently learn interesting things in science” (p. 40). This study builds on that finding with evidence of teachers who observed such changes in their students and consequently changed their beliefs and practices about teaching science. They enhanced science learning by promoting student autonomy through open-ended inquiries, and they and their students enhanced their scientific literacy by jointly constructing investigations and explaining their findings.

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Appendices

APPENDIX A: OUTLINE OF PD SESSION 1

- **Activity 1:** Stretchy snakes
 - Materials: Lolly snakes, measuring equipment
 - Part 1: Measure and record the “stretchability” of a snake.
 - Part 2: Record a glossary of any scientific terminology you used while carrying out this task.
 - What decisions did you have to make about how to do this task?
- **“Consensogram” activity:** Write a number from 1 to 10 on a sticky note in response to each of these questions:
 - How important is science in primary school?
 - How would you rate the teaching and learning of science in this school?
 - Compile the sticky notes into two “consensogram” graphs.
- **Group discussion:**
 - What are the main constraints and issues that influence the science curriculum in this school?
- **Program overview** - what is *Primary Connections*? What is scientific literacy?
- **Principles of *Primary Connections*:**
 - Principle 1 - Linking science with literacy
 - Principle 2 - the 5Es teaching/learning model
 - Principle 3 - Teaching and learning about science with an inquiry/investigative approach
- **Activity 2:** Rolling cars
 - Materials: Toy car, ramp, measuring equipment
 - Task: Roll a toy car down a ramp and record how far it goes.
 - Principle 4 - Co-operative learning strategies
 - Principle 5 - Linking assessment with teaching and learning
- ***Primary Connections* organisation:** Stages, years and outcome levels
- **Curriculum resource organisation** – units available for each strand of science

APPENDIX B: OUTLINE OF PD SESSION 2

- **Establish “Cooperative Learning Groups”** (Manager, Speaker, Director) before starting activity
- **Activity 1:**
 - Part 1:
 - How many drops of water can you fit on a 5c coin?
 - Do multiple tests and record your results.
 - Equipment: dropper, coin, cup of water, plate, paper towel
 - Part 2:
 - Record a glossary of any scientific terminology you used while carrying out the above task.
- **Workshop aims:**
 - What is the 5Es teaching and learning model?
 - How do I to apply the model in Primary Connections units?
 - How do I use this model in other units of work I develop?
 - The 5Es....what is it?
- **Working Scientifically** – discuss definitions
- **Inquiry-based instruction** – compare structured/guided/open modes of inquiry
- **Planning an investigation:**
 - In Activity 1 with water drops, what variables influenced the number of drops? Make a list...
- **What is a researchable question?**
- **Designing a “fair test”:** Cows Moo Softly
- **What is a hypothesis?**
- **Activity 2:**
 - Select ONE variable from the dropper activity
 - Design an experiment to test the effect of changing that variable
 - Use an investigation template to document your experiment before you start
- **Activity 3:**
 - Take one of the provided activities (nine different simple investigations, for example, “How does the surface effect the height a ball bounces?”; “Which material makes the slipperiest slope?”). Use a planning template to design your experiment before carrying it out.
 - Using the students you teach as a guide, prepare an age-appropriate visual representation of your findings to present to the group.
- Review the Primary Connections **5Es teaching and learning model**.

APPENDIX C: INSIDE THE CLASSROOM – TEACHER INTERVIEW PROTOCOL

I appreciate your letting me observe your class. I have some questions I'd like to ask you related to this lesson. Would you mind if I taped the interview? It will help me stay focused on our conversation and it will ensure I have an accurate record of what we discussed.

Preliminary

If applicable, ask:

What is the name/title of this course?

What class period was this?

If applicable, ask:

Can I have a copy of the instructional materials you used for this lesson?

[Specify what you would like to have copies of, if necessary.]

A. Learning Goals

1. I'd like to know a bit more about the students in this class.

Tell me about the ability levels of students in this class.

How do they compare to students in the school as a whole?

Are there any students with special needs in this class?

Are there any students for whom English is not their first language?

Are there any students with learning disabilities?

2. Is student absenteeism or mobility a problem for you in this class?

3. Please help me understand where this lesson fits in the sequence of the unit you are working on. What have the students experienced prior to today's lesson?

4. What was the specific purpose of today's lesson?

5. How do you feel about how the lesson played out?

What do you think the students gained from today's lesson?

6. What is the next step for this class in this unit?

B. Content/Topic

7. What led you to teach the mathematics/science topics/concepts/skills in this lesson?

(Use the following probes, as needed, so you can assess the extent of importance of each of these influences:)

Is it included in the state/district curriculum/course of study?

If yes, or previously implied: How important was that in your decision to teach this topic?

Is it included in a state/district mathematics/science assessment? What are the consequences if students don't do well on the test?

If yes, or previously implied: How important were these tests in your decision to teach this topic?

Is it included in an assigned textbook or program designated for this class?

If yes, or previously implied: How important was that in your decision to teach this topic?

C. Resources Used to Design the Lesson

8. What resources did you use to plan this lesson?

(Be sure to get details on sources of materials and activities.)

(If teacher developed materials, SKIP to part D.)

9. Were these resources/materials/activities designated for this class/course or did you choose to use them yourself?

10. What do you like about these resources/materials/activities?

(Compared to what the district designated for the class/course, if applicable.)

What do you not like?

11. a. *If the lesson was based on one resource/material:*

Did you plan this lesson essentially as it was organized in [name of resource/material] or did you modify it in important ways?

11. b. *If the lesson was based on more than one resource/material:*

Did you plan this lesson essentially as it was organized in any one of these resources/materials?

If yes:

Did you modify it in important ways?

12. *If modified:*

Can you describe the modifications you made and your reasons for making them?

D. The Teacher

13. How do you feel about teaching this topic?

Do you enjoy it?

How well prepared to you feel to guide student learning of this content?

What opportunities have you had to learn about this particular content area?

(Probe for professional development opportunities.)

How did you become involved in these professional development opportunities?

Were they required or encouraged by the district?

How helpful were they?

14. How do you feel about teaching with this pedagogy?

How comfortable do you feel using the instructional strategies involved in teaching this lesson?

What opportunities have you had to learn about using these strategies?

(Probe for professional development opportunities.)

How did you become involved in these professional development opportunities?

Were they required or encouraged by the district?

How helpful were they?

15. How many years have you been teaching prior to this year?

Have you taught this lesson before?

If yes: How different was today from how you have taught it previously?

Is there anything about this particular group of students that led you to plan this lesson this way?

16. *If applicable ask:*

I noticed there was another adult in the classroom. Who was that and what was his/her role?

E. Context

17. Sometimes schools and districts make it easier for teachers to teach science/mathematics well, and sometimes they get in the way.

What about your teaching situation influenced your planning of this lesson?

PROBES:

Did the facilities and available equipment and supplies have any influence on your choice of this lesson or how you taught it?

Were there any problems in getting the materials you needed for this lesson?

18. Sometimes other people in the school and district can influence your planning of a lesson. Did your principal have any influence on your choice of this lesson or how you taught it?

Other teachers in the school?

Parents/community?

School board?

District administration?

Anyone else?

Thank you for your time. If I have any additional questions or need clarification, how and when is it best to contact you?