Subject cultures and pedagogy: Comparing mathematics and science

By

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I certify that the thesis entitled

Subject cultures and pedagogy: Comparing mathematics and science

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is the result of my own work and that where reference is made to the work of others, due acknowledgment is given.

I also certify that any material in the thesis which has been accepted for a degree or diploma by any university or institution is identified in the text.

Full Name..................................................………………………………….

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Date......................................................................................……………….
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## Contents

ACKNOWLEDGEMENTS ............................................................................................................................. I

SUMMARY .................................................................................................................................................. IX

PROLOGUE ................................................................................................................................................. X1

CHAPTER 1. INTRODUCTION ................................................................................................................... 1

1.1. “IF YOU CAN TEACH SCIENCE, YOU CAN TEACH MATHEMATICS” ......................................................... 1

1.2. BACKGROUND TO THE RESEARCH ........................................................................................................ 3

1.2.1. The IMYMS project .................................................................................................................. 5

1.3. FOCUS OF MY RESEARCH .................................................................................................................... 6

1.4. STRUCTURE OF THE THESIS ............................................................................................................. 7

CHAPTER 2. REVIEWING THE LITERATURE ....................................................................................... 10

2.1. SITUATING THE “SUBJECT”: MATHEMATICS AND SCIENCE AS SUBJECT CULTURES ......................... 10

2.1.1. Exploring the notion of subject cultures .................................................................................. 10

2.1.2. The nature of subjects ............................................................................................................. 12

2.1.3. Comparing mathematics and science as forms of education .................................................. 14

2.1.4. Challenging the role of subjects and subject cultures in determining pedagogy ................. 22

2.2. SITUATING PEDAGOGY: DEVELOPING A FRAMEWORK FOR INVESTIGATING PEDAGOGY ................ 24

2.2.1. Describing pedagogy ............................................................................................................... 24

2.2.2. Researching pedagogy ............................................................................................................. 26

2.3. EXAMINING THE RELATIONSHIP BETWEEN SUBJECT CULTURE AND PEDAGOGY: CONSOLIDATING

THE RESEARCH QUESTIONS .......................................................................................................................... 35

2.4. SUMMARY ............................................................................................................................................. 38

CHAPTER 3. METHODOLOGY ................................................................................................................ 39

3.1. QUALITATIVE RESEARCH ...................................................................................................................... 39

3.2. CONSTRUCTIVISM AS A METHODOLOGICAL FRAMEWORK .......................................................... 40

3.2.1. A constructivist paradigm ....................................................................................................... 41

3.2.2. Metaphysical beliefs of a constructivist paradigm ................................................................. 42

3.2.3. Role of the researcher and participants .................................................................................. 44

3.3. SUMMARY ............................................................................................................................................. 44

CHAPTER 4. RESEARCH PROCESSES ................................................................................................... 45

4.1. FOCUS OF DATA GENERATION .......................................................................................................... 45

4.2. THE SELECTION OF PARTICIPANTS .................................................................................................... 46
6.2. LEARNING EXPERIENTIALLY THROUGH HANDS-ON ACTIVITY ........................................................... 104
6.2.1. Teachers’ experiences of using activity-based teaching approaches ......................... 105
6.2.2. Phenomena as the focus of instruction in science................................................................. 106
6.2.3. Making the abstract concrete in mathematics ................................................................. 117
6.3. TEACHERS’ BASIC ASSUMPTIONS ................................................................................................. 124
6.3.1. Teachers’ basic assumptions relating to curriculum content organisation.................. 125
6.3.2. Teachers’ basic assumptions relating to hands-on activities .............................................. 126
6.4. SUBJECT PEDAGOGIES ARISING OUT OF WHAT IS CENTRAL ............................................................... 128
6.4.1. “Pedagogy of Support” in mathematics ........................................................................... 128
6.4.2. “Pedagogy of Engagement” in science .............................................................................. 133
6.5. GENERAL AGREEMENT LEADING TO A PICTURE OF VARIATION IN THE SUBJECT CULTURES ............ 137

CHAPTER 7. TRANSLATING RELEVANCE INTO MATHEMATICS AND SCIENCE ..................................139
7.1. A RHETORIC OF RELEVANCE IN SCHOOL .................................................................................... 139
7.2. FINDING LINKS TO STUDENTS’ LIVES IN THE CLASSROOM ............................................................ 141
7.3. SNAPSHOTs OF THREE TEACHERS’ APPROACHES TO MAKING THE SUBJECT RELEVANT ................. 143
7.3.1. Pauline ................................................................................................................................... 143
7.3.2. Donna..................................................................................................................................... 145
7.3.3. Rose ....................................................................................................................................... 145
7.4. PEDAGOGICAL APPROACHES AS CATEGORIES OF MEANING MAKING .............................................. 146
7.4.1. Illustrations of relevance ....................................................................................................... 147
7.4.2. Explorations of familiar contexts ........................................................................................ 150
7.4.3. Humanising stories of historical and contemporary “heroes” ............................................. 153
7.4.4. Representations of the human response ............................................................................. 155
7.4.5. Summarising categories of meaning-making ....................................................................... 158
7.5. THE NATURE OF RELEVANCE IN MATHEMATICS AND SCIENCE .................................................. 161
7.6. KNOWING THE NARRATIVES OF MATHEMATICS AND SCIENCE .......................................................... 169
7.6.1. Negotiating subject boundaries ......................................................................................... 172
7.7. CONCLUSION....................................................................................................................................... 173

CHAPTER 8. THE ROLE OF AESTHETIC UNDERSTANDING IN THE RELATIONSHIP BETWEEN SUBJECT CULTURE AND PEDAGOGY ........................................................................174
8.1. AESTHETICS IN EDUCATION ................................................................................................................. 174
8.2. COMPELLING AND DRAMATIC NATURE OF UNDERSTANDING ................................................................. 179
8.2.1. Aesthetic, passion, and the subject ................................................................................... 180
8.3. LEARNING THAT BRINGS UNIFICATION OR COHERENCE TO ASPECTS OF THE WORLD OR THE SUBJECT ......................................................................................................................... 182
8.3.1. Aesthetic, coherence, and the subject ............................................................................... 183
8.4. PERCEIVED TRANSFORMATION OF THE PERSON AND THE WORLD ...................................................... 184
8.4.1. Aesthetic, identity, and the subject ....................................................................................... 186
8.5. VALUING THE AESTHETIC IN DISCUSSIONS ABOUT SUBJECT CULTURE .............................................. 188
  8.5.1. Appreciation for the aesthetic dimensions of teaching ........................................................ 188
  8.5.2. The aesthetic in the negotiation of subject boundaries ........................................................ 189
8.6. CONCLUSION ....................................................................................................................................... 190

CHAPTER 9. A MODEL FOR UNDERSTANDING THE RELATIONSHIP BETWEEN SUBJECT CULTURE AND PEDAGOGY ................................................................................................................. 192

  9.1. RELATIONSHIPS BETWEEN DIFFERENT TRADITIONS OF SUBJECT CULTURE .............................................. 192
  9.2. DEPICTING THE RELATIONSHIP BETWEEN THE INDIVIDUAL AND SUBJECT CULTURE .............................................. 196
    9.2.1. The mediating personal lens and the culture member ........................................................ 197
    9.2.2. The mediating personal lens and the individual teacher ...................................................... 199
  9.3. SUBJECT CULTURE FRAMING POSSIBILITIES FOR ACTION .......................................................... 200
    9.3.1. The role of subject cultures in teacher and school change ................................................. 200
    9.3.2. Subject culture, school culture imperatives, and the individual teacher ............................ 202
  9.4. THE SUBJECT-SPECIFICITY OF SUBJECT TEACHING ............................................................................ 204
  9.5. THE ROLE OF THE AESTHETIC IN SUBJECT TEACHING ........................................................................... 206
  9.6. CONCLUSION ....................................................................................................................................... 209

CHAPTER 10. CULTURAL AND INDIVIDUAL DIFFERENCES: CONCLUSIONS AND IMPLICATIONS .......................................................... 211

  10.1. RESPONDING TO THE RESEARCH QUESTIONS ................................................................................... 212
  10.2. IMPLICATIONS AND FUTURE RESEARCH ........................................................................................... 221
    10.2.1. Issues faced by teachers teaching out-of-field ................................................................... 221
    10.2.2. Contributing to the debate about generic and subject-specific pedagogical description .. 223
    10.2.3. Cultural and individual differences informing the change process................................... 223
  10.3. METHODOLOGICAL REFLECTIONS .................................................................................................... 224

FINAL MESSAGES ........................................................................................................................................ 225
REFERENCES ............................................................................................................................................227
APPENDICES .............................................................................................................................................242
FIGURES

*Figure 4.1* Research methods contributing to the co-construction process .......... 48
*Figure 4.2* Relationships between the categories of the analytical framework ....... 64
*Figure 4.3* Development of lines of inquiry and themes ........................................ 65
*Figure 6.1* Science teaching practices benefiting the teaching of mathematics .... 106
*Figure 9.1* The Subject Culture Triangle ............................................................. 196
*Figure 9.2* Culture, the individual, and classroom practice .................................... 197
TABLES
Table 4.1 *Teachers and Their Classes Represented in the Research* ........................................... 47
Table 4.2 *Data Events in Each Data Sequence* ........................................................................ 55
Table 4.3 *Class Groups, Topics, and Lesson Codes for Each Teacher* ................................. 57
Table 4.4 *Analytical Framework for Gross Analysis of Sequence 2 Interviews* .................. 62
Table 6.1 *Basic Assumptions Relating to Curriculum Content Organisation* ....................... 125
Table 6.2 *Basic Assumptions Relating to Hands-on Activities* ............................................. 127
Table 7.1 *Characteristics of the Categories of Meaning Making* ............................................. 159
Table 7.2 *Alignment of Categories of Meaning Making with Science and Mathematics Goals* .............................................................................................................. 162
APPENDICES

APPENDIX 1. OBSERVATION PROTOCOL ................................................................. 243
APPENDIX 2. OBSERVATION TEMPLATE ............................................................... 244
APPENDIX 3. INTERVIEW PROTOCOL VSR TRIAL .............................................. 245
APPENDIX 4. SAMPLE OBSERVATION ................................................................. 246
APPENDIX 5. INTERVIEW PROTOCOL S2 VSR AND REFLECTIVE INTERVIEW ...... 249
APPENDIX 6. FOCUS GROUP DISCUSSION STATEMENTS .................................... 252
APPENDIX 7. FOCUS GROUP DISCUSSION EXAMPLE OF FEEDBACK FOR SIMON ... 253
APPENDIX 8. ANNOTATED LESSON FOR LESSON P8 “LANGUAGE OF ALGEBRA” .... 256
APPENDIX 9. INITIAL CODING FRAMEWORK ..................................................... 258
APPENDIX 10. SEQUENCE 2 THEMES, ASSERTIONS AND ELEMENTS ............... 259
APPENDIX 11. FINAL CODING FRAMEWORK .................................................... 260
APPENDIX 12. MATRIX OF THEME CODES AGAINST ALL CODES ....................... 262
APPENDIX 13. ROSE’S LESSON SUMMARIES ................................................... 264
APPENDIX 14. DONNA’S LESSON SUMMARIES ............................................... 266
APPENDIX 15. PAULINE’S LESSON SUMMARIES .............................................. 267
APPENDIX 16. SIMON’S LESSON SUMMARIES ............................................... 270
APPENDIX 17. JAMES’ LESSON SUMMARIES .................................................... 273
APPENDIX 18. IAN’S LESSON SUMMARIES ...................................................... 274
APPENDIX 19. MARG’S LESSON SUMMARIES .................................................. 276
Summary

Teaching a subject requires a teacher to understand its language, epistemology and traditions, and how these characteristics govern what is appropriate for teaching and learning. This research examines how teachers’ experiences of mathematics and science subject cultures, including traditions of practice, beliefs, and basic assumptions, influence their secondary school mathematics and science teaching.

Six teachers from two secondary schools were interviewed and their classroom practice observed over a period of eighteen months. The research involved observing and video recording teachers’ mathematics and science lessons, then interviewing them about their practice, their views of school mathematics and science, and how they see themselves in relation to these subjects.

Four themes emerged which highlight similarities and differences between the subject cultures of mathematics and science: the nature of curriculum organisation across the two subjects; the role of learning experientially through hands-on experiences; the translation of “relevance” as a school culture imperative into teachers’ conceptions of, and practices in, the subject; and the role of aesthetic understanding in how teachers experience, situate themselves within, and negotiate boundaries between the two subject cultures.

Significant cultural and individual differences were found in what teachers considered to be at the core of their subject teaching. Cultural differences make the subject identifiably mathematics or science. In mathematics, supporting students to move through sequentially organised curriculum content, and the importance placed on mathematics in the school curriculum, led to a Pedagogy of Support. In science, the more topic-based curriculum, and an imperative to foster student interest in science, led to a Pedagogy of Engagement. A school culture imperative to link the subject matter to students’ lives was translated differently in mathematics and science.

Individual differences between teachers resulted in a diversity of practices across and within the two schools, particularly with respect to how teachers related practical work to theory. The two schools’ different approaches to open-ended problem solving resulted in varying degrees of latitude for teachers to move away from traditional teaching modes. In addition, whether or not teachers had stories to tell that related the subject matter to students’ lives influenced their approach to making the subject relevant. Teachers’ passions, coherence in their understanding of content and pedagogy, and their identity, were shown to be integral to the way they
positioned themselves in relation to the subject, and in shaping their confidence and competence.

Teachers experienced different traditions within the subject cultures. Some traditions perpetuated practices that might be considered “outdated”. Emerging traditions challenged current practices through innovation and new ways of thinking about teaching and learning. Local traditions developed within the school as expectations for practice. Teachers experienced these different traditions in the process of moving forward from basic assumptions that they saw as characterising the subject, while translating school culture imperatives, and as they developed a sense of self in relation to the subject.

The significance of this research lies in its contribution to improved understanding of the demands associated with subject teaching. Findings relating to the demands associated with negotiating subject boundaries have implications for the support of teachers who are teaching “out-of-field”. In addition, teachers’ experiences of the demands associated with translating school culture imperatives into their subject teaching raise questions about the usefulness of generic descriptions of pedagogy. These findings indicate that teacher and school change processes can be informed by describing subject and individual pedagogies.
Prologue

“The journey of becoming through post-graduate research”

I began my PhD at the end of 2003 on a full-time basis, aware of the perils and seclusion that accompanies full-time postgraduate research… Being full-time meant that I could progress relatively quickly. At least at first. Then my fourth child arrived. Then progress slowed somewhat. Full-time study for me involves lecturing at two universities, family responsibilities and more working at the kitchen table than in my university office. Speaking with other PhD candidates who understand what it means to juggle, my story is not unusual. For me, the luxury of studying full-time, and with a scholarship, is that I have not had to sustain potentially distracting heavy work loads. I ensured that my teaching has complemented my study, such that in my preparation of science teachers I am constantly drawing on stories from my research. As my study and life intersect, I have come to realise that the experience of research involves both emotional and cognitive engagement. It is an aesthetic experience in that I am compelled and passionate about the research. I treasure those moments of epiphany where it all comes together as a unified assemblage of parts. And as I look back I can see that I have been transformed while coming to know what it means to do and be part of research.

(By Linda Darby, extract from Deakin University higher degree student research magazine, Showcase, 2007, p. 30)
Chapter 1. Introduction

The orientation of my research emerges out of the observation that there are apparent differences in the ways school mathematics and science are taught, including differences in what teachers see as important for achieving appropriate educational outcomes. In this chapter I situate my research within current education reforms around Australia and current debates relating to the role of school subjects that are re-negotiating the role that the traditional subjects of mathematics and science play in contemporary education. I explain how my research sits within the context of a larger research project undertaken by Deakin University. I then provide an overview of my research that introduces the research focus, and the participants and their roles. I then outline the structure of the thesis.

1.1. “If you can teach science, you can teach mathematics”

A tradition of subject specialisation at the secondary level in Australia has contributed to the promotion of pedagogies appropriate for specific areas of content. Despite this, teachers, educators and researchers often closely align science and mathematics because they apparently share “linear ways of approaching things, step-by-step procedures, quantitative methods, and a mature paradigm” (Siskin, 1994, p. 174). While mathematics and science have been compared in terms of structural organisation and teachers’ conceptualisation of their work (see Hargreaves, 1994; Siskin, 1994), little research exists that investigates how teachers internalise and deal with these assumptions in their daily teaching. In fact, in 1996, Goodson and Marsh (1996) claimed that the school subject is a seriously under-investigated form.

Such research is particularly important in a climate where, in many Australian and US schools, there is an expectation that teachers trained in either mathematics or science will teach in both areas (Department of Education Science & Training, 2003a; Education & Training Committee, 2006; Harris, Jensz, & Baldwin, 2005; Ingersoll, 1998). In some schools, timetabling and teacher allotments are organised so that one teacher assumes responsibility for mathematics and science for one group of students, sometimes with the intent of encouraging an integrated approach to mathematics and science (see, for example, Schmitt & Horton, 2003). This suggests an assumption that mathematics and science have elements in common, such as common ways of thinking that may imply a similar pedagogy in both subjects. For example, Berlin and White (1995) claim that mathematics and science share attitudes, habits of mind and dispositions, and teaching methods and strategies that overlap. Integration tends to emphasise these supposed commonalities.
In Australia, teaching out-of-field is a significant issue facing many schools. In recent years there has been a focus on the problems associated with the unmet demand of qualified science and mathematics teachers, and the increasing incidence of teaching out-of-field (Department of Education Science & Training, 2003a; Education & Training Committee, 2006). While it is acknowledged that tertiary training will not automatically result in effective teaching, the major concern both nationally and internationally is that without solid tertiary experience in the discipline, teachers lack content knowledge, and without studies in the teaching of a subject, teachers are not equipped with the variety of methods and teaching skills required to teach the subject effectively (Darling-Hammond, 2000; Education & Training Committee, 2006; Ingersoll, 1998; Thomas, 2000).

The expectation that teachers teach both areas is being supported by generic principles of instruction that are considered to transcend disciplinary boundaries (Grossman, Stodolsky, & Knapp, 2004; Shulman & Sherin, 2004). The subject matter disciplines have received varied attention in educational research over the past century, with periods where investigation and implementation were framed around disciplines, and other times when they nearly disappeared in favour of generic principles (Shulman & Quinlan, 1996; Shulman & Sherin, 2004). The current reform in the middle years of schooling in many states of Australia reflects a modified role for disciplinary subjects, where the purpose of the subject matter provides the context for delivering an alternative curriculum concerned with developing the whole student (Arnold, 2000). For example, in Victoria, the curriculum is organised around essential strands of learning, including, personal, social and physical learning; interdisciplinary capacities, such as technology, communication and thinking; and traditional disciplinary subjects, including mathematics and science. The first two sit alongside and are embedded into the third (Victorian Curriculum & Assessment Authority, 2007). Underpinning the interweaving of these three strands of the curriculum are generic descriptions of pedagogy, called Principles of Teaching and Learning (PoLT), developed by the Department of Education and Training (2002b) to embody effective teaching from Prep (first year of schooling) to Year 12. These are used to guide teaching practice and school renewal. In the face of attempts to move towards generic descriptions of pedagogy, it is important to understand how the subjects play a role in determining pedagogy. Is it possible to describe mathematics and science teaching without recognising their epistemological and methodological differences? In order to understand the benefits and limitations of defining pedagogy in generic terms there is a need to first recognise and ascertain how and why teachers’ pedagogy may be different across subject areas.

As with all disciplines, mathematics and science are distinctive in terms of moves, genres, syntax and content, the mastery of which takes time (Gardner, 2004). They are distinguishable epistemologically and methodologically, and these differences are represented in the subject matter, pedagogies and purposes associated
with their respective school versions. Siskin’s (1994) research and research by others (Grossman & Stodolsky, 1995; Grossman et al., 2004; Stodolsky, 1988; Stodolsky & Grossman, 1995), consistently reveal differences in discursive patterns and dominant themes in subjects as teachers talk about their work. Siskin states that these dominant themes are worth exploring because they “translate into systematically different conceptions of the tasks of teaching and learning” (p. 162).

These and other differences place demands on teachers as they make decisions about what needs to be taught, the methods used, and the value that the subjects might have for students. Research is needed to understand how teachers experience the different demands that school mathematics and science place on teaching and learning. Of particular interest is how teachers construct these two subjects for themselves, and factors that influence the way teachers negotiate the boundaries that exist within the secondary school context. Negotiating subject boundaries requires a teacher to understand the language, epistemology and traditions of the subject, and how these things govern what is appropriate for teaching and learning. Teachers are, in a sense, inducted into the culture of the subjects by way of their own experiences of doing, using, learning and teaching mathematics and science. But what attitudes, knowledge, and perspectives are needed for a teacher to teach a subject? And what role does the subject culture play in shaping the pedagogies that emerge?

1.2. Background to the research

There have been two national agenda that have given rise to this project.

The first relates to the positioning of mathematics and science nationally. Australia’s economic, social and technological advancement depends on maintaining a highly educated workforce and citizenry. Science and mathematics have been particularly targeted due to the part they play in advancing technologies, and informing environmentally sustainable development. In 2003, the Australian Government announced mathematical, scientific and technological literacy as a priority in a review of teaching and teacher education (Department of Education Science & Training, 2003a). Mathematics, technology and science education together are positioned as fundamental to developing Australia as a country that “[realises] its potential as a scientifically and technologically sophisticated nation advancing on the creative and innovative capacity of its people” (Department of Education Science & Training, 2003a, p. 153). The Government recognised that mobilization of Australia’s schools to prepare students for this challenge is dependent on high quality teachers. Consequently, various initiatives and research projects, including the project with which my research is associated, have been funded to promote and improve the teaching of mathematics and science.

The second national agenda relates to the changing needs of students in what has been labelled the Middle Years of Schooling. For the past ten to fifteen
years there has been mounting research into student learning needs, teaching approaches, and broader adolescent issues associated with this stage of schooling. As a result of this scrutiny, a number of large scale programs emerged that focused on improving teaching and learning. These projects set the scene for this research into mathematics and science pedagogy.

In 1996, a national focus on the middle years through the National Middle Schooling Project (NMSP) was launched by the Australian Curriculum Studies Association (ACSA) and the Commonwealth Department for Employment, Education Training and Youth Affairs (DEETYA). In 1999, the Victorian Government responded to these concerns by launching the Middle Years Research and Development (MYRAD) project. Through a research-driven approach focusing on improving student learning outcomes, MYRAD identified elements that were considered to be essential for promoting student learning in the middle years. A key finding of the project was that improvement to teaching would require moving “right inside the classroom, to illustrate the actual teaching-learning approaches and practices that are successfully directed to the learning outcomes for the knowledge society” (Centre for Applied Educational Research, 2002, p. 6).

In 2000, the Science in Schools (SIS) project (Tytler, 2003, 2004), now School Innovations in Science, was initiated by the Victorian Department of Education and Training (DE&T) and shaped and managed by Deakin University. Through school-based research, SIS assisted in understanding the nature of effective teaching and learning in science, established a whole school approach to professional development and was shown to improve science teaching and learning. SIS continues to influence practice at both the primary and secondary level, partly due to the emphasis on a whole school approach to teacher development through the SIS Strategy, but also through the SIS Components of Effective Teaching and Learning that provide principles of effective teaching, and a language and an opportunity for teachers to talk about their teaching.

The SIS school improvement model and a set of modified components of effective teaching and learning were adopted at a generic level through a Middle Years Pedagogy Research and Development (MYPRAD) project that ran in a number of Victorian schools, funded by DE&T. The MYPRAD project provided a strategy for planning and implementing pedagogical change in all subjects across the middle years of schooling.

Since then, the Victorian Government used the components arising from MYPRAD and SIS to develop the Principles of Learning and Teaching (PoLT) to guide teaching practice at all levels of schooling, Prep to Year 12, and across all subject areas. This framework is now embedded in the professional development and support materials associated with the Victorian curriculum guidelines, Victorian Essential Learning Standards (VELS).
The development of “generic” components of effective teaching and learning raised questions for the Deakin University researchers about the appropriateness of such generic descriptions of pedagogy across the range of subject areas. Does subject culture shape the application of such generic descriptors?

1.2.1. The IMYMS project

My research was set within the context of a Deakin University project called Improving Middle Years Mathematics and Science (IMYMS): The role of subject cultures in school and teacher change, which was funded by an Australian Research Council (ARC) Linkage Grant\(^1\) granted in 2003, with Industry Partner the Victorian Department of Education and Training. The project team consisted of the Chief Investigators Russell Tytler, Susie Groves and Annette Gough. My project is one of two Australian Postgraduate Awards for Industry (APAI) funded through the grant (APAI–2).

The IMYMS project investigated the extent to which the SIS components and strategy could be extended to improve teaching and learning in both science and mathematics. The SIS components were reconceptualised for the IMYMS project so they formed a set of components, the IMYMS components, which were representative of both mathematics and science, and which incorporated some of the ideas emerging out of the middle years research.

The IMYMS project aimed to improve the teaching and learning of middle years mathematics and science through the development of a school improvement process based on action planning, which involves teachers evaluating their classroom practice. The project investigated the role of mathematics and science knowledge and subject cultures in mediating change processes in the middle years of schooling. It investigated ways in which effective pedagogies in mathematics and science can be monitored; ways in which higher order learning outcomes in mathematics and science can be reliably assessed; and links between teachers’ pedagogies in mathematics and science.

The specific research questions addressed by the project are as follows.

1. What are the specific characteristics of science and mathematics knowledge and learning that require differences in the formulation of effective teaching and learning?
2. How can effective pedagogies in mathematics and science be monitored reliably?
3. How can students’ conceptual understandings in mathematics and science and ability to work mathematically and scientifically be assessed reliably?

\(^{1}\) ARC LP0348631.
4. What are the links between teachers’ pedagogies in mathematics and science? (APAI–2)

5. How do the cultures of teaching and learning of mathematics and science in primary and secondary schools affect the way change is constructed and pursued?

My research addresses the fourth question by comparing teachers’ pedagogies. The following section describes the focus of my research.

1.3. Focus of my research

My research deals only with secondary schooling and focuses on the pedagogical knowledge, beliefs and actions of teachers in order to describe not just classroom actions but also the underlying motives, expectations and orientations of teachers. Understanding what teachers know and believe about the teaching act requires an understanding of the complexity of the teacher’s experiences, incentives, beliefs and perceptions about both teaching and learning. The research is predicated on the assumption that there are relationships between teacher knowledge and beliefs and teachers’ intentions and aims for classroom practice, and seeks to examine how the subject culture is placed in this relationship.

This research, therefore, examines how teachers’ experiences of mathematics and science subject cultures influence their teaching in secondary school mathematics and science. Such experiences come to bear on how teachers come to know and construct for themselves traditions of practice, beliefs and assumptions associated with the subject.

The overarching question guiding the research is:

*What is the relationship between teachers’ pedagogies and their experiences of mathematics and science subject cultures?*

This question examines the relationships between three elements: subject culture, pedagogy and teachers’ experiences. This examination of the relationship between subject culture and pedagogy occurs through the lens of teachers’ reflections on their practice. In doing so, the research provides insight into pedagogies that are characteristic of mathematics and science teaching, and experiences of the subject culture. The role of these experiences of subject culture in contributing to teachers’ pedagogy is central.

By describing and comparing the way teachers teach and talk about mathematics and science, we can begin to understand relationships between how teachers construct:

- their identity in relation to mathematics and science teaching;
- their classroom practice; and
- the features of the subject cultures within which they operate.
Comparisons of pedagogies and subject cultures associated with school mathematics and science are central to this research. Research that incorporates a comparative lens in order to understand and describe teachers’ pedagogies broadens the scope for laying bare the different elements of pedagogy in each subject. A comparative lens can also be used to develop more informed and sophisticated descriptions of teachers’ constructions of the classroom, themselves and the subject cultures.

Such a comparative lens is made possible through the hermeneutic dialectic process (Guba & Lincoln, 1989; 1994). During this process teachers and the researcher participate in a co-constructive dialogue that enables teachers to reflect on and voice their constructions of pedagogy. The different perspectives of the mathematics and science teachers highlight the differences and similarities between, and translation of pedagogy, across these two subject areas. The role of subject culture is forefronted during this dialogue.

As part of the IMYMS project, my research was designed to work closely with a small group of volunteer secondary mathematics and science teachers from two participating schools. Over a period of about 18 months, seven teachers participated in a dialogue with me on what, how and why they teach the way they do. In providing reflective commentary on their practice they shared with me their experiences of learning, teaching and using science and mathematics. Central to this dialogue were the factors influencing their construction of teaching and learning the subject, and the way in which their pedagogical beliefs associated with teaching the subject were manifested in the classroom.

1.4. Structure of the thesis

This chapter has provided an introduction to the research with particular reference to orienting the research towards the issues associated with a re-negotiation of the significance of subjects in the ways pedagogy is conceived.

Chapter 2 describes the theoretical framework that sets the parameters for developing the research questions. The chapter explores literature relating to the notions of “subject cultures” in terms of how these are described in the literature and their historical development, and “pedagogy” in terms of how the notion of pedagogy is applied to my research. I draw from the literature various theories from social and socio-cultural theory and organisational theory that are useful for examining the relationships between subject culture and pedagogy. I then consolidate the ideas from the literature to elaborate on the research question and subquestions.

Chapter 3 provides a rationale for employing a constructivist research approach in responding to the research question and subquestions. The constructivist research approach and its metaphysical beliefs are set within the context of qualitative research. Within this paradigm, the researcher acts as primary instrument
in the data generation and analytical processes. The participants join with the researcher in a hermeneutic dialectic process to generate co-constructive dialogue that leads to better and more informed constructions and meanings.

In Chapter 4 I outline the research methods developed in order to be consistent with the constructivist research approach, and to bring teachers’ experiences of the subject culture and their classroom practice into the co-constructive dialogue. I outline the influence of my involvement in the IMYMS project research team on my developing insights and experiences, and summarise the selection of the participants. The multiple research methods—classroom observation, teacher interviews, artefact collection, and video recordings of lessons—are described and justified. An iterative and complex analysis is “disentangled” to demonstrate how my insights crystallised into the themes represented in Chapters 6, 7 and 8. The criteria for judging the quality of the research and the ethical consideration associated with conducting qualitative research are discussed.

In Chapter 5 I introduce the research field and the themes emerging from the analysis. I introduce the two schools and seven teachers involved in the research. I describe teachers’ pedagogy and commitments to mathematics and science and detail each of the observed lessons in order to contextualise teachers’ reflections from the interviews. I then introduce the four themes that emerged during and after data generation.

In Chapter 6 two themes are explored: the nature of curriculum content organisation and the pedagogical imperatives that emerge as a result of this organisation; and the degree to which learning experientially through hands-on activities was embedded and normalised within each subject. I argue that common basic assumptions about what it means to be a teacher of mathematics or science underpin teachers’ beliefs. Based on these assumptions I develop “subject pedagogies” that encapsulate common views amongst these teachers. I then juxtapose these subject pedagogies with current reform ideals informing science and mathematics education, which have the potential to shape teachers’ thinking about their pedagogy.

In Chapter 7 the third theme is explored: the translation of relevance as a school culture imperative into science and mathematics teaching. Through this theme I examine how teachers situate the learner and themselves in the subject as they respond to and translate a generic push to make school, and in particular the subjects of science and mathematics, relevant to students. I problematise what teachers mean when they talk about and go about “relating the subject to students’ lives.” Teachers referred to four pedagogical approaches each of which can be aligned with contemporary views of relevance in education. I argue that these teachers’ ability to make links between the subject matter and students’ lives depend on their own experiences with the subject and their subject commitments. I argue that these
experiences and commitments, which are aesthetic in nature, come into play as teachers negotiate subject boundaries.

Chapter 8 picks up this aesthetic dimension of teaching by exploring the fourth theme: the role of aesthetic understanding in the relationship between subject culture and pedagogy. Drawing on teachers’ reflections of their experiences with the subject, I explore the aspects of a teacher’s aesthetic understanding—passion, coherence and transformation—and how they inform our understanding of the relationship between the teacher and the subject. I argue that this aesthetic dimension is fundamental to how we think of the subject teacher. This personal dimension to the relationship between subject culture and pedagogy highlights the fact that teacher actions are not simply scripted by the subject culture, but are more likely to be subjectively determined.

In Chapter 9 I present a model through which we can conceive of the subject culture, and how the teacher develops their own version of what it means to be a subject teacher. I use this model to argue that a teacher is both a member of a subject culture coming to understand what might be acceptable ways of thinking about the content and how to teach it, while at the same time being an individual with his or her own set of experiences that lead to individualised conceptualisations of roles, purposes, and pedagogical actions. I argue that we need to respect the subject-specificity of teaching, and that the aesthetic dimensions of teaching play a central role in how teachers’ experiences of the subject culture shape their pedagogy.

Chapter 10 draws together ideas emerging from Chapters 6 to 9 to present eleven conclusions and six implications in response to the research questions. Methodological reflections elucidate the strengths and limitations of the chosen methodology.
Chapter 2. Reviewing the literature

Both pedagogy and subject culture are approached in multiple ways by theorists, researchers and educationalists. Through the following review of the literature I set the parameters for my application of these terms in responding to the research question, What is the relationship between teachers’ pedagogies and their experiences of mathematics and science subject cultures? This chapter is presented in three sections. The first section explores the subject cultures of mathematics and science. The second section describes relevant pedagogical theory and research. The third section consolidates the ideas from the previous two sections to develop the research questions.

2.1. Situating the “subject”: Mathematics and science as subject cultures

This section begins by exploring how the term subject culture will be applied to this research. I draw on the historical development of schooling and subjects in order to frame a discussion on the nature of subject cultures of mathematics and science in contemporary schooling.

2.1.1. Exploring the notion of subject cultures

A cultural perspective on teaching enables the context of the teacher to be considered when attempting to explore the relationship between pedagogy and the subject area that they teach. Over the past twenty years, a growing body of research has explored teaching and learning from the cultural perspective, describing and evaluating various dimensions of school culture, subcultures, and the creation of groupings of people within schools. Some research attempts to represent classroom culture as a context for the teacher, positioning the classroom either as a separate and definite culture (see, for example, Collins & Green, 1992), or as a subset of some larger culture. Shapiro and Kirby (1998) exemplify the latter perspective, with the classroom being represented as a subculture of the larger cultures of both the school (where different subjects represent different subcultures), and the wider science culture (which teachers are attempting to reflect to varying degrees in school science). The subject of science corresponds to the broader science culture that is bound by a set of shared norms, values, beliefs and expectations. The subculture of science as represented in schools is what Shapiro and Kirby have termed “school science learning culture” (p. 224) and acts as the context within which they contend students learn the “particular subset of cultural knowledge we call science” (p. 224).
While Shapiro and Kirby (1998) make reference to the classroom culture as being a subset of the broader school culture, Feiman-Nemser and Floden (1986) question whether teaching could be considered as having a common culture. They suggest that “it is far more likely that many cultures exist in this occupation whose members work in small towns and big cities, rich school and poor schools, and include novices and veterans at different levels of schooling” (p. 506). A school culture is, therefore, more likely to be determined by the broad context within which the members of a school are situated, such as demographic or socio-economic location, making the argument for a common culture for all schools difficult to justify.

Siskin (1994) also describes cultures associated with schooling from the point of view of its members, but instead of referring to the diversity among teachers as being responsible for determining school culture, she focuses on the members of the culture as teachers in a profession of teaching. Siskin entered her research into teachers’ work with the assumption that secondary teachers speak a technical language when talking about what they do. This was found to be problematic early in the research as Siskin recognised that teachers from the selected subject departments of English, science and mathematics spoke different “languages”. These language differences were more than simply “idiosyncratic appearances of technical jargon; rather the discipline’s language and epistemology in the ways teachers—as subject-matter specialists—conceptualise the world, their roles within it, and the nature of knowledge, teaching and learning” (Siskin, 1994, p. 152). School departments form the organising mechanism for subject cultures.

Goodson and Marsh (1996) also approach the description of teachers’ work around the subject. They highlight the fact that subjects are comprised of “a range of conflicting sub-groups, segments or factions” (p. 33). They assert that these groupings or factions can be organised around different schools of thought about knowledge, pedagogy or social purpose. These competing schools of thought often exhibit sufficient continuity over time for them to be characterised as ‘traditions’. In studying school subjects it is important to discern these underpinning traditions for they often exist in the intersection between schooling and the social and economic content. (p.33)

They describe traditions, not as timeless entities, but as “centres of gravity” (p.33) that shift in response to the struggles and tensions around the school curriculum. Different traditions within a subject area are the result.

Becher’s (1989) theory of academic tribes depicts groupings of different sections of academic communities as being associated, in a tribalistic way, with an epistemology and the appropriate systems, behaviours and practices that accompany that epistemology. The tribalistic nature of these communities are manifested though idols, defining artefacts, and language. Becher states that disciplinary discourse
highlights the cultural features that are characteristic of a discipline and its various related knowledge domains and is crucial to establishing cultural identity.

Such tribal characteristics are reflected in schools (Siskin, 1994). Siskin equates academic tribes to the compartmentalisation of subjects in schools that express knowledge as distinct fields, “each specialised discipline with its own ‘territory’, and populated by its own ‘tribe’” (Siskin, 1994, p. 4).

2.1.2. The nature of subjects

Secondary schooling in Australia is based on a departmental model. Teaching occurs through subjects, and teachers usually refer to themselves as teachers of specific subject areas. Historically, subject specialisation developed in American education system between the late 1800s and early 1900 (Hargreaves, 1994), resulting in the “emergence and institutionalisation of the academic department” (Siskin, 1994, p. 38) in high schools. Siskin suggests that this ready acceptance was because high schools were a relatively recent phenomenon during these discussions and the form they would take was still unclear. Departmentalisation remains one of the main differences between primary and secondary education in Australia.

By the 1930s, subjects were firmly grounded in high schools, established through a top-down approach from academic institutions (Siskin, 1994). According to Goodson (1993), the subject begins with the creation of an intellectual discipline by scholars, normally working in a university, which is then “translated” for use as a subject in schools. An academic school subject thus emerges out of a field of knowledge that provides for the subject inputs and general direction. This intrinsic relationship between academia and the development of school curriculum persists today to the extent that “upper secondary requirements are largely determined by the requirements for university entry with inevitable consequences for the lower secondary curriculum” (Dorfler & McLone, 1986).

Teaching became increasingly professionalised as teacher training gradually moved from the school to the universities where the subject specialists were located. Disciplinary boundaries became linked to state certificates of college degrees (Siskin, 1994). With the establishment of specialised subject areas, secondary teachers increasingly came to see themselves as part of a “subject community”, and tended to separate themselves from each other (Goodson, 1993). Curriculum development became overtly subject-centred to the extent that, in America, concerns were expressed through The Norwood Report of 1943 (quoted in Goodson, 1993) that “subjects seem to have built themselves vested interests and rights of their own” (Goodson, 1993, p. 31).

Over the years, the term “subject” has been applied at a number of levels: as a school examination category, a title for a degree or training course, and as a department within a school. Goodson (1993), claims that the
“subject” is the major reference point in the work of the contemporary secondary school: the information and knowledge transmitted in schools is formally selected and organised through subjects. The teacher is identified by the pupils and relates to them mainly through her or his subject specialisation. (p. 31)

Departments act as more than administrative units (Siskin, 1994); they also serve as the primary site for social interaction, professional identity and community, they represent strong boundaries dividing the school, and they influence decisions and shape the actions of individual teachers. According to Siskin, these departments are distinguishable and determined by “realms of knowledge” (p. 5). These realms of knowledge are more than just adjectives or labels for organising the school, “these subjects give departments their very reason for being” (p. 153). The knowledge is recognisable so that understood differences between realms of knowledge construct boundaries that draw people together around a common interest. Therefore, subject departments

are not just smaller pieces of the same social environment or bureaucratic labels, but worlds of their own with their own “ethnocentric way of looking at” things. They are sites where a distinct group of people come together, and together share in and reinforce the distinctive agreements on perspectives, rules, and norms which make up subject cultures and communities. (Siskin, 1994 p. 181)

A teacher’s identity and work, according to van Manen (1982), are organically bound up in what teachers know about their subject. Teachers describe themselves as teachers according to what they know:

to know a particular subject means that I know something in this domain of human knowledge. But to know something does not mean to just know just anything about something. To know something is to know what that something is in the way that it is and speaks to us. (van Manen, 1982, p. 295)

The subject, the subject matter, and personal histories in relation to the subject, are defining elements for teachers. This was demonstrated through Little’s (1995) research into schools that challenged the traditional school structure around subject departments, where it was found that subject allegiance remained high as teachers used subject expertise for maintaining the status of the subject.

Siskin (1994) also found that teachers tended to talk not only about themselves but also about others in terms of their specific subject area as a way of conveying information about their work. What mattered for teachers involved in Siskin’s study was “not simply that they teach, but what they teach” (p. 155, emphasis in original). Disciplinary background is revealed through a teacher’s choice of words, how they structure an argument and their goals for teaching and learning.

Further, pedagogy is influenced by an inextricable link between the way teachers see their students and the subject: teachers understand what students need in order to make the subject matter have meaning, therefore, “teachers understand and value their subjects for what they offer students, and understand their students through the metaphors and assumptions of the subjects” (Siskin, 1994, p. 158). Pedagogical knowledge is tied to how the teacher understands the knowledge of the subject. Conversely, the content knowledge of teachers as representations of the
epistemology of the subject is transformed in a way that meets the learning needs of students. This refers to “pedagogical content knowledge”, as described by Shulman (1986) (see Section 2.2.2).

Clearly, the literature indicates that the subject cultures to which teachers affiliate themselves can strongly influence how they teach. My research explores how the fragmentation of school into subjects is evident within the classroom in terms of differences in teachers’ pedagogies, but also how teachers view their practice in relation to the subject knowledge and culture. Mathematics and science subjects emerge out of academic departments, or ‘tribes’, that reflect different epistemologies. The epistemology acts as the catalyst, object and barrier that group like-minded people. The next section explores epistemological differences between mathematics and science subject cultures and how these differences become pedagogical differences.

2.1.3. Comparing mathematics and science as forms of education
This section introduces some of the main differences and similarities between mathematics education and science education referred to in the literature. Research, policy and theory relating to mathematics or science as forms of education are used to build a picture of the epistemologies, educational purposes, curricula, and curricular reform, associated with school mathematics and science. This review provides an introduction only, as various aspects of the mathematics and science subject cultures represented in this literature are reflected in the themes discussed in Chapters 6 to 8. This review, therefore, frames the historical and current, school-based and broader, perspectives that are part of the context of teachers participating in this research.

Purposes
In Chapter 7, I elaborate further on the purposes of mathematics and science teaching and learning as they emerged through the data and literature. In this initial comparison of the subject cultures, I refer to current and past curriculum guidelines in Victoria, as well as prominent commentators in order to identify utilitarian and aesthetic goals in the lifelong learning of students in both subjects.

The Cockcroft Report (Cockcroft, 1982) was an influential report on the state of the teaching of mathematics in the UK in the 1970s and 80s. The report elucidates various messages about the purposes of mathematics in school that continue to inform mathematics teaching and education research today. Central to the report is the view that mathematics should be presented in schools as a requirement for life so that students recognise the utility of mathematics and are confident in their use of mathematics. The aesthetic dimensions of engaging with mathematics are emphasised, such as enjoyment through the use of puzzles and problems. As preparation for future mathematics learning, the report asserts that students should
understand “the powers of ‘abstraction’ and ‘generalization’ and their expression in algebraic form on which higher level mathematics depends… all students should have opportunity to gain insight, however slight, into the generalised nature of mathematics and the logical process on which it depends” (Cockcroft, 1982, p. 67). These purposes continue to be reflected in current curriculum guidelines. In addition, the Victorian Essential Learning Standards (VELS) for mathematics highlights the empowerment that mathematics provides to individuals as members of a technologically advanced society, and that mathematics, along with science, is central to Australia’s technological and economic advancement (see also Department of Education Science & Training, 2003a): “mathematics also has a fundamental role in enabling cultural, social and technological advances, and empowering individuals as critical citizens in contemporary society and for the future” (Victorian Curriculum & Assessment Authority, 2005a, p. 4).

Many of the above purposes associated with mathematics are also associated with science. Echoing the citizenship goals for mathematics education, one of the goals for science education is to empower students as members of society through learning and applying science: “Science education contributes to developing scientifically and technologically literate citizens who will be able to make more informed decisions about their lifestyle and the kind of society in which they wish to live” (Board of Studies, 2000b, p. 5). The development of science capabilities, including interest and curiosity, creativity and problem solving, and reasoning and critical thinking, are stressed by the Science VELS (Victorian Curriculum & Assessment Authority, 2005b). The work of scientists is emphasised in the goals for science education, perhaps more than mathematicians and their work are recognised in the Mathematics VELS. Where work in the science discipline is about using scientific evidence to develop scientific theory (Board of Studies, 2000b), science education allows students to be exposed to scientific ideas through participating in practices employed by scientists (see Gunstone & White, 2000).

The purposes attributed to the subjects arise out of the epistemology of the underpinning knowledge, and the way this knowledge is organised in schools. The following two sections briefly examine these aspects.

Epistemologies
The academic disciplines of mathematics and science are represented as school subjects; however, the nature of what is represented as the subject does not, and perhaps can not, necessarily mirror that of the academic version of the discipline. The foundational knowledge of mathematics and science are translated and organised for the purpose of meeting the outcomes of education (Beane, 1995).

The Victorian Mathematics Curriculum and Standards Frameworks II (Board of Studies, 2000a) states that “because mathematical knowledge is about relationships between things, it is inherently an abstract discipline. This abstractness
makes it applicable in a wide variety of situations, but presents particular challenges to teachers and learners” (p. 5, emphasis in the original). Problems are contextualised for students in both familiar and unfamiliar everyday situations by applying concepts and skills as part of problem solving (Cockcroft, 1982). Mathematics is also a system of instruments as tools to assist with decisions and actions in a broad range of social practices and techniques (Niss, 1994). In Chapter 8 I examine other literature that challenges this assumption of applicability of abstract mathematical concepts to students’ lives.

Siskin (1994) characterises science as being less abstract and more activist than mathematics. For example, where mathematics patterns are often taken out of context, such as tile patterns on a bathroom wall, patterns in science usually deal with real life contexts. Scientists then “do something with it” that places the theory into practice, what Siskin calls “activist” and “making a difference”. The Science Curriculum and Standards Frameworks II (Board of Studies, 2000b) describes the application of scientific knowledge and making connections between the science community and society. This can be linked to the application of scientific principles to real life contexts: “science knowledge is characterised by a complexity of application of conceptions to the real world, and to classroom activities” (Tytler, Smith, Grover, & Brown, 1999, p. 211).

While both mathematics and science educators would agree that their teaching is underpinned by a rich conceptual base, the richness of the relationships between different science concepts and across science disciplines, such as physics and chemistry, adds complexity to the way scientific phenomena can be understood. By comparison, the mathematics curriculum is characterised by a highly structured sequence. The National Council of Teachers of Mathematics (2000) identified that one of the distinguishing features of an effective mathematics teacher is having an understanding of the “big ideas of mathematics and [being] able to represent mathematics as a coherent and connected enterprise” (p. 17). Organisation of content is discussed further in the following section.

**Nature of mathematics and science content and curriculum**

Another point of comparison draws on the assumption of Siskin (1994) that mathematics is a single discipline, whereas science is a cluster of disciplines, that is, chemistry, biology, physics, geology. This difference has a number of implications for teaching.

Where Siskin (1994, p. 170) characterises mathematics by an “ordered progression from place to place through a sequence of steps” and different levels, science is characterised by a progression through disciplinary routes.

In mathematics, Siskin (1994) claims that teachers in her US study developed general agreement about “what counts as knowledge, and how it is organised and produced” (p. 170). Counter to such claims of general agreement, Schoenfeld (2004)
states that, as with other subject areas, controversies exist about the epistemological foundations of the mathematics discipline, particularly “what constitutes ‘thinking mathematically’, which is presumably the goal of mathematics instruction” (p. 243). Variation in the conceptualisation of what should be learned and how it should be taught has sparked curriculum reform.

Despite these controversies, mathematics has often been, and continues to be, characterised by incremental learning, “a slow systematic and progressive movement from the simple to the complex” (Hargreaves, 1994, p. 139). Mathematics activities are, therefore, often seen as “a sequential progression through a series of topics, each of which is a prerequisite to what follows” (Sherin, Mendez, & Louis, 2004, p. 208). With this as a teaching model, Siskin claims that “math teachers value testing, placement, and tracking as the means of assigning students to the right rungs during their progress up the ladder” (p. 170). In her US study, Siskin found that tracking was a distinguishing feature of mathematics teachers: where tracking was viewed by mathematics teachers as a means of meeting student learning needs, tracking was viewed by teachers from other subjects as simply “convoluted” and extraneous.

One of the consequences of having widespread agreement on the content and sequence—what Siskin (1994) calls “the tight paradigm of mathematics”—is that teachers are able to learn the routines, and thereby follow the same curriculum. Siskin claims that homogeneity in curriculum can lead to homogeneity in the mathematics instruction within a department. Similarly, Reys (2001) notes that a generally agreed upon core body of basic knowledge means that, in the US, mathematics texts from different publishers are almost indistinguishable. The best sellers are emulated by other publishers – deviation from the “norm” (best seller) results in low book sales. This limits motivation to change textbooks dramatically to address the reformed, but controversial, US standards-based curriculum. In 1986, Dorfler and McLone expressed views congruent with Reys and Siskin stating that “the material content of school mathematics is to a high degree internationally standardised. Deviations from this standard are only minor and depend on the educational system, local traditions and influences and perhaps special local demands” (p. 58). This view to some extent dominates accounts of how subject matter is organised as “coherent sets of topics” worldwide (National Curriculum Board, 2008, p. 2). In the Australian context, the framing paper for the proposed National Mathematics Curriculum (National Curriculum Board, 2008) acknowledges content variations across the Australian states and territories, but proposes a content structure that is based on “the most common categorisations of the basic content strands…in the compulsory years: Number, Measurement, Space, Chance and data, and Algebra” (p.2). Curriculum-related controversies in the document relate not to what is taught, but to the nature of the proficiency strand incorporating processes involved in “working mathematically”, and the need for “thinning-out” a “crowded curriculum” (p.8).
By contrast, there is difficulty in reaching the same level of agreement in school science. For example, the framing paper for the *National Science Curriculum* identifies the inherent challenges in prescribing a curriculum that takes account of both the “core body of science knowledge and understanding that is fundamental to the learning of science”, as well as the “rapidly increasing body of science knowledge” (p. 7) coming out of contemporary science. This challenge is responded to differently in the different Australian curricula structures. For example, compared to the Victorian curriculum document—*Victorian Essential Learning Standards* (Victorian Curriculum & Assessment Authority, 2005b)—the proposed National Curriculum framework includes an additional “element” that emphasises science as a human endeavour.

On another level, according to Siskin (1994), the multi-disciplinary nature of school science “brings together not different ways of knowing the same content, but the same scientific method used to know different topics” (p. 174). According to Schoenfeld (2004), claims to a scientific method that permeates all the scientific disciplines is overstated, suggesting that different disciplines of science, such as physics and biology are more disparate in both theory and method than are anthropology and sociology. It is beyond the scope of this thesis to explore the debate surrounding either the nature of science as represented in schools, or how representative the “scientific method” is of the way scientists operate. Many writers in science education focus on the nature of science as the underlying thread of school science curriculum and pedagogy, preferring to recognise the disciplines of science as adopting many methods but being subject to some basic tenets of science, although the question of what these tenets should be is still unresolved (see, for example, Longbottom & Butler, 1999; MacDonald, 1996). Studies have investigated how the nature of science is represented, with more recent research promoting the importance of explicit instruction of, and participation in, the nature of science in school science curriculum and pedagogy, preferring to recognise the disciplines of science as adopting many methods but being subject to some basic tenets of science, although the question of what these tenets should be is still unresolved (see, for example, Longbottom & Butler, 1999; MacDonald, 1996). Studies have investigated how the nature of science is represented, with more recent research promoting the importance of explicit instruction of, and participation in, the nature of science in school science classrooms (see, for example, Hart, Mulhall, Berry, Loughran, & Gunstone, 2000; Lederman, 1992, 1999). Relevant learning experiences can be achieved by providing authentic science experiences (Rahm, Miller, Hartley, & Moore, 2003; W. Roth & McGinn, 1998) where students are considered as non-scientists participating in the scientific community of practice by engaging in “habits of thought” cognisant with scientific thinking (Trumbull, Bonney, Bascom, & Cabral, 2000, p. 1).

**Contestations surrounding mathematics and science modes of instruction**

Over the years, there have been a number of debates in the literature around what should be emphasised through the science and mathematics curriculum, and hence through the type of activity students should engage with in their learning.

In science, Rico and Shulman (2004) argue for a divergence from the entrenched and much criticised “science-as-facts” model towards “science as ‘doing’, investigating, conducting research, actively seeking solutions to yet-solved
problems” (p. 162). They state that poor models are perpetuated by commercially produced materials that “emphasise facts, formulae, demonstration, and vocabulary” (p. 162). Processes of science are seen to be “add-ons” rather than necessary for learning science content. Van den Berg (2000) claims that American textbooks tend to have little educational value partly because the experiments are dictated by tradition, and utilize largely recipe style procedures.

A related debate surrounds the role of practical work in science. The 1960s saw a revival of hands-on science, which had emerged before the turn of the century, but which had lost its foothold post-war. The Nuffield Science Project in America was instrumental in putting the focus back on experience and a hands-on approach to instruction (Turner & Turner, 2000). However, twenty-five years ago, the effectiveness of practical work was in question (Hofstein & Lunetta, 1982; Turner & Turner, 2000). The contention was not so much that practical work should be neglected, but the question surrounded the kinds of experiences that students should have and how to incorporate these with conventional classwork.

In mathematics, traditional modes of instruction have been researched and critically examined. Commentary on mathematics education for the past twenty years has shown that, while mathematical research has advanced our understanding of how student learn mathematics and effective learning and teaching environments, many classrooms fail to reflect these new ideas (Tytler, Osborne, Williams, Tytler, & Cripps Clark, 2008). Siskin’s (1994) research finding that a content-driven focus dominated the views of the participating mathematics teachers was typical of the way mathematics curriculum is conceived. In 1988, the Victorian Ministry of Education (Ministry of Education, 1988) launched a curriculum framework that dealt with the pervading problem of classroom approaches that failed to encourage students in their mathematical learning: “the type of mathematics that has tended to be offered to students in the past has become abstract at too early a stage” (p. 11). Underlying the recommendations in the framework was the need to broaden students’ experience of mathematics so as to “develop skills, concepts, applications and processes which allow meaningful participation in society” (p. 12). Schoenfeld (2004) and Sherin et al. (2004) reiterate this paradigmatic shift in mathematics curriculum towards making both content and process essential for mathematical understanding. A teacher participating in Sherin et al.’s research on Fostering a Community of Learners (FCL) reported that when he began to rethink mathematics as content and process, the classroom discourse was transformed with greater emphasis given to students sharing and responding to each other’s ideas. This emphasis is indicative of the general movement in mathematics education reform where effective mathematics instruction is reconceptualized as “a human construction based on historical efforts to solve particular problems, accepted modes of discourse and validation that are essentially social in nature” (Tytler, et al., 1999). The Cockcroft Report (1982) described six elements of successful mathematics teaching: exposition, discussion, practical work,
practice, problem solving and investigational work. Clearly, this emphasis on content and process has been evident in the mathematics education literature for some time but continues to be neglected in many classrooms.

**Similarities between mathematics and science**

As mentioned in Section 1.1, educators and researcher often closely align science and mathematics because of what they are perceived to have in common, such as “linear ways of approaching things, step-by-step procedures, quantitative methods, and a mature paradigm” (Siskin, 1994, p. 174). Situated within “the sciences”, mathematics and science often sit in tandem, for example, in:

- schools and university faculties (such as, the *Australian Science and Mathematics School* in South Australia, website [http://www.asms.sa.edu.au](http://www.asms.sa.edu.au));
- government initiatives (such as, current funding earmarked for science, technology and mathematics projects by the Australian Government);
- policy and policy directions (such as, the Victorian Government Department Mathematics and Science Strategy currently under a Parliamentary Inquiry; and Department of Education, Training and the Arts, 2007)
- research into teaching and learning (such as, the *Trends in International Mathematics and Science Study* [TIMSS], and *Science, ICT and Mathematics Education in Rural and Regional* [SIMERR]);
- academic journals (such as, *School Science and Mathematics*) and other education-based publications (such as, Clarke, 2001b; Pehkonen, Ahtee, & Lavonen, 2007);
- inquiries into the state of the education (see, for example, Department of Education Science & Training, 2003b; Education & Training Committee, 2006; Tytler, Osborne et al., 2008); and
- through subject integration (such as, Berlin & White, 1995; Venville, Wallace, Rennie, & Malone, 1998).

What makes science and mathematics so compatible? Research by Corrigan and Gunstone (2007) that compares the values of mathematics and science summarise what science and mathematics have in common within the context of education. The authors state that both are “taken as ways of understanding that are embedded in rational logic—focusing on universal knowledge statements” (p.143). Society views both as essential components of schooling. “In their teaching, both involve following routines, although not exclusively. Both involve modelling, albeit with different emphases. Similarly, each is incorporated into the other’s applications but in an asymmetrical relationship” (p.143).

Compatibility of mathematics and science is most emphasised by proponents of the integration of science and mathematics. As part of a move in the 1990’s to
promote the integration of mathematics with other subject areas, Berlin and White (1995) made an argument that integration tends to emphasis characteristics of the subjects that overlap. They emphasised that, “Habits of mind or dispositions specific to current curricular, instructional, and assessment goals for both mathematics and science include curiosity, creativity, inventiveness, leadership, organization, persistence, resourcefulness, risk taking, self-confidence, self-direction, self-reflection and thoughtfulness” (p. 27). They also identified the following common attitudes that mark the mathematics and science disciplines:

- desiring knowledge (as a way of knowing and understanding);
- being sceptical (recognizing when to question “self-evident truths”);
- relying on data (explaining natural occurrences by collecting and ordering information, testing ideas, respecting the facts that are revealed);
- accepting ambiguity (recognise that data are rarely clear and compelling, appreciate new questions and problems that arise);
- being willing to modify explanation (seeing new possibilities in the data);
- cooperating in answering questions and solving problems (working together to pool ideas, explanation and solutions);
- respecting reason (valuing patterns of thought that lead from data to conclusions, and constructing theories);
- being honest (viewing information objectively without bias).

While these characteristics suggest that the subjects are compatible, the nature of the knowledge, the purposes associated with each subject, and the teaching strategies that are used to teach each subject at the secondary level are different. Corrigan and Gunstone (2007) summarise some of these differences. Science textbooks include sections on the nature of science but mathematics texts tend not to do so; values tend to be explicit in science but are more implicit in mathematics; a “science industry” is more widely recognised than for mathematics; and science is more prominent than mathematics in the media.

Corrigan and Gunstone (2007) also claim that mathematics plays more of a “gatekeeper” role in society than science, with mathematics acting as the basis of selection for tertiary entrance and employment. Broadly speaking, they also claim that while mathematics is considered publicly important, school mathematics is generally considered to be personally irrelevant.

There is limited research that explores how these differences and similarities are reflected in teachers’ conceptualisation of their practice, and how knowledge of these comparisons equip a teacher in teaching across both subject areas. Even the SIMERR and TIMSS research projects, which purport to address the teaching of both mathematics and science, tended to deal with mathematics and science independently of each other, rather than drawing direct comparisons between them. Such a
comparative lens has the potential to signify how the knowledge, beliefs and assumptions in one subject inform teaching in the other.

2.1.4. Challenging the role of subjects and subject cultures in determining pedagogy

A tradition of subject specialisation in secondary schools has contributed to a tendency to promote pedagogy appropriate for specific areas of content. In recent years, various curriculum models underpinning Australian state education systems reflect a re-thinking of the purpose and role of the “subject”. These models are informed by research focused on a contemporary view of the purpose of schooling that has generated, and reported on, a shift in the way pedagogy is conceived, particularly in the middle years of schooling. This section outlines some of the arguments and counter-arguments involved in this debate about the integrity of “the disciplines” as pedagogy is removed from the context of the subject.

Gardner (2004) states that disciplines are “the best answers that human beings have been able to give to fundamental questions about who we are, physically, biologically, and socially” (p. 233). They are distinctive in terms of moves, genres, syntax and content, the mastery of which takes time. However, historically, research in teaching and learning has regarded subject matter disciplines in varied ways: “as the organizing framework for investigation and implementation” (Shulman & Sherin, 2004, p. 135); or as secondary to “generic principles of instruction that could transcend disciplinary boundaries” (Shulman & Sherin, 2004, p. 135). The result was that content areas nearly disappeared from research at various points in history. Today in the US, Gardner (2004) sees disciplines as being threatened by “facts, which are discipline-neutral subject matter, and which serve as just a textbook convenience” (p. 233), and by “interdisciplinarity, which often ignores and obscures disciplinary differences” (p. 233). These pressures are evident in the Australian context where, in many classrooms, specific content is the focus of instruction, and where the notion of interdisciplinary approaches to broad scale and localised curriculum development are being explored.

What does this mean for science and mathematics education? In a review of subject matter, Shulman and Quinlan (1996) predicted that subject matter would again take prominence in determining school curriculum as the work of scholars in creating the knowledge and of citizens and professional practitioners who use and enjoy the knowledge in the real world play a significant role in defining what counts as subject matter. The social contexts or communities within which the knowledge is discovered and used will become part of the definition of how classrooms are organised for its study. And epistemological questions will finally reach parity with questions of substance in characterising the curriculum. (p. 421)

Shulman and Quinlan’s (1996) predictions were not unfounded. There was a considerable evidence leading up to 1996 of student dissatisfaction with school,
especially with what was being offered in the middle years (Anderman & Maehr, 1994; Beane, 1990; Sizer, 1994). For example, in a Victorian inquiry, Hill, Holmes-Smith and Rowe (1993) noted a decline in the engagement of young adolescents in secondary school compared with their engagement at primary school. There was mounting evidence to support a change in direction of curricula and syllabi to recognise the unique needs of middle years students.

The current reform in the middle years of schooling reflects a modified emphasis on subjects where the purpose of the subject matter is as the context for delivering an alternative curriculum concerned with “many of the communicative, expressive, thinking, affective, moral and social experiences which can provide students with impetus to their holistic development as young adults” (Arnold, 2000). Arnold states that middle school curricula and syllabi should “reflect integrated approaches emanating from collaboration between teachers of different subjects and between the teachers with their students” (p. 4). The New Basics curriculum model trialled in Queensland represents such an integrated framework for curriculum, pedagogy and assessment (see Matters, 2001, for a review of the New Basics trial), and signals a move towards generic description of pedagogy. The framework incorporates Productive Pedagogies, derived from Newman’s construct of Authentic Pedagogy, and Rich Tasks that allow students to “display their understandings, knowledge and skills through performance on trans-disciplinary activities that have an obvious connection to the real world” (Matters, 2001, p. 2).

Gardner’s (2001) argument for more purposeful education does not promote the integration of subjects, but advocates that disciplines should provide the context for in-depth study of an area of content. The pressure to get through the curriculum should be replaced with opportunities to develop a “rounded, three-dimensional familiarity with a subject” (Gardner, 2001, p. 5). The subject matter, therefore, remains the context for teachers’ knowledge about teaching and learning, and a tool for drawing out pedagogical knowledge.

In the face of attempts to move towards generic descriptions of pedagogy, it is important to understand how the subject cultures play a role in determining pedagogy. Is it possible to describe teaching of mathematics and science without recognising epistemological differences that distinguish the disciplines underpinning school science and mathematics? In order to understand the benefits and limitations of defining pedagogy in generic terms there is a need to first recognise and ascertain how and why teachers’ pedagogy may be different across subject areas. What is common about teacher practice that affords generic pedagogical description across disciplines? At what point do such generic models become less useful when guiding pedagogy? What is perceived as “common” may in fact only be common in terms of language but have different meanings behind the language or imply different purposes or intentions for teaching and learning.

To Shulman, Gardner and others, it is clear that subject matter is important:
It is not only the subject *qua* discipline that matters. The subject matter, which is the subject transformed, interpreted and arranged for purposes of teaching and learning, matters. (Shulman & Quinlan, 1996, p. 420)

The subject matter is arguably the defining element of the culture of a subject (Siskin, 1994). According to Shulman and Quinlan’s 1996 prediction, “Much of the educational psychologists’ work will involve inquiries into the advantages of different strategies for transforming subject into subject matter” (p. 421). But in what ways does the subject culture within which a teacher operates influence the way he or she teaches the subject matter? Indeed, Stodolsky (1988) noticed striking differences in patterns of instruction in upper primary classrooms that she considered to be a function of the subject matter. In challenging the assumption that teaching and learning were seen as uniform and consistent, Stodolosky highlighted that teachers arrange instruction differently depending on what they are teaching, and that students respond to instruction differently depending on the structure and demands of the lesson.

In order to explore further the effect of subject culture on pedagogy, my research juxtaposes teachers’ level of confidence with both the subject matter and the pedagogical moves required to present that subject matter in an understandable way (can be referred to as “pedagogical content knowledge” [Shulman, 1986]) with their view of themselves as teachers operating within different subject cultures.

### 2.2. Situating pedagogy: Developing a framework for investigating pedagogy

This research is principally concerned with how subject culture comes to bear on pedagogy. This may be evident through classroom practice, that is, the observable actions of the teacher in a lesson, but it is more likely that developing a fuller understanding of the influence of a subject culture requires looking more broadly at the complexity of a teacher’s “pedagogy”.

This section explores how pedagogy has been described and researched. Fundamental to what a teacher does in the classroom is what a teacher knows, believes and values about teaching and learning. Drawing on relevant literature, a theoretical approach is framed that informs the methodological approach to this research. Rather than being a thorough listing of the various applications of the notion of pedagogy in today’s literature, this review selects applications that I consider to be pertinent to understanding what teachers know about how and what they teach.

#### 2.2.1. Describing pedagogy

Pedagogy is commonly defined in contemporary education as the art and science of teaching. The term pedagogy has had different meanings over time that coincide with political purposes and beliefs about the nature of education. The term is also
becoming more frequently applied to contexts broader than education (van Manen, 1999). The social, historical and political development of the term pedagogy has resulted in differences of opinion about what pedagogy should and can possibly mean. The following views of pedagogy describe my approach to “pedagogy” in this research.

Foremost are the views of van Manen (1999) who highlights the relational dimension of pedagogy. Van Manen describes pedagogy as ultimately “the study and practice of actively distinguishing what is appropriate from what is less appropriate for young people” (p. 25). Pedagogy becomes evident in the classroom in the way teachers are “attentive to the manner that students experience their lives in the classroom” (p. 26). He draws on the Latin roots of pedagogy to emphasise the child (“paides”) and the parent or teacher as the pedagogue. Pedagogy from this perspective represents a relationship between the teacher and the learner that is characterised by a sense of care and interest that the pedagogue has in supporting the learner.

According to van Manen (1990), pedagogy cannot be simply seen or observed in classroom settings because to see pedagogy simply “means to observe operational or measurable instances of pedagogical teaching” (van Manen, 1990, p. 149). Pedagogy is much more than the teaching practices that are acted out in the lesson. Pedagogy is consequential to the theoretical overlays and “perspectival frameworks” constructed by teachers “in the paradoxical effort to see more clearly the significance of pedagogical practices” (p. 149). “We don’t have a pedagogy”, he states, “but recall it whenever a situation requires acting educationally, continuously and reflectively being sensitive to what authorises us as pedagogic teachers” (p. 149). Pedagogy is, therefore, situational and context dependent.

In continental countries such as Holland, Belgium, Germany and Scandinavian countries pedagogic analysis is described as the “relational values, the personal engagement, the pedagogical climate, the total lifeworlds and especially the normality of life with children at school, at home, and in the community” (van Manen, 1999, p. 14). As an academic discipline, pedagogic analysis “problematises the conditions of appropriateness of educational practices and aims to provide a knowledge base for professionals who must deal with childhood difficulties, traumas and problems of child-rearing” (p. 14).

In this context, pedagogy refers to the way pedagogues determine what is appropriate and what is less appropriate for children, and includes ways of teaching and giving assistance. For my research, van Manen’s (1999) focus on pedagogic analysis provides the foundation for the way I view teachers as pedagogues. In my research I draw attention to the way subject culture influences how teachers, as pedagogues, distinguish what is appropriate from what is not appropriate for students in learning mathematics and science. I employ a methodology that provides teachers with opportunities to reflect on their planning, choice of content and teaching
strategies, and their interaction with students in the context of mathematics and science.

From a socio-cultural perspective, pedagogy has been defined by Edwards (2001) as “interpretive and responsive teaching” (p. 163). Similar to van Manen (1999), the emphasis is on being sensitive to what the learner needs to learn, but she adds a sense that teachers draw on their social context during this pedagogic act: “a pedagogic act involves those who are teaching in informed interpretations of learners, knowledge and environments in order to manipulate environments in ways that help learners make sense of the knowledge available to them” (p. 163). Teachers draw on their surrounding environment and their own interpretations of learners, knowledge and environments in order to make a difference to the learning outcomes of their students. The context and situation of teachers impacts on the pedagogic act; therefore any pedagogic analysis must include the context of the teacher when making meaningful descriptions of pedagogy. Identifying the subject culture as the cultural setting of the teacher brings into focus the extent to which, and in what ways, teachers are influenced by what is possible and not possible, or in van Manen’s words, what is and is not appropriate for teaching and learning mathematics and science. This may be dependent on the way a teacher perceives, or “interprets”, the teaching environment of the subject at their school or the nature of the knowledge that underpins the subject.

2.2.2. Researching pedagogy
Pedagogy continues to be a major focus in educational research. Research approaches pedagogy in many ways in order to capture and explore its multi-faceted, multi-dimensional nature. There are a number of stakeholders that have an interest in how and what teachers are teaching, from teachers themselves, to their students, parents, school leaders, governments and teacher educators. Consequently, research into pedagogy has many purposes, such as description of effective practices, evaluation, policy development, or validation of perspectives on practice. Pedagogical research may investigate, develop, build on, or simply report innovative or existing practice. Pedagogy may be investigated by focusing on the events of the classroom where teacher and student actions are scrutinised, or by turning the spotlight towards the practitioner who is a person acting on, and in response to, what they know, believe and value. My research will draw on both of these dimensions—the classroom events and the holistic teacher—in order to explore relationships between what teachers do in science and mathematics classrooms, what they know and believe about mathematics and science teaching, and how these things may be influenced by the subject of mathematics or science as their cultural backdrop.

The following literature review draws on four areas of literature relevant to this research: what teachers know and believe, teacher orientation and beliefs,
influences on pedagogy, and how we might learn from studies into effective teaching.

**Researching what teachers know**

Leading up to the mid 1980’s there was a strong focus on “process-product” research, with teacher behaviour as the focus of “process” and a strong reliance on standard achievement tests as the “product” (Shulman, 1999). Little emphasis was given to the domain-specificity of knowledge. Shulman signalled in 1986 a need to make direct links between the subject matter and what teachers know about teaching. This brought into focus the missing element of “teachers’ cognitive understanding of subject matter content and the relationships between such understanding and the instruction teachers provide for the students” (Shulman, 1986, p. 25). Shulman introduced “a new model and set of hypothetical domains of teacher knowledge” (Gess-Newsome & Lederman, 1999, p.3). Today, research on the interaction between content and pedagogy provides valuable insight into discipline- and interdiscipline-specific pedagogies, including what is possible and appropriate for teaching domain specific content.

Shulman (1986, 1987) introduced three domains of teacher knowledge: subject matter knowledge, pedagogical content knowledge and pedagogical knowledge. “Subject matter knowledge”, also called content knowledge, is the knowledge that teachers have about the content considered appropriate for teaching. By comparison, “pedagogical content knowledge” (PCK) adds to this dimension of subject matter the knowledge required for teaching it to students, and includes the “ways of representing and formulating the subject that makes it comprehensible to others” (Shulman, 1986, p. 10). Of greater concern than simply having a good understanding of the subject matter is how the content is delivered in a way that is sensitive to the needs and requirements of the learners. “Pedagogical knowledge” was described by Shulman as “general pedagogical knowledge, with special reference to those broad principles and strategies of classroom management and organization that transcend subject matter” (Shulman, 1987, p. 8). Aware of Shulman’s intention to draw attention away from generic pedagogical research, Morine-Dershimer and Kent (1999) broaden this definition by drawing on studies in classroom organization and management, instructional models and strategies, and classroom communication and discourse. They make the point that, in reality, “it is literally impossible for a teacher to implement pedagogical knowledge in the absence of content. Similarly, we would argue, it is literally impossible to teach content effectively without using pedagogical knowledge and skills” (p. 42).

Teachers’ knowledge of pedagogy and content are therefore inextricably linked, as represented by Shulman’s PCK. Although consensus has been difficult to reach about what PCK might be (Gunstone & White, 2000), much insight about the complexity of teacher knowledge has developed out of a renewed awareness of this.
inextricable link (see Gess-Newsome & Lederman, 1999). For example, recent work by Monash University, Melbourne, explores and compiles the knowledge that groups of teachers have of particular scientific concepts, such as the particle model, by collaborating with teachers to identify the main “big ideas” that students need to learn in order to understand the concept (Loughran, Berry, & Mulhall, 2006; Loughran, Mulhall, & Berry, 2004; Mulhall, Berry, & Loughran, 2003). The knowledge that teachers have relating to each of the big ideas is tabulated and includes knowledge of students’ struggle to understand the big ideas and a variety of successful teaching strategies. This research provides a framework for exploring what teachers know about a specific area of content and the expertise needed to teach it effectively.

Lijnse (2000) feels research that evaluates how well content is taught is still lacking. He closely aligns PCK to “didactics”, where “research in science didactics … comes down to analysing, describing and improving teachability and learnability of science. It does not take the science content for granted, but studies it from this particular point of view” (p. 311).

In mathematics, Lee, Meadows and Lee (2003) explored mathematics instruction by looking at how teachers’ PCK determined their teaching of mathematics. They examined teachers’ knowledge of four areas: mathematics content, children’s understanding of mathematics content, children’s mathematics problem-solving process, and organization of the mathematics environment based on how students understood the mathematics content and the problem-solving process. Represented in Lee et al.’s research are three aspects of PCK that Baxter and Lederman (1999) categorise as what a teacher knows, what a teacher does, and reasons for the teacher’s actions. Baxter and Lederman assert that any research into teachers’ PCK must strategically target these areas. Difficulties arise in researching PCK because PCK is by its nature “both an external and internal construct” (p. 158). They make the assumption that there is a relationship between cognition and action, such that teachers’ knowledge and beliefs are enacted through classroom practice. This assumption underpins my research.

Mathematics and science education are delineated fundamentally by the difference in subject matter. As stated by Gunstone and White (2000), “Science education concerns the understanding of specific content” (p. 294), that is, “concepts and natural phenomena in the terms that scientists use” (p. 293). A similar statement could be made concerning mathematics education. But what is it about the nature of the content knowledge that predisposes a particular way of knowing how to teach it? Are there links between what teachers know about mathematics and science teaching that allow them to draw on a single body of knowledge, or are the knowledges that teachers have about mathematics and science teaching distinct from each other? General pedagogical knowledge, which is strongly embedded in these questions, has already been shown to be tied to the content area, but is perhaps more transferable to
different subjects. Given that PCK is knowledge confined to a specific area of content, it is unlikely that PCK is “translatable” as such. Perhaps what is translatable is the pedagogical knowledge that feeds pedagogical content knowledge, but which must be reframed and remoulded depending on the subject matter under study.

**Researching teacher orientation, beliefs and identity**

A teacher’s pedagogical approach is influenced by what they know about teaching, as well as by their orientation to the subject, their teaching of the subject, and themselves in relation to the subject. John (2005) claims that “Different kinds of personalities may be attracted to different subject matter; a process that may link personal beliefs, values and orientations to shared proclivities” (p. 473). Researching a teacher’s orientation requires being attentive to the “personal” aspects of the teacher, such as teacher beliefs, commitments and identity. Research in these areas is well established in education, although how the subject culture comes to bear on these personal aspects of the teacher is less researched. Below I discuss the literature relating to teacher orientation, beliefs, and identity relevant for framing my research.

Askew (1999) states that examining **teacher orientation** towards teaching can help to understand why practices that have surface similarities may result in different learner outcomes. Also, the nature of interaction can vary according to the teacher’s orientation. “The orientations provide insight into the mathematical and pedagogical purposes behind particular classroom practices, and may be more important than the practices themselves in determining effectiveness” (p. 102). Research by Brown, Askew and others (Askew, 1999; Askew, Brown, Rhodes, Johnson, & Wiliam, 1997) explored teachers’ classroom practice in, beliefs about, and knowledge of mathematics, pupils and teaching. A major difference between the teachers was in their “orientation” and associated beliefs. My research encompasses teachers’ observable actions and commentary of their teaching in order to give voice and meaning to teacher intentions and commitments that are informing classroom actions.

As part of his argument for moving teachers toward a more humanistic approach to teaching science, Aikenhead (2006) pointed to some salient influences on the development of teacher orientation, including “a teacher’s values, assumptions, beliefs, ideologies, self-identities, self-images and loyalties to traditional school science” (p. 64). Each of these influences attracts attention in research, either individually, or in tandem with another. Defining and distinguishing each of these terms has been shown to be difficult due to the tendency for researchers to use terms in an undefined way or interchangeably with other terms (Clandinin & Connelly, 1987; Pajares, 1992).

**Teacher beliefs** are complex constructs that have been the focus of research for some time. Jones and Carter (2007) claim that, while teacher beliefs and attitudes are key to understanding and reforming science education, these areas are poorly
understood. No apparent consensus exists about “what constitutes beliefs or whether they include or simply reflect behaviour” (Wilson & Cooney, 2003, p. 144). Part of the issue is that distinguishing beliefs from knowledge is difficult (Pajares, 1992). They are commonly distinguished in the following way: “Belief is based on evaluation and judgement; knowledge is based on objective fact” (Pajares, 1992, p. 313), although Pajares recognises that this is a somewhat artificial distinction. From an epistemological viewpoint, knowledge is seen to be socially constructed, but beliefs are individually constructed (Jones & Carter, 2007).

In an attempt to reconcile these difficulties in distinguishing knowledge from beliefs, there has been a recent turn in the research literature towards “personal epistemologies”, which are one’s beliefs about “knowing and learning that play a mediating role in the processing of new information” (Jones & Carter, 2007, p. 1077). Epistemological beliefs play a role in knowledge interpretation and cognitive monitoring (see Pajares, 1992). According to van Driel, Verloop, and deVos (1998), a personal epistemology is comprised of belief systems that form the perspectives with which one views a particular behaviour. Instructional behaviours in the classroom are influenced by a teacher’s epistemologies, which include beliefs about the content, and the teaching and learning of the content. Pajares also maintains that “beliefs teachers hold influence their perceptions and judgements, which, in turn affect their behaviour in classrooms” (p. 307). Keys and Bryan (2001) state that every aspect of teaching is influenced by the complex web of attitudes and beliefs that teachers hold, including knowledge acquisition and interpretation, defining and selecting instructional tasks, interpreting course content, and choices of assessment.

While it is accepted that beliefs have some bearing on practice, the congruency between practice and beliefs cannot be taken for granted. Tensions can arise for teachers as they grapple with factors that constrain their enactment of their beliefs. Jones and Carter (2007), in their review of research into teacher beliefs and attitudes, emphasise that a teacher’s epistemology affects their response to reformist ideals. For example, they claim that many US science teachers hold epistemological beliefs congruent with a behaviourist tradition, and that shifting from these beliefs can be difficult. They refer to work by Czerniak and Lumpe from 1996 that found that the adoption of constructivist strategies by practising teachers in their classrooms did not necessarily effect change in teachers’ epistemologies. Other research supports this common disjunction between a teacher’s beliefs and their practice (see, for example, Davis, Konopak, & Readence, 1993). Also, Karaa_uc and Threlfall (2004) described an instance where a mathematics teacher’s awareness of the conflict between his beliefs and practice did not prompt change in his practice. They concluded that external goals within the setting of the teacher can overwhelm teacher beliefs. Leatham (2006) takes a different approach to this incongruence. Drawing from Pajare (1992), Leatham asserts that, rather than highlighting inconsistencies,
research into teacher beliefs should employ a framework that acknowledges that teachers’ beliefs consist of inherently sensible systems. The difficulty is not with the mismatched beliefs and practices, but with researchers’ inability to adequately access and interpret these beliefs.

Teaching actions or practices represent only one aspect of an entire belief system (Richardson, 1996). Teachers hold beliefs and attitudes that they are not aware of, but which influence their learning and behaviour with regard to the subject (Jones & Carter, 2007). Studies with a comparative focus (such as Grossman & Stodolsky, 1995; Siskin, 1994) found that beliefs about subjects were part of a subject culture worldview. These beliefs, although often tacit (Polanyi, 1966) in the sense that they are often unstated and unexamined, can nevertheless be examined in light of observations and interview data, which offer a reflective, iterative process that encompasses the belief system as a whole (Richardson, 1996). Research methodologies used in recent research reflect the general shift from a post-positivist to social constructivist influence on educational research (Jones & Carter, 2007). Qualitative methodologies have been shown to be more suited to examining the individuality and complexity of teaching, with more researchers relying on observation and interviews to understand the nature of teachers’ thinking and worldviews.

Research into teacher identity in relation to the subject they teach is growing, but still limited. Much of the research mentioned in Section 2.1.3 explores how a teacher’s identity is often derived from the subject they teach. Subject affiliation is a powerful component of a professional community: teachers are proud of their subject specialism, and they are loyal and committed to it (Little, 1993). Of course, a teacher’s identity is derived from every part of their life as a teacher, and their life outside of teaching. Teachers assume multiple identities due to the many contexts that they find themselves in (Beijaard, Meijer, & Verloop, 2004), such as different subjects, and other roles assumed within the context of school and outside of school. In developing and assuming an identity there is familiarity with, and richness to, one’s historical interaction with that context. Taylor (1995) adds a moral dimension to identity by emphasising that what we value and is important to us is positioned in relation to others.

To have an identity is to know “where you are coming from” when it comes to questions of value or issues of importance. Your identity defines the background against which you know where you stand on such matters. To have that called into question, or to fall into uncertainty, is not to know how to react, and this is to cease to know who you are in this ultimately relevant sense. (Taylor, 1995, p. 58)

Helms (1998) focuses on the relationship between subject matter and teacher identity, but adopts the term “sense of self”. What a person does, their affiliations, what a person believes, values and wants to become influences the teacher’s sense of self. She recognises self is influenced by external factors, and as such, she defines the self as “the experienced self in context” (p. 829). “Professional context, actions, how
others see us, and moral sensibilities each play a role in defining a sense of self” (Helms, 1998, p. 814).

Research into identity has increased since the early 1990s, when Goodson (1993) asserted the importance of understanding the teacher’s sense of self in understanding educational issues: “In understanding something so intensely personal as teaching, it is critical that we know about the person the teacher is. Our paucity of knowledge in this area is a manifest indictment of the range of our sociological imagination” (p. 69, emphasis original). He recommends the use of personal biographies and life histories in “[re-personalising] the process of schooling and the lives of teachers” (p. 21).

Teacher beliefs are central for understanding how teachers have constructed the purposes, processes, traditions and actions associated with teaching the subject. Focusing on teacher identity allows the researcher to consider how teachers see themselves in relation to the subject, and on what basis they make these claims about themselves. The effect of their experiences of the subject cultures, while not a lone contributor to teachers’ constructions of themselves, is of particular important in this research. Researching teacher orientation, beliefs, and identity puts a personal layer to this analysis by taking account of how a teacher’s beliefs about themselves as teacher, consumer and learner of the subject influence their pedagogy. Further, asking teachers to reflect on their practice can explain possible gaps between teachers’ espoused beliefs and what actually occurs in the classroom. This type of reflection provides better opportunities to take into account how social and physical context of the teacher bears on what the teacher does.

**Researching influences on teachers’ pedagogies**

When reflecting on what influences their pedagogies in mathematics and science, teachers are likely to draw from a variety of experiences. Influences may be related to the subject culture, for example the nature of foundational knowledge, or they may be independent of the subject culture, for example the work place or teacher personalities. Experiences may be sourced from the classroom, membership of subject departments, learning teams or other groupings in school, personal experiences with the discipline, and interactions with young people within and outside the school community. These experiences are part of the socialisation of teachers.

Research in the areas of socialisation and teacher’s work has helped to understand what factors come to bear on teachers. Socialisation refers to “coming to participate in a social group…by selectively acquiring that group’s values, attitudes, interests, knowledge and skills” (Tinning, MacDonald, Wright, & Hickey, 2001, p. 53). Tinning et al. describe different types of socialisation that teachers go through in the process of learning how to become a physical education teacher:
• occupational socialisation (relates to those values, beliefs, skills and expectations that individuals bring with them to the group);
• professional socialisation (relates to the process of acquiring and maintaining values, beliefs, skills and knowledge that are considered necessary for teaching); and
• organisational socialisation (relates to learning how to participate as an employee within particular organisational structures).

Siskin (1994) explains that the workplace of teaching can be understood to be open, embedded and socially constructed. An open workplace refers to the variety of influences that contribute to teachers’ and students’ expectations of what is tolerated and desirable, and these influences are considered to emanate from internal and external sources. The workplace is considered to be embedded within the context of the external influences, for example, external testing. Although such influences are external, teachers participating in networks are able to bring in new ideas or send ideas outwards to policy makers. Within a socially constructed workplace, teaching is seen to be influenced by external, explicit strategies such as policies and testing, as well as “more complex and subtle influences – the implicit ones of shared cultural understandings” (Siskin, 1994, p. 39).

These explicit and implicit influences are of interest in my research, particularly those “cultural understandings” surrounding the norms, rules and attitudes associated with the teaching of mathematics and science. To understand workplaces as socially constructed focuses attention on the active side of construction where teachers are not conceived of as passive workers stripped of power to make decisions about their practice. Rather, a view of a socially constructed workplace enables the explicit and implicit influences to be seen not as determining factors but as “a set of constraining and enabling conditions within which individuals actively and collectively shape meaning, and the practice, of teaching” (Siskin, 1994, p. 39). This explains how teachers operating in schools fraught with constraining conditions are still able to build and maintain effective practice.

Culture itself is socially embedded and socially constructed, therefore, descriptions of a teacher’s practice are enlightened by drawing on his or her ideas, beliefs and values about the subject areas within which they operate. A teacher’s practice is also probably dependent on the experiences that the teacher has had with the subject or discipline. These experiences are not necessarily related to exposure at university level. For example, Askew’s research into teacher orientation of effective primary mathematics teachers showed that being a highly effective teacher and displaying the knowledge, understanding and awareness of the connections between mathematical concepts that they taught was not necessarily associated with teachers’ qualifications in mathematics (Askew, 1999; Askew et al., 1997). Other factors, such as beliefs and understandings underpinning teaching (Askew, 1999) and career
trajectory (Siskin, 1994), have been found to be important in determining how teachers approach teaching and learning. There is a sense that teachers are inducted into the culture of the subject through their experiences. For example, research on the effectiveness of science and mathematics based professional development for primary teachers by Tytler et al. (1999) reported that the purpose of professional development for teachers relatively inexperienced in a content area is “to induct them into the culture surrounding the content, or into new ways of looking at it” (p. 210). For science, this meant productive activities as opposed to “disembodied content knowledge” so that mastery of content could be achieved through the introductory activities that represented the content knowledge.

These research outcomes highlight the importance of paying attention to teachers’ experiences of the subject they are teaching. Consequently, my research provides opportunities for teachers to reflect on their experiences when attempting to make sense of how the culture of the subject influences why they teach the way they do.

Interaction between these influences has the potential to shape teachers’ behaviour, and I contend, shapes their response to different traditions, either within a subject, or as they teach across subjects. What is in question is the extent to which the teacher’s background shapes the pedagogical decisions they make in subjects to which they are committed compared to others to which they are less committed.

Gibson’s (1977) Affordance Theory considers how factors in our environment influence us, and act as constraining and enabling conditions. Those conditions that enable a particular action, attitude or practice are called affordances, while those that are inhibiting or constraining are called constraints. Affordances are being more frequently described in research, especially in areas of design (Dickey, 2003) and educational research. Watson (2003) applies Affordance Theory to understand how learning takes place through perception of, and in interaction with, a mathematical activity environment. Affordances are considered by Watson to be a perceived potential for action; constraints are factors limiting possible interactions with the environment.

In my research, Affordance Theory provides a useful perspective for understanding how teachers talk about the factors that come to bear on their practice. How might the nature of the subject afford or constrain particular practices? How does the culture of the mathematics or science departments at their school, the timetabling, the room allocation, availability of equipment, and teachers’ beliefs about the role of student and teacher in learning afford or constrain a practice that the teacher claims to represent the way they would like to, or should, teach? How do the effects of these things come to bear on teachers in mathematics as compared with science? Researching these questions provides insight into which conditions are considered to be specific to, and a product of, the subject culture, and which are more generic and a product of “school”, “education”, “teaching” and “learning”. Exploring
these conditions will require both the teacher and the researcher to draw on valuable and rich experiences of the classroom.

2.3. **Examining the relationship between subject culture and pedagogy: Consolidating the research questions**

I am approaching the relationship between subject culture and pedagogy from the individual teacher’s perspective, recognising that, although there may be a (or a number of) subject culture(s) that these teachers are operating within and contributing to, teachers respond to this in their own way dependent on their personal beliefs, experiences, knowledge. Borrowing from cultural theory relating to cultural organization and leadership, I am framing subject culture as those patterns of “shared basic assumptions that the group learned as it solved its problems of external adaptation and internal integration” (Schein, 1992, p. 12). Basic assumptions are derived from the previous experiences of the individual, and consist of perceptions of the nature of people and objects in the work environment. They are tacit and typically escape the conscious awareness of the individual. These assumptions work well enough to be considered valid and are taught to new members during enculturation. In the teaching context, enculturation involves a lifetime of experiences of learning, practising and teaching the subject. If the “group” here refers to all science teachers across all schools, then subject culture refers to those shared basic assumptions that govern the dominance of certain “subject paradigms” (what should be taught) and “subject pedagogies” (how this should be taught) (Ball & Lacey, 1980). These basic assumptions act as signposts and guidelines for teaching and learning the subject.

Paechter (1991) prefers to use the term “subject subculture” to recognise that every school is likely to have their own consensual view about the nature of the subject, the way it should be taught, the role of the teacher, and what might be expected of students. Schwab (1969) refers to this consensus as unity, which he sees as important in providing opportunities for group action (see also Ball & Lacey, 1980). Schwab also expresses the importance of diversity of practice and beliefs amongst teachers. This view acknowledges that teachers will bring with them their own interpretation of teaching the subject. Similarly, Goodson (1985) argues that teachers have a personalised concept of a subject and what constitutes the practice of teaching.

The subject matter acts as a context for teachers’ activity. Lave’s (1988) distinction between “arena” and “setting” is useful in understanding the relationship between the context as it stands apart from the person, and an individual’s interpretation of that context. The “arena” refers to the larger institution that has features that can constrain or afford certain activities; the “setting” is the individually constructed and represented version of the arena (John, 2005). Through interaction,
“a setting is conceived … as a relation between acting persons and the arenas in relation with which they act” (Lave, 1988, p. 150). John claims that “the construct of setting can … help us understand why individuals can experience the same arena differently and why subject culture is still open to individualised interpretation” (p. 472).

Various conceptions of how the individual teacher is situated in the context of subject culture emerge from this literature, including how the individual teacher sits in relation to the subject department, the subject more widely, the discipline, and their own personal experiences. Each of these relationships is represented in the Research Question:

*What is the relationship between teachers’ pedagogies and their experiences of mathematics and science subject cultures?*

The Research Question focuses on teachers, their pedagogy and the influence of their experiences of the subject cultures of mathematics and science on their pedagogy. The literature review in this chapter identifies various elements and assumptions that underpin my approach. These ideas and assumptions can be consolidated in the following way.

Teachers and their practice are considered to be socially, culturally and historically embedded in such a way that their knowledge and beliefs interact with their social environment. The assumption underpinning this research is that there is a relationship between teachers’ knowledge and beliefs and their intentions and aims for classroom practice. In this research, teachers reflected on their teaching practice to clarify what they know and believe about teaching mathematics and science.

Pedagogy is in essence the study and practice of distinguishing what is appropriate and not appropriate to support learning. The assumption is that there is a relationship between cognition and action such that teacher’s knowledge and beliefs are enacted through classroom practice. These knowledges and beliefs represent a teacher’s perspectival framework. They are influenced by many factors, some of which will be generic and evident in both mathematics and science, others which will be specific to the subject culture. Investigation of pedagogy, therefore, requires looking at both what happens in the classroom and drawing from what teachers know and believe about what is appropriate, and not appropriate, for their students in learning mathematics and science. Pedagogy, then, becomes a particularly useful lens when taken in a broader sense and not simply in the sense of describing and interpreting practice. The construct of “teacher orientation” is attentive to the relationship between teacher knowledge, beliefs, values and identity. There are, of course, other contextual factors that influence the way the teacher teaches.

Subject culture is socially embedded and socially constructed. The subject culture is part of the social environment of teachers, and is evident in the norms,
practices and attitudes that teachers associate with the subject. The subject culture includes the nature of the school subject, the nature of the knowledge underpinning the subject and the nature of the teaching practices. Teachers experience and contribute to the subject culture. Some elements of the subject culture are endemic, being underpinned by defined and organised academic knowledge, while other elements may be more a matter of habit or tradition, or may flow from the perceived purposes of the subject in school. The subject culture comes to bear on practice via sets of assumptions that may or may not be explicitly understood. The influence of subject culture on pedagogy can be explored by drawing on the experiences of the classroom and allowing teachers to reflect on what affords and constrains teaching in these subjects.

Three subquestions help to explore the different elements of the research question:

Subquestion 1. What pedagogies are characteristic of the subject cultures of mathematics and science?
Subquestion 2. What experiences of the subject cultures of mathematics and science become evident through teachers’ reflections on their practice?
Subquestion 3. How do teachers’ experiences of the subject cultures shape their pedagogy?

These subquestions provide for various elements of the teacher’s pedagogies in mathematics and science to be examined both at the classroom level and from the broader view of teachers’ underlying assumptions and beliefs about teaching and learning. Each research question is explained below to introduce the focus of the question and how the question will be approached.

Subquestion 1. What pedagogies are characteristic of the subject cultures of mathematics and science?
This subquestion is concerned with describing what happens in the classroom in light of what teachers know and believe about what is appropriate, and not appropriate, for their students in learning mathematics and science. In doing this, I take account of teaching strategies employed by teachers, how and why they interact with students, and how they represent and use the content and artefacts of the subject (such as, equipment and textbooks). In looking for what are common pedagogies, I can get a sense of the “subject pedagogies” that may characterise the way these teachers make pedagogical decisions in mathematics as compared with science. I approach this subquestion by isolating certain aspects of teaching and learning that highlight differences and similarities between the subjects.
Subquestion 2. What experiences of the subject cultures of mathematics and science become evident through teachers’ reflections on their practice?
This question explores the various influences that teachers recognise as impacting on how they perceive the subject, what is appropriate for teaching and learning, what actually happens in the classroom, and how they see themselves in relation to the subject. I approach this subquestion through my continual reference to teachers’ critical commentary on their practice where they explored such things as the affordances and constraints of the school and subject departments, the content matter, expectations within the subject culture, and their personal styles and experiences at teachers, learners, doers and users of the mathematics and science.

Subquestion 3. How do teachers’ experiences of the subject cultures shape their pedagogy?
This subquestion looks for relationships between the ideas emerging in response to the first and second subquestions, and thus examines the various ways that subject culture can inform teachers’ conceptualisation of what is required to teach the subject and, therefore, their pedagogy. In considering teachers’ experiences of the subject culture, this subquestion problematises the idea that there is a subject culture. Informed by Lave’s distinction between setting and arena, I examine how teachers individually construct the subject cultures of mathematics and science. Through this question I focus on how a teacher’s construction of the subject culture, together with their commitments, assumptions, beliefs and identity, comes to bear on a teacher’s pedagogy.

2.4. Summary
This chapter has explored the two central aspects of this research: the culture of the subject, and teacher pedagogy. The concepts arising from a survey of the literature were then consolidated into a theoretical framework that guided my investigation of the research question. Three subquestions encapsulate the various dimensions of the main research question. In the following chapter, I describe my methodological approach when responding to these questions.
Chapter 3. Methodology

In this chapter I outline a rationale for using a constructivist research approach. I argue that this methodology promotes reflective discussion between the researcher and participant. I begin by describing the nature of the qualitative paradigm as it is applied to my research. I then describe constructivism as a paradigm for social research, and two research approaches that are consistent with this paradigm. I argue that Guba and Lincoln’s (1998) “constructivist paradigm” is most relevant to my research, and explore its metaphysical beliefs and the roles assumed by the researcher and participants in such inquiry.

3.1. Qualitative research

Early in the research I reflected on my beliefs about how, as a researcher, I come to know (ontological question), the nature of what is possible for me to come to know (epistemological question), and the process by which I come to know (methodological question). Inherent in these questions is the nature of the interaction of the researcher with the participants in this process of a researcher coming to know, and claiming to know through evidence, analysis and interpretation. Past experience in qualitative research led me to a methodology consistent with the belief that we construct meaning through interaction with our social setting; meaning arises out of a co-construction between the participants and myself as researcher.

Such an emphasis is consistent with “qualitative research”, an umbrella term used by Merriam (1998) to refer to orientations to inquiry focussing on understanding and explaining the meaning of social phenomena. Qualitative inquiry evolved out of recognition that the complexity of social settings can be only partially understood through the positivistic process of scientific experimentation that simply tests existing theory.

A positivist paradigm demands an adherence to procedures that are reproducible, based on refutable knowledge claims, and controlled for researcher errors or bias. Cohen, Manion, and Morrison (2000) describe positivism as being “characterised by its claim that science provides us with the clearest possible ideal of knowledge” (p. 9). It is objective and quantifiable. Reality is considered to be stable, observable and measurable (Merriam, 1998). Used within the social sciences, the methodological procedures used to investigate social phenomena mirror those used in the natural sciences, and the end-product is expressed as laws or law-like generalisations akin to those established for the description of natural phenomena (Cohen et al., 2000).
In contrast, Bogdan and Bilken’s (1992) scope of research includes a qualitative research mode emphasising “description, induction, grounded theory, and the study of people’s understanding” (p. ix). They broaden the scope of what qualifies as research to reflect a paradigmatic shift from positivism towards qualitative research, also referred to as post-positivism, or anti-positivism. The nature of such inquiry is naturalistic (Cohen et al., 2000) because there is a rejection of the positivist view of an objective observer of phenomena on the basis that the behaviour of individuals “can only be understood by the researcher sharing their frame of reference: understanding the world around them has to come from the inside, not the outside” (p. 19).

A philosophical assumption underlying naturalistic inquiry is that “reality is constructed by individuals interacting with their social worlds” (Merriam, 1998, p. 6). It is these constructions of reality, or meaning perspectives of individuals, that my research is interested in accessing and understanding. I am interested in exploring the complex ways that teachers construct for themselves their ideas about teaching and learning, and the factors involved in the way that these constructions may appear to be manifested within classroom settings. The qualitative paradigm qualifies this subjective knowledge of teachers, the emic\(^2\) or insiders’ perspective, as worthy of investigation, useful and informing of educative practice, and provides a vehicle for understanding the complexity of the social setting within which these teachers are situated. Furthermore, qualitative research has the potential to provide rich and meaningful information to the body of educational research as it characteristically builds abstractions, concepts, hypotheses or theories through an inductive process rather than simply testing existing theory (Merriam, 1998).

3.2. Constructivism as a methodological framework

The emergence of an alternative research approach to the positivist paradigm has resulted in many different ways of talking about research, such as by describing alternative “traditions” (Merriam, 1998) or “paradigms” (see Guba & Lincoln, 1998). Paradigmatic structures offer different ways of positioning the ontology, epistemology and methodology of research, referred to by Guba and Lincoln (1998) as the metaphysical or basic beliefs or postures that declare the theoretical assumptions underpinning a piece of research. My research is most suitably called constructivist as my intention is to understand and reconstruct the constructions held by both the participants and myself as researcher. Constructivist inquiry, Guba and Lincoln claim, “denotes an alternative paradigm whose breakaway assumption is to move from ontological realism to ontological relativism” (1998, p. 203).

\(^2\) as distinct from and preferred over the etic or outsiders’ perspective.
3.2.1. A constructivist paradigm

Constructivism as a paradigm for social research is oriented towards producing reconstructed understandings. Schwandt (2000) asserts that the world of experience as lived, felt and undergone by social actors is of interest to inquirers operating within the constructivist family of persuasions. Constructivists accept the premise that knowledge and truth is constructed, not discovered by the mind; and that reality is both expressed in a variety of symbols and language systems, and “stretched and shaped to fit purposeful acts of intentional human agents” (Schwandt, 2000, p. 236). Schwandt situates a number of research approaches within the constructivist paradigm. Two of these are: “social constructivist”, also called “social constructionism” (Gergen, 1985); and the “constructivist paradigm” from Guba and Lincoln’s fourth generation research (see, for example, Guba & Lincoln, 1981; Guba & Lincoln, 1998), previously called naturalistic inquiry.

In brief, research consistent with Guba and Lincoln’s (1998) constructivist paradigm focuses on what is real as constructions of the mind of individuals. Researchers acknowledge that there are multiple, often conflicting, constructions, and that all are potentially meaningful. The nature of knowledge generated by research is as individual reconstructions coalescing around some consensus (Denzin & Lincoln, 1994a).

In social constructivist research, the emphasis is on collective generation of meaning shaped by conventions of language and other social processes (Schwandt, 2000). Meaning is constructed by an individual within the sociocultural context, and reality and the individual knower are considered to be socially constructed (Bredo, 2000). This approach to inquiry moves away from constructivism within the mind, to the world of intersubjectively shared, social construction of meaning and knowledge. Both approaches acknowledge that the “mind is active in the construction of knowledge, but social constructionist epistemologies forefront the historical and sociocultural dimension to this construction (Denzin, 1989). Construction, therefore, occurs “against the backdrop of shared understandings, practices, language and so forth” (Denzin, 1989, p. 197). The world is understood as social artefacts, as “products of historically situated interchanges among people” (Gergen, 1985, p. 267).

There is some overlap between the two approaches, indeed, Crotty (1998) claims that the two are often used interchangeably; however, social construction tends to be attractive to research with a more critical agenda, such as providing commentaries and critique on social issues like gender, racial inequality, and power relations. Such research considers knowledge to be ideological, political and permeated with values (Denzin, 1989).

My research focuses on how the mathematics and science teachers are constructing for themselves pedagogy while operating within, and in response to, the social setting of mathematics and/or science teaching, making the constructivist
paradigm suitable. A social constructionist approach would be only minimally suited to the research because of my emphasis on the individual teacher’s construction within this setting. Although I focus more closely on the individual teacher’s constructions, I used my interactions with these teachers, their setting, and the literature to assist me in constructing a broader picture of the teachers’ social setting. The teacher’s context—that is, the subject, school and subject department—are the social setting for the research. The research questions require a methodology that allows the various lifeworlds of the teacher to emerge by providing teachers with opportunities to reflect on their pedagogy. My interest in the relationship between the individual and their setting is, therefore, consistent with Guba and Lincoln’s “constructivist paradigm”.

The following sections describe the metaphysical beliefs underpinning the research as situated within a constructivist paradigm.

3.2.2. Metaphysical beliefs of a constructivist paradigm

Guba and Lincoln (1998) describe a constructivist paradigm as having a relativist ontology, a transactional epistemology, and a hermeneutic, dialectical methodology.

Relativist ontology claims that

realities are apprehensible in the form of multiple, intangible mental constructions, socially and experientially based, local and specific in nature (although elements are often shared among many individuals and even across cultures), and dependent for their form and content on the individual person or groups holding the construction. (Guba & Lincoln, 1998, p. 206)

Constructions are considered to be “more or less informed and/or sophisticated” (p. 206), rather than absolutely “true”. Constructions and the realities associated with them are subject to change as the constructions become more informed and sophisticated. This results in the potential for multiple and sometimes conflicting social realities of the human intellect.

Arising from this relativist position, epistemologically, constructivist inquiry is transactional and subjective. Guba and Lincoln (1998) claim that the distinction between ontology and epistemology is challenged because what can be known is assumed to be “inextricably linked” to the researcher. The “findings” or reconstructions are literally created during the investigative process.

A methodology operating under this paradigm must acknowledge the variable and personal nature of social constructions, and as such, eliciting and refining an individual’s constructions must involve interaction through a dialectical interchange “between and among” the researcher and respondents (Guba & Lincoln, 1998). “A hermeneutic methodology,” they argue, “involves a continuing dialectic of iteration, analysis, critique, reiteration, reanalysis, and so on, leaning to the emergence of a joint (among all the inquirers and respondents, or among etic and emic views) construction of a case” (p. 84). I refer to this dialectical interchange as a co-construction (see Section 4.3) between myself and the participants, where, in
accordance with Guba and Lincoln’s dialectical interchange, the aim is to distil a “consensus construction” by comparing and contrasting previously held constructions using hermeneutic techniques. These reconstructions are more informed and sophisticated than the constructions of both the participants and the investigator.

Constructivist research is characterised by and cognisant of a number of “entry conditions” (Guba & Lincoln, 1989): natural setting, researcher as instrument, tacit knowledge, and qualitative methods. In the context of my research, these conditions were met in the following ways.

Firstly, the research was pursued in a natural setting where the constructors remain in the time and context within which the multiple realities of the teachers are constructed.

Secondly, the research relied on the researcher as instrument (Denscombe, 1998; Denzin & Lincoln, 2000a; Woods, 1992), an instrument highly adaptable that “can enter a context without prior programming, but that can, after a short period, begin to discern what is salient (in the emic views of the respondents) and then focus on that” (Guba & Lincoln, 1981, p. 175, emphasis in the original). I cannot claim to know the constructions of the participating teachers before entering the field; I also do not assume to know nothing.

Thirdly, I used qualitative methods as these are most suitable in understanding the intentions and reasons underpinning pedagogical actions. Qualitative methods, Guba and Lincoln (1989) state, are most readily available and understandable by the human instrument, although they do not discount quantitative tools such as questionnaires and surveys so long as the questions emerge through prior interaction with the participants in the research. They suggest “talking to people, observing their activities, reading their documents, assessing the unobtrusive signs they leave behind, responding to their non-verbal cues” (Guba & Lincoln, 1989, p. 176).

Fourthly, I relied on my own tacit knowledge, described by Guba and Lincoln (1989) as “all that we know minus all we can say” (p. 176). All that we know refers to the propositional knowledge that is easily accessible, and which the constructivist researcher moves into the research with no set formulations. A tacit understanding of the situation allows the researcher to enter the inquiry with an intuitive sense of how to access “the emic material that remains opaque to the investigator’s propositional formulations” (p. 176). For this reason, I adopted an emergent research design, where the data events planned for data generation remained only partly conceptualised.

My interaction with the participants was informed by the hermeneutic dialectic process, what I call co-construction. Guba and Lincoln (1998) describe a process where inferences and lines of inquiry are cycled and recycled until a consensus (or non-consensus) is reached between the researcher and the participant. Change is facilitated for both the participants and researcher as reconstructions are
formed and individuals are stimulated to act on them. This was important since this research was set within the context of a teacher change program. It was conceivable that teachers’ knowledge and beliefs about teaching and learning would be tacit and at first difficult for them to express. Through a dialectical interchange using hermeneutic methods, I hoped that these constructions would become accessible to teachers for active reflection. These methods are discussed in Chapter 4.

3.2.3. Role of the researcher and participants
In qualitative research, the researcher is considered to be the primary instrument, also referred to as “researcher as instrument”, for data generation and analysis. Insights generated by the research are mediated through the researcher, rather than through inanimate tools such as questionnaires or computer generated analytical systems. Merriam (1998, p. 7) describes the human researcher as being:

- responsive to the context; he or she can adapt techniques to the circumstances; the total context can be considered; what is known about the situation can be expanded through sensitivity to nonverbal aspects; the researcher can process data immediately, can clarify and summarize as the study evolves, and can explore anomalous responses.

Within a co-constructive dialogue, the role of the researcher and the researched become intermeshed as the researcher becomes more of a co-participant and facilitator in the construction process.

Given this, I question the efficacy of asking teachers about their beliefs for the purpose of comparing their stated orientation with “the reality” of their teaching practice as manifested through video recorded footage or observations of pedagogical actions in the classroom. More useful and rich information can be gained by providing teachers with an opportunity to identify for themselves any discrepancies or contradictions, which increases the likelihood of participants and researcher gleaning something of educative value from the research process.

Educational research can be delineated from other research by the educative purpose driving the inquiry. Such inquiry focuses on what educators need to know – the practice of education – and is couched in the language and understandings accessible for these educators (Pring, 2000). Therefore, further to being recognisable to teachers as educational, greater purpose and value is given to research where teachers have played an active role in generating both the data and its interpretation.

3.3. Summary
My research focuses on how the mathematics and science teachers are constructing their pedagogy while operating within and in response to their social setting, making a constructivist paradigm a suitable methodological approach. In the following chapter I describe the qualitative methods I used to co-construct teachers’ experiences of their cultural setting and their practice.
Chapter 4. Research Processes

A constructivist methodology demands a research design that is iterative, emergent and promotes dialogue between the researcher and the participants. In this chapter I outline the framework I used to generate such dialogue. I provide justification for the multiple methods I used. I then describe the research program. The analysis was an embedded part of the research design, occurring continually through the research. My disentangling of this analysis demonstrates how the analysis informed each of the sequences of data generation. I then discuss the criteria I used to judge the quality of the research, and the ethical considerations.

4.1. Focus of data generation

Teachers’ personal responses to teaching mathematics and science was central to understanding the link between their practices and their commentaries, therefore, an examination of the classroom is more meaningful in light of their beliefs and subject commitments. Data generation focused on the teaching strategies employed in the classroom, and teachers’ commentary on what influenced their practices. I looked particularly for evidence of teachers’ experiences of the traditions, expectations and assumptions associated with teaching the subject.

Given the complexity of classroom interactions, a number of aspects of teachers’ practice could be considered. Baxter and Lederman’s (1999) three-part framework for examining Pedagogical Content Knowledge (PCK) provides a suitable lens for examining teachers and their practice. According to this framework, PCK is constituted by:

- teachers’ actions (“what a teacher does”);
- teachers’ knowledge of what and how to teach (“what a teacher knows”); and
- beliefs and intentions of teachers’ pedagogical actions (“reasons for the teacher’s actions”) (p. 158).

Teacher knowledge of subject matter, teaching approaches, the traditions of the subject, and general pedagogy are important factors in how a teacher sees themselves as subject teachers. Rather than evaluate “what a teacher knows” specifically, I examined teachers’ perceptions of their knowledge as part of discussions about their teaching. “What a teacher knows” refers to the knowledge that teachers have about teaching strategies, the ways in which children learn, management of the classroom learning environment, the content of the subject, and the nature of knowledge underpinning the subject.

In my research, “What a teacher does” refers to the actions of the teacher in the classroom, their pedagogical acts, and their planning for learning. Included in the
analysis were the visual and verbal operations of the teacher in the classroom, such as the strategies used to teach a concept, the way the teacher relates with students, the way the teacher organises the classroom and learning, and the use and purpose of assessment. Also encompassed was the planning process undertaken by the teacher before, during and following the lesson. Additionally, I focused on the way a teacher responded to cues within the classroom environment emanating from students, the resources used for instruction, and other semiotic messages in their surroundings.

“Reasons for the teacher’s actions” relates to the beliefs and attitudes towards children, student learning, the subject and teaching. This element underpins reasons why teachers operate in the ways that they do. Such reasons may be associated with:

- teachers’ commitment to the subject as manifested by their enthusiasm, participation in and response to professional development in the subject area, amount of time and effort invested in planning, and their preference for teaching that subject;
- level of confidence that a teacher has in teaching the subject, possibly a function of their content knowledge and PCK;
- teachers’ socialisation into the subject area, including their own experiences as a learner, their personal experiences with the discipline in informal settings, their university experiences, and their experience of teaching the subject;
- context-related factors such as year level, the particular class group, time of day, classroom surroundings, school support for the subject area and teacher training;
- teachers’ perceived purposes for the subject;
- teachers’ perceptions of their role in student learning of the subject and in general (philosophy of teaching), captured by the teacher’s orientation towards teaching, including teaching approaches;
- teachers’ intentions for their actions;
- teachers’ beliefs underpinning the way they relate with children and how the classroom environment is constructed; and
- teachers’ expectations of students in the learning process.

I employed research methods that provided opportunities for teachers to reflect on their practice, while giving me valuable exposure to these constituents of PCK. As the research developed, this dual focus of teacher practice and teachers’ explanations of practice opened up a number of rich lines of inquiry.

4.2. The selection of participants

My research involved mathematics and science teachers from schools participating in the IMYMS project. The IMYMS project drew data from four “Clusters”, or groupings, of state schools in Victoria involved in the *Schools for Innovation and*
Excellence in the Middle Years program. Each cluster comprised one or two secondary schools and between five and nine primary schools, all of which participated in the IMYMS project. The project was aimed at middle years mathematics and science teachers, but also had the involvement of principals, heads of department and other key leaders in the school. School co-ordinators and cluster co-ordinators oversaw certain aspects of the research, such as the interviews associated with component mapping (likened to the convergent, self-reporting scales reviewed in Baxter and Lederman, 1999) and distribution of student surveys and tests.

Two of the four clusters were invited to participate in my research (which became known as the “Video Study”). My choice was largely pragmatic—proximity to the researcher to enable more efficient data generation. Schools and their teachers then made the final commitment to being video recorded.

Initially, my research was designed to draw from teachers in both primary and secondary schools with a view to exploring differences in teaching across the entire middle years of schooling. I decided to limit my attention to the secondary setting after the second data sequence (see Section 4.4.2) in order to limit the research to settings that are constructed around subject-specification.

Consequently, data from seven teachers from two schools, School A and School B, are included in this thesis. These teachers were selected on the basis that they had a teaching allotment that included mathematics and/or science subjects. For each teacher, the data generation focused on:

- two mathematics classes;
- two science classes; or
- a mathematics and a science class.

Table 4.1 shows the breakdown of classes. The nature and extent of these teachers’ involvement is described further in Chapter 5.

Table 4.1
Teachers and Their Classes Represented in the Research

<table>
<thead>
<tr>
<th>SCHOOL A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rose</strong></td>
<td>2 x Mathematics classes</td>
</tr>
<tr>
<td><strong>Donna</strong></td>
<td>2 x Science classes</td>
</tr>
<tr>
<td><strong>Simon</strong></td>
<td>1 x Science class</td>
</tr>
<tr>
<td></td>
<td>1 x Mathematics class</td>
</tr>
<tr>
<td><strong>Pauline</strong></td>
<td>1 x Science class</td>
</tr>
<tr>
<td></td>
<td>1 x Mathematics class</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SCHOOL B</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>James</strong></td>
<td>2 x Science classes</td>
</tr>
<tr>
<td><strong>Ian</strong></td>
<td>1 x Science class</td>
</tr>
<tr>
<td></td>
<td>1 x Mathematics class</td>
</tr>
</tbody>
</table>
4.3. Research methods

There is scope within a constructivist paradigm to employ multiple methods in order to explore relationships between subject culture and pedagogy. Genuine opportunities were needed for both the teachers and myself to participate in de-constructing and re-constructing pedagogy. Figure 4.1 shows how different methods provided more or fewer opportunities for co-construction. The various methods are situated within regions showing who is doing the constructing, the teacher or the researcher. The shaded area indicates the space where there is likely to be co-construction between the teacher and researcher. The Focus Group Discussion and Reflective Interviews were designed to allow for an authentic sharing of ideas, so are located in the shaded region, indicating opportunities for co-construction. Data generated through classroom observation and video recording were directed more by the researcher. The Informal Discussions were directed by the researcher, but were not necessarily designed to feed emergent lines of inquiry back into the conversation. They did, however, play an important role in contributing to my construction of the teacher. Teachers reflected on their practice both privately and through interviews via a Modified Video-stimulated Recall process. The mere involvement by these teachers in this project may have prompted them to reflect on their constructions of pedagogy, or to be more aware of their classroom actions, especially when I was present in the classroom. Likewise, my viewing of the videos added to my construction of elements of the classroom and teaching.

![Diagram](image)

*Figure 4.1 Research methods contributing to the co-construction process.*
I consider myself a researcher-as-bricoleur (Denzin, 1998) who constructs a research design, the *bricolage*, by using and modifying whatever methods are available. In my research, use of these methods was pragmatic (relating to time constraints and availability of teachers and the researcher), opportunistic (depending on when potential events occurred) and emergent (being directed by the needs of the developing analysis). Continual analysis was an important driver in determining how the methods were used. In the following section I discuss practicalities and theoretical justification for each of the research methods.

### 4.3.1. Classroom observation

Classroom observation formed the basis for accessing teachers’ practice. Observation provides the researcher with the means for directly experiencing the classroom and school setting. Observation techniques can be considered participatory or non-participatory, although a sliding scale is often used to represent varying degrees of each. Participant observation research involves the researcher acting in two roles:

First of all, of course, he is an observer; as such, he is responsible to persons outside the milieu being observed. But he is also a genuine participant; that is, he is a member of the group, and he has a stake in the group’s activity and the outcomes of the activity. (Guba & Lincoln, 1981, pp. 189-190).

For example, in an earlier ethnographic study reported in Darby (2005b) my classroom observations were participatory because I adopted assistant and teacher roles at various times during the year.

In comparison, non-participant observation means that the researcher remains detached and aloof from the setting, and does not participate in the social setting in any way.

In this research I employed observation closer to the participatory end of the scale. I do not regard myself as a participant of the classroom as such, but as a participant in the reflective process that teachers were undergoing through their involvement in both the IMYMS project and my research. My direct experiences of the classroom gave me insights into the teacher’s practice that I would not have gained through interview data alone. McCall and Simmons (1969, cited in Guba & Lincoln, 1981, p. 195) broaden the typification of participant observation to include participation

in the sense that [the fieldworker] has durable social relations in the setting. He may or may not play an active part in events, or he may interview participants in events which may be considered part of the process of observation.

Guba and Lincoln (1981, p. 193) identify other methodological arguments for employing observation techniques:

- Observation maximises the inquirer’s ability to grasp motives, beliefs, concerns, interests, unconscious behaviours, customs;
- Observation allows the inquirer to see the world as the subject sees it, to live in their time frames, to capture the phenomenon in and on its
own terms, and to grasp the culture in its own natural, ongoing environment;

• Observation provides the inquirer with access to the emotional reactions of the group introspectively by permitting the observer to use themselves as a data source; and

• Observation allows the observer to build on tacit knowledge, both his own and that of members of the group.

Observation also enhances the ability of the observer to understand complex situations, and classroom environments and pedagogies are certainly complex in nature. Some of the knowledge and beliefs underlying teachers’ pedagogies are likely to be tacit and situational, and some behaviours are taken for granted, so these may escape recognition or be too difficult to describe through words (Guba & Lincoln, 1981). Patterns of behaviour or critical incidents may be recognised by the researcher and later incorporated into the co-constructive dialogue.

Critics of observation refer to the potential for reactivity of the participants or the setting. Adler and Adler (1994) refer to these as observer effects; however, Guba and Lincoln (1981, p. 194) claim that the presence of an observer rarely produces “massive imbalances” within the setting. Another criticism is that observation leans heavily on interpretation. Guba and Lincoln question why this is an issue, when the researcher’s experiences can provide rich insight. They do suggest, however, using a variety of methods to check that the researcher’s involvement as observer is not distorting experiences and causing bias.

Adler and Adler (1994) outline other problems associated with observation, such as questions of reliability and validity, observer and setting bias, and the absence of member checking. Ethnographic researchers such as Carspecken (1996) and Goetz and LeCompte (1984) stress the importance of a number of processes that can ensure the reliability of the interpretations of the researcher, such as seeking ways to incorporate member checking, for example returning observation or interview transcripts to the participant; and triangulation of observational data with other forms of data. In my research, the inherent nature of the co-constructive dialogue ensured that lines of inquiry, researcher insights, and interpretations, were placed into that dialogic space for clarification, re-orientation and contextualisation.

Carspecken (1996) and Goetz and LeCompte (1984) informed the general procedure and technique for making observations. Based on my earlier ethnographic research (Darby, 2002, 2005b) I followed an Observation Protocol when conducting and recording my observations (see Appendix 1). Observation notes were generated for all observed lessons, including the video recorded lessons. I usually sat at the side of the class or at the back because I found that students felt too self-conscious if I sat amongst them.
4.3.2. Video footage

Video recording in classrooms has its own set of attractions and problems. Video was selected for this research because it allows a permanent record of classroom events in greater detail than can be made through observation notes and captures both visual and verbal accounts, unlike audio-taping. Video footage acted as an analytical tool for the teacher, and a hermeneutic tool for the dialectic process. Video recording is both efficient and capable of providing a rich data source from which a variety of data can be extracted, including dialogue, behaviour, clues towards attitudes, time frame, and mapping of movement and interaction. Video is becoming increasingly accessible and useful to research. The *Trends in International Mathematics and Science Survey* (TIMSS) employed video to investigate and describe teaching practices in mathematics and science in the eighth grade of schooling across initially three countries, and later 13 countries worldwide (see Stigler, Gonzales, Kawanaka, Knoll, & Serrano, 1999). In the study, pedagogy is equated to teaching methods. The video footage was used to describe patterns of teaching practice in these countries. Exemplars of classroom practice are presented as short video snippets (Hollingsworth, Lokan, & McCrae, 2003).

Although, the TIMSS study was fruitful in capturing practice across many countries, the study limited the scope of the analysis by focusing primarily on classifying and describing teaching practice in mathematics and science. Attempts were made through questionnaires to understand teachers’ intentions for the lessons, but it was beyond the scope of the study to generate substantive discussion of the underlying values, knowledge and beliefs underpinning teachers’ classroom practice. A smaller study, such as my research, has the potential to use video footage in ways that generate insight into what motivates the teaching act.

The video footage of the public release lessons (Hollingsworth *et al.*, 2003) from the TIMSS study modelled how placement of still and roving cameras can be used to capture the actions of the teacher. In my research, either one or two digital video cameras were used, with one of the video cameras roving around the classroom to follow the teacher throughout the lesson. A camera technician was employed for this task so that I could focus on the events of the classroom and record observational notes. Lessons were dubbed onto a VHS video for the teacher to view, and then returned to the researcher during the Reflective Interview. The digital video tapes were recorded onto DVD discs.

The video data were used to compile outlines of the lessons described in Section 5.2, for developing the annotated lessons for Data Sequence 3 Reflective Interviews, and as part of the modified video-stimulated recall process, described in Section 4.3.3. No detailed analysis of the video data was carried out; however, the video data remains in use by the researchers in the IMYMS project.
4.3.3. Modified Video-stimulated Recall and Reflective Interview

Video-stimulated recall has been shown to promote reflective discussion on teaching practice, student learning and teacher thinking (see, for example, Clarke, 1997, 2001a; Lyle, 2003; Meade & McMeniman, 1992; Morgan, 2007; O'Brien, 1993; Stoffels, 2005). Normally video-stimulated recall (also called “video reflection”, see Senger, 1998) involves the video recording of an event, followed by an interview between the participant and the researcher where the video is replayed to stimulate and lead discussion. The participant may be directed to comment on the events on the video or to draw on the events to respond to ideas identified by the researcher. Sometimes the remote control is given to the participant and they are asked to fast forward the video to instances where certain feelings, attitudes, and responses occur, and the participant is encouraged to talk about this (Clarke, 2001a). A video recorded event can be used as a stimulus for individual (Clarke, 2001a) or group discussion (Lyle, 2003). This method of analysis and reflection has been found to produce positive outcomes in promoting teacher reflection surrounding teacher change processes (Senger, 1998). Lyle (2003) provides a critique from a cognitive perspective of the use of stimulated recall processes in naturalistic research. He claims that one advantage of the stimulated recall method is that it is applicable across a broad range of research designs. A limitation, however, is its dependence on immediate recall: such methods, he claims, are most effective when there is no lapse in time between the event and the stimulated recall. Another concern is the “extent to which the subjects have ordered their thoughts before or during the recall process” (p. 872), presumably shifting the focus from thinking in action, to reflection on practice.

My research was not centred on determining teachers’ decision making or thoughts-in-action as they occur in individual lessons, but was concerned more with teachers’ experiences as they shape their perceptions and beliefs about themselves as teachers of the subject, and how this has some bearing on their classroom practice. This research focus requires a more contemplative environment for teachers. Consequently, video stimulated recall methods as they would normally be used were not appropriate. Also, I considered it unreasonable to expect teachers to view two complete lessons within an interview setting and to respond reflectively rather than reactively to the video representation of their teaching. One option was to select segments for the teacher to view; however I wanted the teachers to view their entire lessons. Teachers were, therefore, asked to view the video-recorded lessons privately and reflect on a set of questions focusing on intentions for classroom actions, and beliefs about teaching, learning and the mathematics and science subjects. I called this a “modified video-stimulated recall” (modified VSR) technique because the video served as a stimulus for reflection, which teachers would then discuss in a Reflective Interview. (See Sections 4.4.2 and 4.4.3 for the instructions and questions guiding the private teacher reflection.)
The Reflective Interview

The Reflective Interview provided the space for the co-constructive dialogue to take place. During and after the lesson observations, I developed a list of critical incidents, questions and key observations through a preliminary reflective analysis (see Section 4.5.1). These questions and observations often reflected patterns that emerged during the lesson and related to an individual teacher’s teaching approach, or reflected my thinking across the range of teachers and subject areas.

The Reflective Interview took place after the teacher had watched the video. This meant that during the interview there was a juxtaposition of our pre-considered thoughts, leading to co-constructions that were more likely to result in rich dialogue regarding teachers’ beliefs, concerns, experiences, knowledge and commentary on their practice.

This lapse in time is counter to the normal procedure for a stimulated recall research design. What Lyle (2003) considers a limitation, I consider as a strength of the modified VSR and Reflective Interview process, that is: “the extent to which the subjects have ordered their thoughts before or during the recall process” (p. 872).

Videos were played quietly in the background during interviews in Data Sequence 2, but their role in stimulating discussion depended on how the interview progressed. Some interviews progressed with neither the researcher nor teacher turning to the video. In other interviews, the video provided stimulus for the teacher to share anecdotes about particular students or pedagogical actions. Teachers often referred to things they had noticed on the video during private viewing, and they almost always appreciated the opportunity to review their teaching practice.

The Reflective Interview provided the main opportunity for the teacher and I to share and build on ideas. The “inner”, personal world of the teacher was opened up, with rich stories revealing more about the pedagogical practices of these teachers than could have been gained through observation, video recording, or uncontextualised interviewing.

4.3.4. Other teacher interviews and discussions

According to Guba and Lincoln (1981) when the rules governing behaviour, events or situations are latent, the significance must be sought through means other than observation—for example through interviews. As a naturalistic inquiry, this research is based on the proposition that schools, as social settings, “have pluristic sets of values” (Guba & Lincoln, 1981, p. 156) that bear comparison. In order to gain a deeper understanding of the factors that come to bear on teachers’ pedagogies, “it is necessary to ground inquiry…in the multiple perspectives that are held by group or community leaders and participants” (p. 156).

Unstructured and semi-structured interviewing techniques were employed during the research. All of the Reflective Interviews (previous section), the Informal Discussions and the Focus Group Discussion described below were audio recorded.
The interviews and discussions were transcribed verbatim, without interpretation, and checked for accuracy (Green, Franquiz, & Dixon, 1997). The transcript became the principle data source used in the analysis (see Section 4.5).

**Informal Discussions**

These interviews focused on broader issues than teaching practice and intentions by exploring such things as the effect of teacher background and socialisation on pedagogical development, and the units within which the video recorded lessons were included. They ranged from unstructured semi-structured, and occurred prior to or following a lesson.

**Focus Group Discussion**

I conducted one focus group discussion with teachers at School A. Focus groups provide opportunities for participants to prompt each others’ thought processes during group interaction so that differing perspectives can come in contact (Maykut & Morehouse, 1994). Interviewing multiple participants is considered useful: for topics that are better discussed by a small assemblage of people who know each other (Glesne & Peshkin, 1992); when considerable research precedes the group discussion (Denzin & Lincoln, 1994b); when they are carefully planned discussions in a permissive, non-threatening environment (Kreuger, 1988); and where participants have a specific experience of, or opinion about, the topic under investigation (Merton & Kendall, 1946). My research complied with these conditions. The teachers knew each other well. All teachers could respond to the questions confidently because the conception of the questions was informed by an analysis of the responses from previous interviews. The teachers received materials before the Focus Group Discussion that included the questions, some of their quotes from their earlier interviews, and some ideas from the literature. I tried to ensure that all participants were given time to voice their opinions in a safe environment. As these teachers respected each other and valued this opportunity to share practice, their interaction was largely enabling and productive.

**4.4. The Data Sequences**

Data generation took place over four school semesters. The research was divided into “Data Sequences” that focussed on different dimensions of pedagogy on order to build up a rich picture of what the teacher was doing, what they believed and why. Each data sequence has a number of data events. Artefacts were collected on an opportunistic basis at all stages of the research, and included planning documents and classroom resources. Table 4.2 summarises the data events at each Data Sequence.
Table 4.2  
Data Events in Each Data Sequence

<table>
<thead>
<tr>
<th>DATA SEQUENCE</th>
<th>DATA EVENT</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data Sequence 1 (S1)</td>
<td>Data Event 1</td>
<td>Familiarisation with the classroom, teachers, and schools through classroom observation and informal discussions with teachers</td>
</tr>
<tr>
<td></td>
<td>Data Event 2</td>
<td>Modified VSR trial</td>
</tr>
<tr>
<td>Data Sequence 2 (S2)</td>
<td>Data Event 3</td>
<td>Classroom observations, video taping</td>
</tr>
<tr>
<td></td>
<td>Data Event 4</td>
<td>Modified VSR and Reflective Interviews based on discussion questions</td>
</tr>
<tr>
<td>Data Sequence 3 (S3)</td>
<td>Data Event 5</td>
<td>Comparing ideas about what it means to teach the subject through a Focus Group Discussion</td>
</tr>
<tr>
<td></td>
<td>Data Event 6</td>
<td>Classroom observations, video recording</td>
</tr>
<tr>
<td></td>
<td>Data Event 7</td>
<td>Individual informal discussions to place the video recorded lessons into the context of the broader unit</td>
</tr>
<tr>
<td></td>
<td>Data Event 8</td>
<td>Modified VSR and Reflective Interviews based on annotated lesson plans</td>
</tr>
</tbody>
</table>

4.4.1. Data Sequence 1 (S1)  
The purpose of this sequence was to familiarise myself with the settings, the teachers, the dimensions of the research questions, and the research methodology. Two major events occurred during this Sequence.

Data event 1: S1 Teacher interviews and observations  
A group meeting with the participating teachers was used to explain the purpose, methods and expectations of the research, to decide the classes to be observed, and to gain informed consent (Section 4.7). This was important for gaining successful access to the research site and for setting expectations for teachers’ involvement. I observed one lesson per teacher during subsequent visits to the school. My observations consisted mainly of notes on teacher and student interactions and cultural artefacts that might be specific to mathematics or science classrooms, and “Observer Comments” [OC] that posed potential questions and foci that might form the basis for the interview, and purposes and foci for future observations. These observations led to the development of an observation template (Appendix 2.)

Observation played various roles during my research. During the initial stages, observations were useful for:
- introducing me as a visitor to the class;
- familiarising myself with teaching styles and classroom organization; and
- gaining initial insights into the questions that could be asked during interviews following video recording.
Data event 2: Modified Video-stimulated Recall trial

Questions and observations arising from the first two data events were used to develop a set of questions and instructions to guide the Modified VSR and Reflective Interview process (Appendix 3). A trial of this process was conducted with a trial teacher who was not a participant in the IMYMS project, but who had a reputation for being articulate and reflective about her practice. She provided some preliminary insights into the differences between mathematics and science teaching, and some valuable feedback on the research method. At that time, my intention was to include Year 5 to Year 10 classrooms, so it made sense to have a primary based trial.

4.4.2. Data Sequence 2 (S2)

The purpose of this sequence was to generate data on what teachers do in the classroom and why. The sequence of observing, video recording, Modified VSR and Reflective Interview took place in 2004 for the four School A teachers, and in 2005 for three of the four School B teachers (excluding Marg, see Section 5.2.7).

Data event 3: S2 Classroom observation and video recording

During these observations I followed a teacher through a sequence of related lessons, one of which was video recorded. Table 4.3 provides a summary of lessons observed and video recorded across all sequences.
### Table 4.3

*Class Groups, Topics, and Lesson Codes for Each Teacher*

<table>
<thead>
<tr>
<th>TEACHER</th>
<th>YEAR AND SUBJECT</th>
<th>TOPIC</th>
<th>LESSON CODES++</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Observed only</td>
</tr>
<tr>
<td>Pauline</td>
<td>7 Science</td>
<td>Circulatory system</td>
<td>P1</td>
</tr>
<tr>
<td>Simon</td>
<td>7 Science</td>
<td>Data representation</td>
<td>S1</td>
</tr>
<tr>
<td>Rose</td>
<td>8 Mathematics</td>
<td>Algebra</td>
<td>R1</td>
</tr>
<tr>
<td>Donna</td>
<td>8 Science</td>
<td>Skeletal system</td>
<td>D1</td>
</tr>
<tr>
<td>James</td>
<td>7 Mathematics</td>
<td>Patterns in number problem solving</td>
<td>J1</td>
</tr>
<tr>
<td>Ian</td>
<td>7 Science</td>
<td>Separating mixtures</td>
<td>I1</td>
</tr>
<tr>
<td>Marg</td>
<td>7 Mathematics</td>
<td>Directed number</td>
<td>M1</td>
</tr>
</tbody>
</table>

**Data Sequence Two – Semester 2, 2004**

<table>
<thead>
<tr>
<th>TEACHER</th>
<th>YEAR AND SUBJECT</th>
<th>TOPIC</th>
<th>LESSON CODES++</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Observed only</td>
</tr>
<tr>
<td>Pauline</td>
<td>8 Science</td>
<td>Static electricity</td>
<td>P2</td>
</tr>
<tr>
<td></td>
<td>8 Mathematics</td>
<td>2- &amp; 3-dimensional shapes</td>
<td>P4</td>
</tr>
<tr>
<td>Simon</td>
<td>7 Science</td>
<td>Friction</td>
<td>S2</td>
</tr>
<tr>
<td></td>
<td>7 Mathematics</td>
<td>Algebraic equations</td>
<td>S4</td>
</tr>
<tr>
<td>Rose</td>
<td>8 Mathematics</td>
<td>Percentages</td>
<td>R3</td>
</tr>
<tr>
<td></td>
<td>9 Mathematics</td>
<td>Median and mode</td>
<td>R5</td>
</tr>
<tr>
<td>Donna</td>
<td>7 Science</td>
<td>Adaptations &amp; Ecosystems</td>
<td>D2</td>
</tr>
<tr>
<td></td>
<td>9 Science</td>
<td>Light</td>
<td>D4</td>
</tr>
<tr>
<td>James*</td>
<td>7 Science</td>
<td>Electric circuits</td>
<td>J2</td>
</tr>
<tr>
<td></td>
<td>10 Science</td>
<td>Genetics</td>
<td>J4</td>
</tr>
<tr>
<td>Ian*</td>
<td>7 Science</td>
<td>Separating mixtures</td>
<td>I2, I3</td>
</tr>
<tr>
<td></td>
<td>7 Mathematics</td>
<td>Factors, primes &amp; multiples</td>
<td>I5</td>
</tr>
<tr>
<td>Marg*</td>
<td>7A Mathematics</td>
<td>Investigating number</td>
<td>M2</td>
</tr>
<tr>
<td></td>
<td>7B Mathematics</td>
<td>2-dimensional shapes, algebra</td>
<td>M4</td>
</tr>
</tbody>
</table>

**Data Sequence Three – Semester 1 and 2, 2005**

<table>
<thead>
<tr>
<th>TEACHER</th>
<th>YEAR AND SUBJECT</th>
<th>TOPIC</th>
<th>LESSON CODES++</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Observed only</td>
</tr>
<tr>
<td>Pauline</td>
<td>7 Science</td>
<td>Bones, reflection</td>
<td>P6</td>
</tr>
<tr>
<td></td>
<td>7 Mathematics</td>
<td>Algebra</td>
<td>-</td>
</tr>
<tr>
<td>Simon</td>
<td>7 Science</td>
<td>Chemical reaction</td>
<td>S6</td>
</tr>
<tr>
<td></td>
<td>9 Mathematics</td>
<td>Algebra</td>
<td>-</td>
</tr>
<tr>
<td>Rose</td>
<td>8 Mathematics</td>
<td>Area</td>
<td>R6</td>
</tr>
<tr>
<td></td>
<td>9 Mathematics</td>
<td>Algebra, expansion</td>
<td>R8</td>
</tr>
<tr>
<td>Donna</td>
<td>7 Science</td>
<td>Report writing, chemical change</td>
<td>D6</td>
</tr>
<tr>
<td></td>
<td>8 Science</td>
<td>Energy, classification</td>
<td>D8, D9</td>
</tr>
</tbody>
</table>

**TOTAL** 52
++ Lesson codes are based on lessons summaries included as Appendices 13 to 19.
*Data generated semester 1 2005 during Data Sequence 3, using Data Sequence 2 methods of interviewing.

Observations in sequence 2 focused on:
- gaining firsthand experience of the events that teachers drew on in follow-up interviews;
- noting key events or experiences that I raised during the follow-up interviews, which, to some extent, acted as “member checks” for the classroom observations; and
- gaining insight into the teaching practices employed by the teacher to contribute to my understanding of differences in teaching practices across mathematics and science.

The focus of the classroom observations changed depending on the purpose of the lesson and the opportunities that the lesson provided. For example, a teacher-directed discussion lesson might proffer mainly verbal interchanges between teachers and students; whereas a practical or activity-based lesson may proffer a variety of experiences, such as teacher student interaction as a class group, small group, or one-on-one, use of equipment might be more pronounced, and other pedagogical issues such as class management and organization may emerge. Most lessons were audio recorded.

A sample observation is provided in Appendix 4. These observation notes were useful in planning for the Reflective Interview.

**Data event 4: S2 Modified VSR and Reflective Interview**

Two lessons were video recorded for each teacher. A set of directions and reflective questions (Appendix 5) were given to each teacher with their videos, and each was asked to watch the videos and reflect on these questions. During the Reflective Interview teachers were encouraged to:
- talk generally about their approach to mathematics and/or science teaching, including background in, commitments to, and beliefs about each;
- respond to the reflective questions that accompanied the video; and
- respond to the ideas emerging from my preliminary analysis, for example, exploring lines of inquiry that emerged from preliminary analyses of classroom observations or prior interviews.
4.4.3. Data Sequence 3 (S3)

The third sequence provided further opportunities to inform teachers about my emerging ideas and lines of inquiry. A Focus Group Discussion, a second sequence of observations and interviews, and an Informal Discussion were included.

Data event 5: S3 Focus Group Discussion

Section 4.5.2 describes how I arrived at the stimulus statements used in the Focus Group Discussion (see Appendix 6 for these statements, and Appendix 7 for an example of the feedback materials given to each teacher). The interview involved the four teachers from School A and occurred during the period of S2 teacher observations and video recording. The teachers were asked if they wanted to be involved in a follow up individual interview, but they declined.

Data event 6: S3 Classroom observation and video recording

As in Sequence 2, these focused on interactions between members of the classroom, teachers’ activities, and typical practices. Sequence 2 data for the School B teachers was generated at this time. Only a static camera was used as the video technician was not available during this period.

Data event 7: S3 Informal Discussions

I met with teachers individually shortly after the lesson sequence to discuss how the observed lessons fitted within the broader unit. See Appendix 8 for directions given to teachers. All School A teachers participated. Artefacts such as syllabi and activity sheets were collected. Teachers were given the videos and directions for the Sequence 3 Modified VSR and Reflective Interview process.

Data event 8: S3 Modified VSR and Reflective Interview with annotated lessons

Teachers were asked to view their video-recorded lessons and use an annotated lesson plan (see an example in Appendix 8) to record “things” they considered to be important in their teaching. I used the open term “things” so that what might be considered important was open to interpretation. During the interview, the teacher discussed their notes. One of the teachers, Pauline, expressed difficulty with this lack of direction at a time when she was under particular stress (see Section 5.2.3.). This lead to her non-participation in this interview. The interviews did not use the videos.

4.5. Disentangling the analysis

Consistent with a constructivist methodology (see Chapter 3), the analysis was ongoing and intimately connected to data generation. In order to “disentangle” the analysis I use a narrative that demonstrates how theory, data, conceptualisation and analytical processes interacted during the research. My narrative involves a three-part
structure to demonstrate the different stages of analysis I used to embrace, shape and
draw meaning from the data: an ongoing “reflective analysis”, a “gross analysis” of
the written interview transcripts and videos, and an “in-depth thematic analysis” of
all written data.

4.5.1. Analytical Phase 1: Ongoing “reflective analysis”

The first phase of the analysis involved intuitive and continual reflection on the
research, what I call a “reflective analysis”. This preliminary analysis began with the
initial literature review and the development of the research questions. As a research
instrument, and thus a filter for what is perceived (Denzin & Lincoln, 2000a), I was
aware that certain influences, such as my reading of the literature and discussions
with my supervisors, made me more receptive to particular events and nuances of the
classroom and discussions with teachers. For example, the theory surrounding
affordances and constraints dominated my approach to the trial of the Modified VSR
technique, shaping my conversations with the teacher and the subsequent analysis
(see Darby, 2004a).

Entering the research site had an immediate influence on my thinking about
what the research was about, and what meaning I could possibly construct. My time
in these classrooms generated many questions and possible foci for the second round
of data generation, questions relating to teachers’ reasoning for choices made
through the lessons and teachers’ expectations for students, and possible points of
comparison of mathematics and science subject culture. As already mentioned, these
initial reflections were used to generate the interview protocol for the VSR Trial
(Appendix 3) and the first VSR Reflective Interview (Appendix 5).

Reflective thinking continued during the data events, especially during the
classroom observations when particular experiences would trigger a line of thought;
for example, an interest in exploring the differences between the nature of stories
used in mathematics and science was triggered during Simon’s lesson, S4, in
Sequence 2 (for a summary of this lesson, see Section 6.2.4). The observation
templates were structured to provide space for these “Observer Comments” as
possible points of interest.

After observing the teachers, video recording their lessons and replaying the
videos, I spent time looking through the observation transcripts for each teacher.
Usually written as a series of points in my journal, these reflections explored certain
aspects of the classroom experience that characterised teachers’ practice, and
highlighted critical incidents and queries that I wanted to pursue during the
Reflective Interviews. As an example, the following excerpt is taken from a
reflection following Roses’ Sequence 2 lessons:

Presents maths as having not just one solution. Dialogue with one student who
had trouble with this notion. Explore. How do students cope with there being
multiple solutions for one problem? Why might this be problematic for some
students? How do these students’ perceptions relate to the way school maths is presented? (Journal, 25/4/2004)

In the Reflective Interview with Rose we discussed the traditions of the subject, including the content, predominant pedagogies, and the nature of students, that contributed to this type of student response. In this way, these reflections of my observations of the classroom and teachers’ practices were pivotal in shaping a consensual view of some aspects of the nature of the subject culture and its prevailing pedagogies.

4.5.2. Analytical Phase 2: Gross analysis

I carried out a gross analyses of some of the written interview transcripts after the Focus Group Discussion using ideas from Flood’s (2004) research into artists’ personal narratives. Flood identified within her interview transcripts words and phrases that encapsulated the interior and exterior influences on artists’ conceptions of self and identity. I applied this dual focus by examining the “inner” and “outer” teacher with a three-part analytical framework that included construction of self, classroom practice and the subject (see Darby, 2004b). Two of the interviews, S2AR for Rose and S2AS for Simon, were read and coded using this framework. During the coding I added a fourth emergent category in acknowledgement of teachers’ constant references to students in their reflections (see Table 4.5 for a description of the analytical framework).
Table 4.4

*Analytical Framework for Gross Analysis of Sequence 2 Interviews*

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Constructing identity</strong></td>
<td>Focuses on explicit or implicit references to how teachers construct their identity as teacher, learner, consumer and doer of mathematics, and other aspects related to personality, style, beliefs and personal experiences. These references are viewed as elements of the inner teacher.</td>
</tr>
<tr>
<td><strong>Constructing classroom practice</strong></td>
<td>Focuses on how the teacher describes and retells classroom actions, either from the observed and video-recorded lessons or from their overall teaching practice. The observation transcripts were pivotal in contextualizing teachers’ reflections. As outward manifestations of the teacher, these excerpts helped construct the outer teacher.</td>
</tr>
<tr>
<td><strong>Constructing the subject</strong></td>
<td>Focuses on direct or indirect reference to the subjects and disciplines of mathematics and science. Provided insight into how the subject was constructed and represented implicitly and explicitly in the teacher’s private thoughts and classroom practice. Other themes such as the nature and purpose of school and education were included. As personal constructions, these excerpts were viewed as elements of the inner teacher.</td>
</tr>
<tr>
<td><strong>Constructing the learner</strong></td>
<td>Focuses on the way the teacher conceptualises the learner specific to that subject. Included are references to the nature of students, their learning needs, relationships between the teacher and students. As personal constructions, these excerpts are mainly of the inner teacher, but could be seen manifested in the classroom as representation of the outer teacher.</td>
</tr>
</tbody>
</table>

Through this analysis I developed a list of key themes (see Appendix 10) that informed the next data sequence. Using the key themes I developed a set of statements to provide structure to the Focus Group Discussion (see Appendix 6.). The statements are based on the following three broad ideas:

1. **subject-specific demands placed on teachers and students**: emphasises the broader purposes, values and beliefs inherent in each subject, how these demands are presented through the curriculum, and the implications that they have for student learning and teachers’ support for learning;
2. **translatability of teaching practices**: provides a comparative lens to explore what works in mathematics and science and why, in order to highlight fundamental differences between mathematics and science teaching, and signalling what is involved in negotiating subject boundaries; and
3. **the various influences on teachers’ treatment of content in their teaching and their attitude to the subject**: explores how these experiences influence agency and empowerment, and the ways in which the teachers position themselves in relation to the subjects.

I gathered excerpts from the interviews that related to each of these broad ideas. Some of these excerpts were presented to each teacher before the Focus Group.
Discussion, together with three questions and ideas from the literature relevant to each question (see Appendix 7 for an example of the feedback sheet given to teachers). Circulating these ideas was an important step in achieving consensus between myself and the teachers on key ideas relating to their experiences of subject culture. Although their experiences are personal and individual, it was important to get a sense of how, as a group, they conceived of subject culture differences and similarities.

Following the Focus Group Discussion, I reflected on an aspect of teaching that teachers stated was central to their conceptualisation of teaching: passion. I drew on Day (2004) to reinforce and give some structure to the interplay between the subject and the student as the targets of teachers’ passions. I developed a conceptual framework that shows the relationship between the categories of the analytical framework (Figure 4.2). This conceptual framework was an important referent as I refined and developed the various lines of inquiry into themes.

Analysis of the Focus Group Discussion involved categorising the interview into three sections corresponding to the interview questions. A series of salient themes emerged. The analysis gave further clarification to the nature and importance of passion for teaching and the subject, as well as further insight into the different pedagogical demands that the subjects placed on the teacher.

At this time I was considering how I would present my data and interpretations in the thesis. I identified key lines of inquiry (referred to as emergent themes), such as the notion of story telling, in order to present the interactions between recurring ideas identified from the Focus Group Discussion, and from previous analytical thinking. Figure 4.2 shows how these emergent themes from the Focus Group Discussion arose from the key ideas and assertions (Appendix 10), and the statements used in the Focus Group Discussion (Appendix 6). The figure also shows how the emergent themes changed as they became part of the analytical framework for the in-depth analysis discussed in Section 4.5.3. Decisions about what to include in the thesis led to further change to Theme 2, “Promoting activity-based learning experiences”. Figure 4.2 is an analytical trail representing the ideas to which I was attentive in the data, and how my focus shifted or developed during the research.
Figure 4.2 Relationships between the categories of the analytical framework.
Key ideas and assertions emerging from Sequence 2 analyses

Learning culture
Students respond differently in maths than in science. In science students have a shorter attention span so need to have a greater number of activities.

Curriculum
The nature of the maths and science curriculum are essentially different and demand different ways of teaching.

Student response to curriculum
A student absent from maths for an extended period of time is at a greater disadvantage than a student absent from science for an equal amount of time.

Pedagogical knowledge
There are some elements of classroom teaching that cross subject boundaries. However, these generic elements may look different depending on the subject due to:
- the nature of the learners;
- the teacher’s interests and expertise;
- and demands of the subject.

Purposes
In both maths and science teaching, making connections to students’ lives is a fundamental purpose. Students make connections to real life easier in science because science is more observable than maths.

Discipline versus school version
School science and maths are essentially different from maths and science outside of school.

Enculturation
A teacher’s experiences with and interests in maths and science influence how they teach and identify themselves.

Statements for the FGD

Statement 1
Different demands on students and teachers

CENTRALITY - Central structural elements of the subject culture that place demands on teaching and learning.

MEDIATION - Orientations to teaching that are dependent on the mediation of cultural norms and traditions by an individual teachers’ personal beliefs, experiences and knowledge.

Relevance - Showcase of how teachers make maths and science meaningful to illustrate that the effect of subject culture in shaping pedagogy is dependent on teachers’ beliefs, values, commitments and experiences with respect to the subject and discipline.

AESTHETIC - Relationship between teacher commitments to the subject and the need for teachers to understand the subtle and complex environment of the subject.

Emergent themes from the FGD

Themes forming part of the analytical framework for the In-depth analysis

PROGRESSION - Teachers’ views about student progression and the nature of curriculum content organisation; implications for teaching.

DISCOURSES - Discourses of the subject culture that influence the teachers, including traditional strategies for teaching and perspectives on teaching the subject; educational needs for teaching the subject; nature of shift in discourses.

THINKING - How teacher provides opportunities for students to engage with the ideas and act and think mathematically and scientifically; questioning, intrigue

STORIES - Use of stories about maths and science to make the subject relevant; humanising the subject; comparing story telling as a teaching strategy giving insight into the nature of the subject matter.

PASSION - Relationship between the personal and the public as an aesthetic overlay shaping pedagogy/subject culture interface. Passion for the subject matter; passion for making this knowledge accessible for students; passion for relationship with the students; Teachers teaching outside of their specialty. Aesthetic of the subject

Final themes represented in the thesis

Theme 1. The nature of curriculum content organisation
- Draws links between the arrangement of the mathematics and science curriculum content and the students’ learning experience.
- Examines the pedagogical imperatives as a result of the demands placed on students.

Theme 2. Promoting activity-based learning experiences
- Explores a pedagogical imperative to engage students through activity-based learning experiences.
- Compares the epistemological, pedagogical and cultural demands of activity in maths and science

Theme 3. Telling stories to make the subject meaningful
- Explores a common imperative to relate the subject to students’ lives and interests.
- Interrogates the translation of this imperative into teachers’ conceptions of the subject, teaching and learning, and teaching practice.

Theme 4. The role of aesthetic understanding in the relationship between subject culture and pedagogy
- Explores the role that aesthetic dimensions of teaching play as teachers experience, situate themselves within, and negotiate boundaries between the subject cultures of mathematics and science.
- Draws on teachers’ personal responses to the subject and examines the role of subject commitments and histories in shaping pedagogy.
A thematic analysis at this point identified some gaps in the data, mainly in the area of analytic commentary on the classroom by the teachers. My research had taken a turn towards looking at how the teacher was constructing themselves in relation to the subject, their classroom practice and their pedagogy. Much of the information produced by the first and second rounds of data generation related to the teachers’ views rather than the units and concepts that they were actually teaching.

Consequently, Sequence 3 observations and interviews focused on how teacher developed ideas through the unit. Shortly after the classroom observation I had an Informal Discussion with each teacher about how the unit was constructed and how the video recorded lesson was situated within the unit. Following that I used a different tool to promote teacher reflection. Along with the videos, I provided each teacher with a description of each phase of the lesson (see Appendix 8 for an example), and asked them to identify the parts of the lesson that they considered to be important both for developing the content, and for students’ learning. I found this preliminary analysis of the lessons to be useful when preparing the lesson summaries in Section 5.2. Analysis of these interviews became part of the in-depth thematic analysis described below.

4.5.3. Analytical Phase 3: In-depth thematic analysis

The in-depth analysis involved coding all of the Reflective Interviews (Sequence 2 and Sequence 3), Informal Discussions (Sequence 3) and Focus Group Discussion (Sequence 3). I read each of the transcripts, labelling and annotating phrases, sentences or paragraphs if they pertained to any of the codes. I then used NVIVO to code electronically\(^3\). The codes were mostly pre-set before the coding began, but some sub-codes were added during the coding process (see Appendix 9).

The purpose of the analysis was to gather evidence to further develop, enrich, and counter where necessary, the “Themes” (see Figure 4.2), which would frame the exploration of relationships between subject culture and pedagogy. I also collated information on:

- teachers’ views on, or references to, different aspects of teaching mathematics and science;
- the teachers’ biographies;
- general reasoning associated with classroom teaching approaches or moves;
- the effect of the research on the teacher;
- general references to the nature of the subjects (subject-related codes assisted with subject-based comparisons); and

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\(^3\) I used NVIVO Version 5/6 to code because I was familiar with it. I transferred the project file to NVIVO Version 7 because it allowed me to manipulate and search the data and coding categories more intuitively.
• the various cultural influences on teachers and their practice.

Appendix 11 describes each coding category. The Theme category descriptions (codes 4.1 to 4.5) include a list of other codes that tended to be double coded with them, as indicted by Appendix 12. Appendix 12 is an NVIVO generated matrix showing the occurrence of double coding of a theme category with the other categories. The higher the number, the more times the categories were coded together. For example, the stories theme code (4.1) and subject matter code (2.3) were double coded more than any other code, suggesting that teachers referred to subject matter when they expressed the need to make the subject relevant.

I then grouped and mapped the excerpts in each theme category. I also collated critical incidents from the classroom that were mentioned in my journal or reflected on during the Reflective Interviews. These incidents were important for representing what happened in the classroom, and sometimes required me to go back to the video and observation notes to record the speech acts and actions.

Revisiting the research questions at this time was necessary to ensure focused and meaningful analysis of the data and conceptualisation of the argument for the thesis. I developed the themes in a way that represented the subject cultures, as well as teachers’ individual responses to these subject cultures. I used the conceptual framework (Figure 4.1) as a referent for what should be included in a discussion about each theme, that is, the teachers constructing the subject, their students and their practice, and themselves.

The formation of each theme involved developing a concept map for a theme, then reviewing relevant literature that would assist me in drawing out the salient features in the data. This implies a linear process, but of course this does not truly represent the role of the literature. During the research I was influenced by the literature and other researchers in various ways. I had written three conference papers by then (Darby, 2004a, 2004b, 2005a). One of these (Darby, 2005a) assembled theory relating to narrative and story in order to highlight some differences in the use of stories in mathematics and science, so that by the time I had reached the in-depth analysis I already had a preliminary argument and theoretical framework. The in-depth analysis yielded a categorisation of “meaning making” strategies that broadened the notion of stories from my previous argument, and opened up for discussion the idea of relevance as a general school imperative. This now forms the basis for Chapter 7.

Passion was a line of inquiry that emerged through the Focus Group Discussion and continued through the various iterations of the research (as shown in Figure 4.1). Passion was subsumed within a broader theme of “aesthetics” that I conceptualised after attending a conference in 2006. At this time I was conceptualising how teachers’ passions fitted into the relationship between subject
culture and pedagogy. Day (2004) had by this time provided me with insights into the interplay between the subject and the student as the targets of teachers’ passions. The notion of aesthetics as developed by Wickman (2006), using Dewey’s (1938) construct of aesthetic experience, enabled me to broaden the notion of passion to consider Dewey’s notion of “serious interest”, which I interpreted as people being inducted into the interests of the subject. Aesthetics, through a framework of “aesthetic understanding” adapted from Girod, Rau and Schepige (2003), provided a framework for understanding how teachers coped when moving between the subject cultures of mathematics and science when their background and various commitments were bound up in their identity in relation to the subject. A book chapter (Darby, 2008) and a conference paper (Darby, 2007) led to the early development of this theme as Chapter 8.

The data for the two themes represented in Chapter 6 were analysed last. The theme relating to curriculum content organisation (Section 7.1) emerged in the Sequence 2 interviews. The coherence of this theme can be seen in the data matrix in Appendix 12, where the relatively small number of occurrences of coded transcript, compared to the other themes, are situated around three categories, “progression” (22 out of a total of 25 coding occurrences), and “learning” and “support” (both with 21 out of 25 coding occurrences). These categories are integral to a theme looking at the effect of organisation of curriculum content on student learning and the implications for teachers. This theme highlighted similarities and differences between the subjects in terms of the role that subject culture played in shaping the practices of these teachers. I drew on curriculum theory and cultural theory to describe the basic assumptions underpinning the teachers’ beliefs.

The theme relating to the dimensions of, and demands associated with, teachers’ use of activity-based teaching approaches (Section 7.2) can be directly traced back to Statement 2 of the Focus Group Discussion where teachers discussed the translatability of certain practices between the two subjects. As shown in Figure 4.2, this theme draws on ideas from the “discourses” and “thinking” themes from the in-depth analysis. Research and theory relating to active learning and forms of activity in both subjects informed the development of this theme.

These themes provide the contexts for exploring various aspects of the relationship between subject culture and pedagogy. The analysis that led to the inception of these themes was complex, iterative, and based on the constructivist notion that humans construct understanding from experience. By allowing teachers to reflect on their practice, the teachers became co-constructors at various stages of the research. In the end, however, I had to make my own decisions about what I would focus on and what stories I would tell. Although I sent my research papers to the teachers, they were unable to be involved further due to their teaching commitments.
I am confident, however, that the discussions that follow reflect the teachers’ intentions and experiences at the time of their involvement.

4.6. **Criteria for judging the quality of the research**

My intention is not to reconstruct the subject culture in a way that can be generalised or reproduced across middle years mathematics and science classroom. The positivist criteria of validity, reliability, generalisability and objectivity are, therefore, inappropriate for this research. The constructivist perspective states that “Traditional positivist criteria of internal and external validity is replaced by such as terms as trustworthiness and authenticity” (Denzin & Lincoln, 2000b, p. 158, emphasis in original). The notion of trustworthiness was an early attempt to “resolve the quality issue for constructivism” (Guba & Lincoln, 1994, p. 114) and included the criteria of credibility, dependability and conformability, although these tended to parallel the positivist criteria (Woods, 1992; Guba & Lincoln, 1998).

A preferred alternative is to talk about the authenticity of the research, which can include the criteria of fairness, ontological authenticity, tactical authenticity, educational authenticity and catalytic authenticity (Guba & Lincoln, 1998). Woods (1992) describes authenticity as marked by “criteria of fairness, enlarging personal construction, improved understanding of the construction of others, stimulating action, and empowering action” (p. 59). The criterion of understandability is suitable for this research as my purpose is to allow the reader and myself to “understand rather than to convince” (Woods, 1992, p. 59). In keeping with the constructivist tradition I acknowledge that, because knowledge is seen to be co-constructed between the researcher and the participant (Guba & Lincoln, 1998), mine will not be the only interpretation of how subject cultures can be seen by these teachers to influence their teaching in mathematics and science.

Triangulation is often associated with judging the quality of qualitative research. I prefer to use Richardson’s (1994) metaphor, “crystallisation”, to characterise my use of multiple methods, and the quality of my interpretations of the data. According to this metaphor, the crystal “combines symmetry and substance with an infinite variety of shapes, substances, transmutations, multidimensionalities, and angles of approach. Crystals grow, change, and alter, but are not amorphous” (p.522). My research took account of many facets of the teachers and their practice in order to develop a “deepened, complex, thoroughly partial, understanding of the topic” (p.522). Observational and video data were compared with teacher commentaries during interviews; and the video and interview data, and emerging analyses and interpretations were discussed with the other IMYMS researchers. Efforts were made to elaborate and member check salient themes through the
dialectic hermeneutic process where subsequent interviews and observation foci were structured in accordance with the emerging lines of inquiry. The analysis has shown how some of the earlier assertions were developed and enriched by subsequent data events. These strategies enabled me to generate authentic accounts of salient aspects of the research focus within the limitations of my interpretive and reflexive frame, and to produce adequately warranted claims of how the subject culture comes to bear on teaching in mathematics and science.

4.7. Ethical considerations

Ethical issues are “intrinsic” to this type of research due to the nature of eliciting personal values, beliefs and meaningful experiences of the participants. The researcher and participants work towards increasingly rich and sophisticated constructions of the pedagogical approaches during this co-constructive process (Guba & Lincoln, 1998). Consequently, Guba and Lincoln assert that there is incentive for the intent of the inquirer to be overt or otherwise run the risk of endangering the dialectic process. However, the researcher must be aware that such personal interactions can result in difficulties with confidentiality and anonymity, as well as be subject to interpersonal difficulties. In my research, an open and overt approach that was sympathetic to the busy lives of teachers helped to ensure, in most cases, that the teachers continued to see the usefulness of the video recording and reflective interviews in informing their teaching practice. A plain language statement and informed consent form were used in accordance with Deakin University ethics approval for teachers, parents and students to ensure that the participants were suitably informed of the purpose and intended outcomes of the research. I found that it was important for me to meet with the teachers and discuss the statement and consent forms to bring to light any incorrect information or assumptions that teachers had received or developed about the research.

4.8. Summary

This research design affords an exhaustive and rich foray into the classrooms and minds of the participating teachers. The main feature is the Modified VSR and Reflective Interview process that invited teachers to be participants in the analysis of classroom practice. The research is characterised by dialogue between myself and the teachers, an emergent research design, and an ongoing multi-faceted analysis, over a period of 18 months, which has seen the seeding of key lines of inquiry and subsequent crystallisation into a set of themes on which the rest of the thesis is based. In the following chapter I begin to unveil these themes by providing a glimpse of each teacher and their practice.
Chapter 5. The research field and themes

In this chapter I set the scene for the research by introducing the schools, the teachers and their lessons, and the themes that form the basis for the rest of the thesis. The research field consisted of seven teachers from two schools, and their lessons. Each teacher can be distinguished on the basis of their subject commitments, styles, personality, choice of strategies, and the way in which they chose to represent the subjects. Goodson (1985) asserts that such individuality arises because each teacher has a personalised concept of a subject and what constitutes the practice of teaching. It is this individual approach to teaching and learning that I am calling “personal pedagogy”.

I begin the chapter by describing the school contexts of the teachers, and then introduce the teachers, their classrooms and their stories. I then describe each of the themes and provide a brief rationale for their inclusion.

5.1. Introducing the schools

Two secondary schools, School A and School B, provided the context for the participating teachers. In this section I introduce the schools and some of the contextual factors that provided the backdrop for the trails of conversation that emerged during the interviews.

5.1.1. School A

Located in a provincial city in regional Victoria, School A is a co-educational government secondary school offering Years 7 to 12 to about 1,300 students. The city has two girls’ schools (one private, one government) that capture a high proportion of girls that would normally attend School A, resulting in a higher proportion of boys than girls in many of the classes I observed.

School A became the main research school due to teacher availability and proximity, so most of the data generated came from four participating teachers: Rose, Donna, Pauline and Simon. All teachers participated in all data events over the two year period, except for Pauline who did not take part in the Sequence 3 Reflective Interview due to stress-related issues. These teachers were selected by the Head of the Science Department as participants for what the teachers called the “Video Study” component of IMYMS. The principal volunteered these teachers to be involved, and they agreed.
5.1.2. School B

School B is located in an eastern suburb of Melbourne. It is a co-educational Year 7 to 12 government secondary school with over 900 students from neighbouring suburbs. The school was involved in two professional development programs during the data generation period – IMYMS and MYPRAD.

Data from three teachers, Ian, James and Marg, were included in the analysis. A fourth teacher consented but had no junior year level classes during Sequence 3. Marg was video recorded during the Sequence 3 but did not continue with the interview process due to time constraints. All teachers were observed for one lesson during Sequence 1. No teachers were involved in the filming or interviews for Sequence 2. The Head of the Mathematics Department invited these teachers to be involved, and they agreed.

5.1.3. Context of change

Both of the participating schools, at the time of the research, were engaged in a range of curricula enhancements. Some of these are discussed below.

Across Victoria, all schools were preparing for the introduction of a new curriculum framework called Victorian Essential Learning Standards (VELS). The language of VELS and the potential impact of the curriculum changes were discussed in some of the interviews. Teachers from both schools were thinking about the influence these changes would have on their current syllabus documents and reporting procedures. During some of the interviews, some teachers talked about their response to the curriculum changes and the effect they might have on their teaching. The more experienced teachers were particularly scathing of the seemingly cyclic nature of changes imposed on them over the years.

Both schools were involved in the IMYMS project. All science and mathematics teachers at the middle school level (Year 7-10) were involved in a process of school change where emphasis was on a whole school approach to improving the teaching of mathematics and science (see Section 1.2 for an outline of the IMYMS project). School B was also involved in the MYPRAD project (Department of Education & Training, 2002a).

Teachers at School A had also decided during the first year of the research to restructure the Year 9 and 10 curriculum, resulting in major changes to the timetable, the timing of subject selection, and organisation of the mathematics and science curricula. During the interviews, teachers referred to various discussions or debates that were taking place within the schools associated with these changes. During Sequence 2 teachers were preparing for the changes, and in Sequence 3 teachers were enacting them. Two of the changes are outlined below:
• Period length changed from 50 minutes (as observed during Sequences 1 and 2) to 75 minutes (as observed during Sequence 3). This change had implications for how teachers planned and conducted their lessons.

• With the implementation of an elective curriculum at Years 9 and 10, students selected subjects at the end of Year 8 for Year 9 and at the end of Year 9 for Year 10. Prior to this change, students only made Year 10 subject selections at the end of Year 9. The Year 9 and 10 curriculum was restructured so that students could select from a variety of mathematics and science subjects. These subjects provided multiple pathways through the compulsory mathematics and science courses. The selected pathways determined the type of senior mathematics and science courses in which a student could enrol.

5.2. Introducing the teachers

This section introduces the seven teachers and their lessons. I constructed the following descriptions to provide a snapshot of some of the key characteristics of their teaching practice. Certain characteristics are emphasised to set the scene for the various classroom experiences and descriptions of practice used to develop the themes in Chapters 6 to 8. The information given at this point begins the gradual unfolding of each teacher’s response to, participation in, and contribution to the cultures of school mathematics and science.

The descriptions are in three parts.

In the first part I describe the teachers’ background and experiences with the subjects, and whether they preferred to identify themselves as a science or mathematics teacher.

In the second part I briefly identify any contextual factors around the observed lessons. Lesson summaries for each teacher are attached as Appendices 13 to 19, and provide a point of reference for the various discussions and classroom events mentioned in ensuing chapters. I use the term “public” to refer to whole class events, which are teacher-led discussions and lectures, and times when the teacher responded to a student’s question by addressing the whole class. I use the term “private” to refer to individual or small group focused events, including students copying notes, completing problems, carrying out a practical experiment, and a teacher dealing with a student query by addressing only that student or a group of students. Times indicate the approximate length of each lesson segment. Lessons do not total 50 or 75 minutes because the time taken for administration and classroom

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4 Compulsory years of secondary school are Years 7 to 10.

5 Senior years of secondary school are non-compulsory, and award the Victorian Certificate of Education (VCE).
management is not included.

In the third part I briefly describe the key characteristics of each teacher’s practice. The selected characteristics represent common practices observed, and patterns of beliefs about knowing, learning and teaching the subject emerging from the interviews.

James, Ian and Marg from School B are discussed in less detail than the teachers from School A due to their involvement in only Sequence 1 and 2. Marg’s description is based on the observed lessons only because she did not participate in the Reflective Interview.

Excerpts from the interview transcripts are labeled with the name of the transcript and the paragraph number. Labels for the Reflective Interviews are comprised of the sequence (S2 or S3), school (A or B), and teacher (R for Rose, P for Pauline, as so on.). The Informal Discussion transcript is denoted as “Inf”; and Focus Group Discussion as “FGD”. Events from the classroom are labeled with the lesson number (see Table 4.3 and Appendices 13 to 19 for the lesson codes).

5.2.1. Rose (School A)

Teaching background and preferences
Rose had been a mathematics teacher for about 15 years. At the commencement of this research, Rose had been teaching at School A for eight years, teaching mathematics at all year levels. In the second year of the research, Rose assumed the role of Head of Junior Mathematics.

Rose’s impetus for becoming a teacher came from her lifelong interest in children and her relative success in school. As a young girl, Rose was interested in and took care of children: “all through my life all I wanted to do was teach them, because I just loved kids” [S2AR:126]. In Year 12 she planned to become a primary school teacher until her high school principal, recognising her success and enjoyment of mathematics, encouraged her to become a secondary school teacher. Rose completed a science education degree, studying mathematics, statistics, chemistry and physics. She had no interest in the science, however, only completing these units because she thought it was a requirement. Although she has taught science, she chose early in her career to teach only mathematics.

Rose’s lessons
Five Year 8 and four Year 9 lessons are outlined in Appendix 13. Lesson R1 was a “filler lesson” for students not attending the school camp and unrelated to the normal sequence of classwork.

Characterising Rose’s teaching practice
Rose described herself as a teacher of students first and foremost, rather than a teacher of the subject. This strong focus on the student was evident both in the classroom and throughout the various interviews and discussions. For example, her interrogation of her video-recorded lesson during Sequence 3 focused on “how the kids were working, what I said and how I responded to the kids, their needs” [S3AR:86], and “to make sure they are working and understanding it” [S3AR:90].

Her pedagogical choices about how to teach the subject were based on what she believed “worked”. For Rose, knowing “what works” relied on, and was a product of, her being attentive to the learning needs of her students, knowing the content well enough to determine where student understanding was lacking, and knowing how to use teaching strategies and approaches to support conceptual development.

The growth of such knowledge and responsibilities comes with experience. Experience led Rose to a judicious use of the textbook: “When you first start [teaching], the textbook is good. But when you’ve taught for a while…you find out what you like…[the textbook often] muddies the water and makes it not as clear cut as you want” [S3AR:16].

As Head of Junior Mathematics, Rose believed that it was important for her and other experienced teachers to share their knowledge of effective teaching practices with less experienced teachers. She worked with teachers to make them aware of activities and effective teaching techniques for particular topics, such as, how to make abstract concepts more “relevant” by talking about $a$ and $b$ as apples and bananas (lesson R9), judicious use of the textbook, and using terms such as “altitude” instead of “height” in the formula for the area of a triangle to limit students’ confusion when three-dimensional shapes were introduced (lesson R7).

Out of a commitment to the learning needs of her students, Rose believed that learning mathematics requires teaching that is teacher directed. It was for this reason that she disagreed with the recent depiction of teaching as “facilitation”:

ROSE: Facilitate learning. I hate that word. I think I teach. There are some times when you can facilitate, but a lot of time you are really teaching...I think a lot of the kids need that, they need those steps. And if you don’t put them in they are lost…And if you only give them bits of it they are lost. [Inf:112]

Rose’s impression of “facilitating learning” was teachers assisting students to work through worksheets. “But I would rather get up and say this is the way to do it” [Inf:113]. Instead, Rose assumed responsibility for transmitting and supporting the mastery of conceptual and procedural knowledge. She described the roles of herself and her students as follows: “I am the instructor at the beginning and they are the listeners, and then I become the helper while they are the active learners” [S2AR:241]. This pattern was evident in all of the observed lessons except for R3 and R8. Board work was often used to focus students at the beginning of the lesson.
She found students responded to this teaching strategy positively. For example, she said that she relied heavily on the blackboard in the Year 9 lesson because “the Year 9s like me to actually write the questions on the board” [S2AR:14], “I find often that you can engage them more, they are eager to do it” [S2AR:18]. While this pattern may appear traditional and reliant on transmissive styles of teaching, I observed that these teacher-directed segments included explicit questions that resulted in students being active participants. For example, when introducing the terms and procedures in lesson R4, Rose’s questioning played an important role in drawing on prior knowledge, checking understanding, and building new ideas, using questions such as: “What do we know?”, “What do I have to add to get 20?”, “Who can remember the median?”, and “When we’ve got a median what’s the first thing we must do with the number?” This type of classroom discourse was typical of the teacher-led segments of her lessons.

Rose took a personal approach to teaching, sharing explicitly with students snapshots of her personal life and beliefs. For example, she felt that she was a better teacher since becoming a mother because she could relate to her students, and she would talk with her students about her children and husband. She was careful to develop an environment of respect in the classroom based on a belief that “I don’t think it’s an ‘us and them’, I think it’s an ‘us together’” [S2:245].

5.2.2. Donna (School A)

Teaching background and preferences

Donna was in her fourth and fifth years of teaching during the research. Donna went through high school with the intention of becoming a veterinarian but then decided to explore her interests in zoology and ecology through a Bachelor of Science. Prior to doing a Graduate Diploma of Education in 1999, Donna worked at a tourism park as an education officer, taking tour groups on possum prowls and conducting other environmental activities. She also worked at a horse-riding park managing school and other groups, and was involved in dolphin research. Donna recognised that these experiences impacted on her teaching practice by providing examples and stories of science-related ideas, experiences and phenomena.

School A was Donna’s second school. Throughout her teaching career, she had taught junior science at all year levels, senior biology, and some junior mathematics. Science was her preferred subject, especially senior biology because she was able to draw on her experiences and interests. She recognized that physics was not her forte since she was not “physics trained,” nor did she have much interest in it. She confessed that even with a “science mind” she tended to struggle with chemistry and physics. She, therefore, could identify with students who saw science as boring, scary and hard.
**Donna’s lessons**

I observed ten of Donna’s science lessons, as outlined in Appendix 14. Included are lessons from Years 7, 8 and 9. I observed three Year 8 lessons in Sequence 3 because there were technical problems with the video equipment in lesson D9.

**Characterising Donna’s teaching practice**

At the heart of Donna’s practice was a commitment to supporting the development of students’ conceptual understanding. Donna often reflected on the need for her students to understand and be exposed to the language of science, which involved exposing students to concepts at the appropriate level of complexity. These commitments are demonstrated in the following excerpt.

DONNA: The whole idea of ecosystems, if you ask Year 7s for a definition later, which I did in this lesson [D3], and I gave them as much of the concept they need at this level. I want a really detailed definition of “ecosystem” when I teach Year 11 Biology. They have to know the whole thing. Whereas I would just like to think that these guys can say that it’s different areas, like rainforest or there is a lot of things relying on each other, like living and non-living parts. So I thought hopefully by the notes on the board they have got a definition, so some of the kids will have a clue on, and “If I’m asked I can go look in my book for a definition,” or they learn it for tests. Really cluey kids (some of the other kids are a bit weaker) they might remember it if they have got it written down, it is good for them to have. Then some of the others it is good that maybe they have read a definition so they have absorbed it somehow, they have heard me talk about it and then perhaps they do a bit more hands-on stuff, like the posters [D3], there are a few different ways they could do that. Sometimes they have pictures like on work sheets, or we go into the computer room and there are different groups that are looking up different ecosystems. [S2AD:37]

As mentioned in the above excerpt, Donna appreciated the need to present science ideas in a variety of ways. As a result, she typically employed a variety of strategies to build a multi-dimensional picture of the curriculum content. Some of these strategies are discussed below.

Donna seemed to use worksheets frequently (lessons D3, D4, D5, D8, D9) with pictures, definitions and questions, although she claimed that she “does not rely heavily on them” [S2AD:47]. She believed that students, especially “juniors,” used them as a reference point where they can “follow ideas, like they can learn a concept, answer some different questions and then use work sheets to find out what they know and what they don’t know” [S2AD:47].

Note taking (lessons D1, D2, D6, D7) was typically used to introduce and reinforce definitions, such as “ecosystems.” Donna recognised that some students used the notes as a reminder of learned concepts “if I’m asked” (S2AD:37); other students, she hoped, would “absorb” the ideas, somewhat passively.

Class discussions and direct teaching of major terms and concepts (all lessons to varying degrees) gave Donna a measure of control over the depth and complexity
of the science ideas delivered to students. An illustration of this can be found in her rationale for dealing with small groups rather than the whole class when demonstrating refraction of light (see below). Donna explained that because she could empathise with the difficulties students faced when learning some physics concepts, she was careful to closely scaffold students’ interpretation of refracted light in a water tank:

DONNA: I try and bring up a few kids at a time to actually say, you can see the coin there and they go grab where they can see and then we can all see that they are not getting it. Is the light bending? Do we have to aim in front of it? Where does she or he now have to move their hand or aim for? Is it behind the image they see, or in front? And that’s because the light is bending. [S2AD:69]

Hands-on experience with natural phenomena (lessons D1, D4, D6, D7, D8, D9) were included, Donna explained, as another version of the science ideas. Such experiences allowed students to have some control over their own conceptual development. For example, in lesson D5 when Donna explained transparent materials, a student enquired about the degree to which lemonade would transmit light, to which Donna said that she would bring some lemonade in next lesson. In the Reflective Interview Donna explained that she felt it was important for students to develop ideas out of their own experiences: “You can be very, as a teacher, you can be really ready to give the information, and so [I like to say] ‘No, we will bring a glass of lemonade in and you tell me’”[S2AD:65].

According to Donna, this variety “breaks up” the monotony of textbook-based teaching. This belief was informed in part by her discussions with a sports psychologist who found that using a variety of activities during football training increased players’ performance. At a time when the school was considering extended periods, Donna paralleled this strategy with the need for a number of “short, sharp” and varied activities to maintain motivation in the classroom. A second purpose of Donna’s use of variety related to the theory of different learning styles: “My philosophy is to try and teach something a few different ways, so that you are then tapping into maybe the different ways the kids learn” [S2:114].

5.2.3. Pauline (School A)

Teaching background and preferences
Pauline was in her second and third years of teaching during the research. She completed a three-year Bachelor of Science majoring in physics, then enrolled in a two year teaching degree that prepared her to teach Prep to Year 12. Her methods were general science, senior physics, and mathematics. Pauline stated that mathematics was her “fallback method”, and chose the combination of science and mathematics due to the demand for science and mathematics teachers.

School A was her second teaching appointment. At both schools she taught
junior mathematics and science, and Year 11 and 12 Further Mathematics and Physics. In junior science, physics was her preferred discipline due to her strong physics background. She was also confident in her knowledge of biology, but considered herself to be weaker in the chemical sciences.
Pauline’s lessons

A total of eight lessons are outlined in Appendix 15: five in science and three in mathematics. Pauline was ill during Sequence 3, and this prevented consecutive science lessons being observed, and resulted in me observing only one mathematics lesson during that sequence.

Characterising Pauline’s teaching practice

As a new teacher Pauline felt that she still had much to learn about how to effectively teach both mathematics and science. She stated in the first interview that part of her professional development plan was to develop a repertoire of interesting ways to engage students in their mathematics learning, to cater for individual learning needs in both subjects, and to gain better classroom management techniques generally. Indeed, Pauline struggled with the demands of teaching at times. She did not participate in the Reflective Interview in Sequence 3 because she said she was overwhelmed with work and did not see any benefit in continuing with the Video Study, and that, in fact, she was considering going part-time. While this admission was unexpected, I had seen a hint of this struggle when she discussed her mathematics teaching. On a number of occasions Pauline confessed to being dissatisfied with her mathematics teaching because she did not have an intuitive sense of how to teach mathematics at the junior level. These ideas are discussed further in Chapter 10. Pauline shared her inadequacies in the Focus Group Discussion, saying that she received more positive responses from her students in science than in mathematics:

PAULINE: I find it demoralising to go into a maths class and have kids go “I hate maths, what do we have to learn this for?” I just find that grinds me down and I have to really push myself up. And I never have to do that in science… But I guess in some ways that anti-maths culture wears away at me. Maybe I am alright as a maths teacher, but I don’t feel like I am, I feel like I must be able to do something to get past this negativity. [FGD:231]

Donna gave Pauline a boost when she reported that a number of her senior students had been positive about Pauline’s senior mathematics teaching:

DONNA: I had half your maths class last year in my Year 12 Biology class and all they did was talk about how good you were.

…

PAULINE: I like to make sure that I am really approachable.

DONNA: Yeah, and that was one of the things that they were saying that you were approachable and you’d help them. [FGD:235-239]

Pauline’s attentiveness to her students as “help” was evident during the observations, particularly in the algebra lesson (lesson P8) where she spent much of the class answering students’ queries about the algebra worksheet. She was careful to
support student learning, particularly in mathematics because she understood that some students needed assistance more than others. She explained that at times students need individual attention and she gave one example where recently she took aside one student after class “because class is too loud and crazy” [Inf:5]. She explained that she “used the fruit bag analogy to explain collecting like terms and [the student] goes, ‘This is easy!’ Even though I’ve been through it on the board, sometimes they just need it one on one” [Inf:5].

In her reflections, Pauline talked about using interesting activities in mathematics, such as “projects that the kids are working on, especially when we do things like statistics or measurement, where you can do more practical hands-on stuff” [S2AP:16]. Unfortunately, I did not see her use any of these other activities, except for an extension activity that she gave only an advanced group of boys in lesson P5. She was less positive about her teaching of algebra (lesson P8) despite her best intentions, saying, “God, if we are doing algebra then it is going to be left hand side of exercise X and I don’t always think that is the best way to teach mathematics” [S2AP:16].

Pauline explained aspects of her teaching approaches in mathematic and science teaching:

PAULINE: [In science] there are prac lessons and then there’s discussion lessons and then there are lessons where we work through questions in the book to reinforce stuff that we have talked about, and that was what [lesson P3] was. I like to spend, and I do spend at least fifty percent of my time doing prac work because I am into observing things and then talking about them. It doesn’t always work out that way, but that is the way I like to learn science rather than just talking all the time. And I guess maths just doesn’t work that way. This is why I don’t like my maths, we don’t discuss enough. It is really hard to get kids to talk in maths…I sort of did that with the lesson that we taped actually, how much Greek do you guys know, how much do you remember about shapes? [S2AP:36]

Pauline spoke more positively and in more informed ways about her science teaching, and her lessons included a greater variety of teaching strategies. Pauline mentioned some of these strategies in the above excerpt [S2AP:36]: experiments and demonstrations allowed students and herself to engage with science through hands-on experiences (lessons P2, P7); she provided opportunities for herself and her students to share personal and historical stories to contextualise and make meaningful the science content (particularly lesson P3); and she depicted an approach to science teaching that intertwines personal experience with science theory, where sharing personal experiences through class discussion was considered a safe activity (see lessons P1, P3 and P6). By comparison the lack of opportunities to publicly discuss personal experiences in mathematics was constraining for Pauline. In mathematics, she had difficulty knowing how to provide an environment where mathematical knowledge could be socially constructed from prior experiences,
other than, for example, drawing on students’ prior knowledge of “greek” in lesson P5.

A rowdy classroom seemed to be typical for Pauline. In science particularly my impression was that Pauline’s enjoyment of sharing her experiences and knowledge with her students meant that she got distracted at times. In lessons P3 and P4 I observed a high amount of energy in the way she shared with her students, initially, the experiences of static electricity with the van de Graaff generator and other experiments, then, her personal interest in the history surrounding the discovery of static electricity. She remarked that she spoke for too long and discussed too little in lesson P4. She felt that she got carried away by students’ strange attentiveness resulting from the absence of the more rowdy students and the presence of the video camera:

PAULINE: The classroom management thing that I normally have like with Charlie yelling out at the top of his voice and people being idiots and chucking pencil cases, I didn’t have that, and so I went a bit drunk with power and talked about all sorts of stuff like Benjamin Franklin and how he became a big political leader. [S2AP:6]

Despite her apprehension about the way she imposed on students the story of Benjamin Franklin (see Section 7.3.1 for more detail of this episode), Pauline recognised that her use of stories was a strength in her science teaching because it enabled her to “find a personal approach” [Inf:18]. She believed that her passion for science translated into energy in her classroom performance, and she felt that this was picked up by her students.

5.2.4. Simon (School A)

Teaching background and preference
Simon was in his third and fourth years of teaching during the research. School A was Simon’s second school. His training consisted of a four year Bachelor of Education degree, preparing him to teach science to Year 10 and mathematics to Year 12. His degree also prepared him to be a primary school classroom teacher.

Simon’s preference for teaching mathematics over science stemmed from a lifelong interest in mathematical problem solving and relative success at school. His school experiences of science were of a subject that was disengaging and he confessed that he did not take the subject seriously, being reprimanded often for misbehaving. As a result, a developing knowledge of content, limited personal interest, and limited resources meant that he was apprehensive about his science teaching.

Simon’s lessons
Four mathematics and four science lessons as outlined in Appendix 16. Lesson S1
was an integrated Year 7 lesson where students worked with data generated in a previous science lesson. The other three mathematics lessons were based on algebra at Year 7 (lesson S4 and S5) and Year 9 (lesson S8) levels. All lessons were at the Year 7 level except for the Year 9 mathematics lesson. The Year 9 lesson was timetabled in a textiles laboratory.

Characterising Simon’s teaching practice

Much of Simon’s pedagogical reasoning reflected his own learning style. His history of disengagement from school work had the effect of creating in him a desire to excite and respond personally to students. This was evident in his lessons and his reflections in the following ways.

It was typical for Simon to give a series of instructions for tasks to be completed while students were working, making it difficult at times for me to distinguish between public and private segments. Evident in most of his lessons, this strategy had the effect of maintaining the pace of the lesson and kept students on task or busy. For example, in the second segment of lesson S7 he asked students to begin a task then continued to assign further tasks. Also, in the first segment of lesson S4 while students completed some board problems he explained and assigned the second task. I queried Simon about his rationale for overlapping tasks. He replied:

SIMON: We’ve got a few whiz kids and I don’t want the kids that are sitting in this class to be going “This is so easy,” do five minutes work and then wait ten minutes. I would rather they do something. And if the smart kids, or the kids that are advanced can do it in five, then I’ll introduce it in six minutes time, but I would get everyone to look and the ones that are a little bit slow might have to do it for homework. But I would prefer to have a packed class than have two activities then have kids stuffing around for the last 15 minutes of class or doing tasks that don’t relate to any sort of work like going on to the computer and playing games.

As can be seen above, Simon felt the need to keep students focused on their work not only to keep them busy but also because of his commitment to “get them to do the proper process” in readiness for future studies. Juxtaposed against this view of himself as orchestrating a busy classroom, Simon regarded himself as “a bit of a relaxed person” [S2AS:194] who saw little benefit in stressing junior students with tests and heavy work loads:

SIMON: I can remember doing tests all the time, having pressure and boredom and I just try not to do all those sorts of things, and people see that as me being a bit relaxed on the kids. I have got kids in Year 9 and Year 10 that come and watch me play footy and they are happy to see me. I get a buzz that they are learning, but they’re still sort of happy. I would hate them to come in, work flat out, leave, and have no personality. [S2AS:194]

My impression was that Simon was well regarded by many of his students because of his energy, friendly nature and propensity for making the classroom light-hearted and active. In science, this translated as making science “fun.” Many of his reflections in
the interviews focused on engaging students in the science content through “fun” activities. For example, his rationale behind using a fun volcano modeling activity with a Year 8 class was to provide memorable moments that would “win kids over” to science:

SIMON: The kids loved it to death and then I thought probably that’s another fun thing that when they’re in Year 11 they will go, “Remember that day we did the volcano.” And if I can win a few kids when they’re in Year 8 and go, “Gee science isn’t that bad. I like it more than maths or I like it more than English because sometimes you get to do fun things and when we do the fun things I’ll learn a little bit about what happens when we’re only playing.” If you can’t do all the fun things or the activities that will promote a deeper thought process, it’s probably harder to win kids over. [S3AS:96]

Basically, Simon sought out activities that promoted a positive affective response. The friction game (lesson S3) was used to promote “the friction fun side of it” [S2AS:18] in a competitive environment. Compared with “chemical experiments that go ‘kapow’” [S3AS:103], magnets (lesson S2), he found, lacked that “wow factor” [S3AS:102].

Simon paralleled these “fun” science experiences to student generated mathematical investigations that incorporated mathematical concepts and processes. Simon explained that he had told students in one Year 7 class who were asking for some activities: “for every topic we’re going to do an activity where they get to think of a topic, like an activity that we can relate to” [S3AS:104]. He gave the example of analysing basketball scores to focus on percentages and decimals as part of the current unit on decimals: “we converted the decimal to the fraction and worked out place value and stuff like that” [S3AS:104].

Simon’s personal response to students was evident also by promoting student ownership of their learning, such as students generating their own questions in lesson S4; and accelerating students beyond the syllabus for that year level in both mathematics and science, for example by introducing students to complex processes normally reserved for higher year levels (observed in lesson S4).

5.2.5. James (School B)

Teaching background and preference
James was an experienced teacher of mathematics and science. At School B he taught junior mathematics and science and senior physics. Science was his subject of choice. James began his professional life as a civil engineer. He also worked in a laboratory for a couple of years. Despite having “the odd dropkick teacher” and no “inspirational teacher” [S2BJ:248], he recalled having been interested in science since Grade 6. Astronomy and Julius Sumner Miller were his earliest recollections of engaging with science:

JAMES: Oh I was interested in science in about Grade 6 … Right from an early stage I had an interest in science and I can remember watching Julius Sumner Miller before
the Cadbury ads and just thinking he was so good. So clever. And his body language, the ideas that he developed, his presentation style. It just made science fun. [S2BJ:238, 242]

After graduating as a teacher he taught for a short time in Zimbabwe. James explained that he was heralded as an elder because he was white and had a beard. As a result, and despite having class sizes of 45 students, he had no management troubles, but “couldn’t get the kids to say anything” [S2BJ:276], nor produce a report consisting of more than one word!

James’ lessons
Five of James’ lessons were observed as outlined in Appendix 17. These included one Year 7 mathematics lesson and four science lessons in Sequence 2, two each of Year 7 and Year 10. James was originally recruited to participate in this research as a mathematics/science teacher, but in Sequence 2—which occurred two years after Sequence 1 for the participants at School B—I observed only science lessons. Lesson J3 was to be video recorded but too few students had returned consent forms so video recording was postponed and carried out in lesson J4.

Characterising James’ teaching practice
Because I saw fewer lessons and had fewer discussions with James and Ian, I could gain only a limited sense of what characterized their teaching practice. In James’ interview, he expressed a willingness to engage students by giving them interesting and challenging activities. I also noticed that some of his attempts in the classroom were thwarted by extensive classroom management issues. For example, in lesson J3 James used the problem of lighting a bulb with different arrangements of components. While he was happy with students’ activities during the task, I observed that the class discussion following the activity was not forthcoming due to student interruptions. Disruptive behaviour was even more pronounced in lessons J1, J2 and J4.

James explained that his science teaching over the years has become less-textbook based and far more activity oriented, “whether it be experiments—which is my favourite—or video or internet based” [S2BJ:154]. Also, James spoke a number of times about his propensity to plan his units in detail often consisting of “a couple of pages and I’ll have concept, teaching idea, activity, resources. There’ll be a hyperlink to another type of worksheet for students, a hyperlink to a website if it’s appropriate. And I’ll have a couple of key issues that I need to ensure that the students look at as well” [S2BJ:154]. He explained that he has become increasingly interested in “concepts and issues,” giving as an example [S2BJ:160] his fascination with the contemporary advances in gene technology [lesson J4] that he believed
represent for students the opportunity to “see that science isn’t stagnant” and that there is “scope” for students to “play a part in the growth of science.”

While James felt competent with his mathematics teaching, he demonstrated a greater commitment to, and richer understanding of, what science is, and can be, in schools. In the following excerpt James compares the subject cultures of mathematics and science:

JAMES: One of the questions was about subject culture. I’ve written down that science involves experiments, theories, chemistry, biology. Stating the obvious. And maths has topics, so they’re smaller areas of study. So you can always in science talk about how there’s this part of biology. Looking at animals, humans, plants. In maths you can look at simultaneous equations. Doesn’t have the same ring to it to me as talking about volcanoes. Or talking of erosion. I find it easier, much nicer. Science is talking about concepts and maths is talking about processes…In science you can do the experiments. You can talk about the concepts. We can talk about some personal history where you’ve used science. So that’s a bit easier. [S2BJ:224]

Experiments, personal histories, concepts and the natural world dominated James’ construction of science, all of which he excluded from the realms of mathematics, which is confined to “processes,” or procedures.

5.2.6. Ian (School B)

Teaching background and preference
Ian was an experienced science and mathematics teacher, coming into teaching in the 1970s after being a “qualified chemist” [S2BI:97]. He came into teaching with methods in junior science, mathematics to Year 12, senior chemistry, and physics to Year 11. A number of factors contributed to the way Ian positioned himself in relation to mathematics and science. He saw himself as mainly a science teacher for the following reasons; firstly, chemistry was his “major area” [S2BI:171] as he was a tertiary-trained, chemist; secondly, a history of teaching Year 11 and 12 chemistry meant that he had never had a senior mathematics load; and thirdly, his “maths qualification is not as great as a person who has done a tertiary in maths” [S2BI:171].

Ian’s lessons
In Appendix 18 I outline seven lessons, four science and three mathematics, and all at Year 7 level. The single lesson in Sequence 1 and the three lessons in Sequence 2 were from a separating mixtures unit. The three mathematics lessons were from a multiples and indices unit, with lesson I6 following up from the problem solving activity used in lesson I5, and lesson I7 being the last lesson of the unit.

Characterising Ian’s teaching practice
It was difficult to get a sense of Ian’s general mathematics teaching practice because all of the lessons I saw involved problem solving activities, although lesson I6 did
involve students being assigned textbook problems to consolidate the concept of multiples that they had encountered through the RIME activity in lesson I6. Ian explained in the Reflective Interview that, in recent years, he has used more activities in his mathematics teaching, perhaps indicating that what I witnessed was not uncharacteristic:

IAN: When I first came in my maths would have been what my father had taught me. You know the kind of way I thought I was taught. Even though we did some activities it was very much text book teaching. But that could have been just part of the school I was in. I came into teaching in the 70s. A lot of this stuff was around in the 70s but I don’t know that it all got out into schools. [S2BI:101]

All of Ian’s observed science lessons involved practical activities (lessons I1, I3 and I4) or students designing and preparing for an experiment (lesson I2). I saw no straight “theory” lessons, partly because Ian had rescheduled his science lessons so that my observation of lesson I1 was in a laboratory and was, therefore, an experiment instead of a theory lesson in a normal classroom. In comparison with his mathematics teaching development, Ian felt that his science teaching had not changed because he always appreciated the need to give students experiences where they could make their own discoveries and draw their own conclusions: “I’ve been aware of that since day one for science. When they do an experiment there’s an obvious conclusion or discovery” [S2BI:103]. Ian explained that he had come to value (perhaps refining what he has always known) “very well guided questions after an experiment” [S2BI:107] that allowed students to “come up with the most amazing obvious logical conclusions for themselves” [S2BI:107]. He gave an example of the class discussion around an experiment that involved extinguishing a candle with vibrations:

IAN: Last year we did a little experiment blowing a candle out by having a cardboard tube and a stretched balloon on one end. You pull out the stretched balloon and the other end puffs and blows the candle out. And so why did the candle blow out? Because the air blew it out. Okay. What blew it out? The air at this end of the tube or the air at this end of the tube? And they quite quickly came to the conclusion that the particles must be knocking each other along the tube. “Dominoes” was the word they used. And I went wow! I never thought of that as a way of explaining it, but the class worked it out and that’s a very abstract concept. I was proud that it happened because I was thinking about how that was going to work. It came to me on the day. Okay now we’ve done the experiment, let’s bring this together and I just thought of those questions on the spot and it went really well. [S2BI:107]

Then Ian explored why he thought that collaborative building of conclusions worked:

IAN: By having it as a class activity they feed off each other. A bit like in the maths and you can come up with, they hear each other giving answers and they can improve on the previous answer and it doesn’t take long to get the right answer out of the group. And if they give a wrong answer it’s possible just by that kind of discussion technique to point out what’s wrong with that answer. Can we improve on that and it does work really well? So I just find it a bit like maths. Experiments in science are often done and then you do the questions in the book but there’s much more that you can get out of it. I have found that generally the book questions aren’t as good as the questions you can put yourself. [S2BI:115]
In these excerpts, Ian seemed to delight in hearing students’ ideas, and was pleased that he had provided a classroom environment that enabled them to share and socially construct explanations, or “conclusions.” Ian claimed to use classroom discourse in a similar way in “the maths” lessons. Certainly, in lesson I5 students were invited to share their solutions in groups and with the class, and consider how the patterns that were emerging through the “Line-up” problem might relate to multiples. In lesson I6, Ian focused students on the patterns emerging through the “Odds and evens” problem-solving activity. Both Ian and Marg used this activity. Where Marg focused on the challenge to solve the difficult numbers, through classroom discussion and private reflection Ian focused students on the emergent patterns and how the activity related to indices and multiples. This pattern seeking perhaps parallels the building of explanations, or “conclusions,” that Ian sought in science.

5.2.7. Marg (School B)

Teaching background and preference
Marg was an experienced mathematics teacher who taught only mathematics and at all year levels. Marg did not participate in the Reflective Interview in Sequence 2 due to logistical difficulties, therefore, I have little knowledge of her background and teaching experience.

Marg’s lessons
I observed five mathematics lessons: a Year 8 lesson in Sequence 1, then four Year 7 lessons in Sequence 2. I have labeled the two Year 7 groups 7A and 7B to distinguish them. The two Year 7A lessons were from an investigating numbers unit. I observed the shapes revision lesson (M4) for Year 7B by accident as Marg was not warned of my attendance, and I got the impression that she was disappointed by not being able to “prepare.” The following lesson (M5) was to be a test, but because of my intended presence she altered her program to do the introductory lesson for algebra.

Characterising Marg’s teaching practice
Marg appeared to schedule the more interesting activity-based lessons for observed lessons, as suggested by her slight but obvious annoyance at not being alerted to my attendance, then the rescheduling of the testing lesson to make way for the OSCAR machine concept lesson. I found, however, that the “unprepared” revision lesson was thoughtfully planned and demonstrated a commitment to training her students in the art of test preparation and execution. Marg also diversified the learning experience by promoting a collaborative learning environment. Ian had mentioned that the Head of the Mathematics Department was encouraging teachers to use more group work in
mathematics, so it is possible that Marg’s pedagogical decisions testified to a cultural shift in the teaching of mathematics at the school.

The lessons used various resources and strategies, including open-ended problems from the *Reality in Mathematics Education* (RIME) project (lessons M2 and M3) to teach concepts and the problem solving process, cards with individual revision questions (lesson M4), and creative strategies for teaching concepts, such as protons and anti-protons for teaching directed number (lesson M1) and the OSCAR machine for conceptualizing rules for algebra (lesson M5). My impression was that Marg used all of these activities and strategies with careful attention to introduce the ideas in simple steps (such as, showing students how to locate, use and understand the purpose of the “power” button on the calculator), and to control for frustration by attending to individual problems, both privately or publicly (this was especially the case for lesson M3 where she felt students struggled to recognise the pattern).

### 5.3. Introducing the themes

These descriptions introduce characteristics of these teachers’ experiences of teaching mathematics and science. The teachers differed in how they approached their teaching, their histories of relating to the subject, and their subject affiliations. Subject differences in terms of teaching strategies, purposes, and assumptions are evident in the above descriptions. Donna and Rose both referred to their approaches to scaffolding student understanding, but how they did this and the nature of the student difficulties were different: Donna used hands-on experiences where she carefully focused students’ attention on the empirical evidence; while Rose used question sequences to support students’ understanding and mastery of mathematical concepts and processes. Pauline’s description emphasised her personal orientation towards science, and the difficulties she faced when teaching mathematics. Ian’s description compares his use of activities in mathematics and science. James’ description raises his beliefs about representing contemporary science practices. These ideas are represented in the themes explored in Chapters 6 to 8.

Four themes isolate different, yet somewhat overlapping, aspects of the cultural activity of teaching. The themes are described below.

**Theme 1. The nature of curriculum content organisation**

The first theme links the arrangement of the mathematics and science curriculum content with the way the subject was experienced by students. I examine the pedagogical imperatives that emerged as a result of the demands placed on students by this organisation of subject matter.

**Theme 2. Promoting activity-based learning experiences**

The second theme explores a pedagogical imperative to engage students through
activity-based learning experiences. I compare the epistemological, pedagogical and cultural demands associated with these types of teaching approaches across mathematics and science.

**Theme 3. Translating relevance into mathematics and science**
The third theme emerged from a common imperative to make the subject meaningful by relating the subject to students’ lives and interests. I interrogate how the rhetoric of “relevance” as a generic pedagogical imperative was translated by these teachers into their conceptions of the subject, teaching and learning, and into their teaching practice.

**Theme 4. The role of aesthetic dimensions of teaching in the relationship between subject culture and pedagogy**
The fourth theme focuses on the role that aesthetics played as teachers experienced, situated themselves within, and negotiated boundaries between the subject cultures of mathematics and science. I explore teachers’ personal responses to the subject by examining the role of subject commitments, and teachers’ histories of engaging with the subjects, in shaping pedagogy.

The themes do not represent a complete picture of the subject cultures, nor the teachers and their practices, nor the entire complex relationship between subject culture and pedagogy. Rather, I use the themes to approach the relationship between subject culture and pedagogy from different angles.

Themes 1 and 2 are used to show how certain subject pedagogies arise out of commonly held assumptions underpinning core teaching practices. These two aspects of the subject cultures appeared to be fundamental for these teachers in shaping their practice and made their teaching identifiably mathematics or science.

Theme 3 explores implications for teachers as they attempt to engage with, and translate, the need for “relevance” from the context of the subject. This aspect of the subject cultures deals with an imperative imposed by the broader school culture.

Theme 4 brings to the analysis the perspective of the individual as cultural member to look at the effect of “being” a teacher on the individual’s sense of themselves in relation to the subject.

In the ensuing chapters I use these themes to examine how a teacher’s experience of the subject cultures of mathematics and science comes to bear on the way they construct the subject, their practice and themselves. I juxtapose these personal constructions with what occurs at the classroom interface. The four themes provide a more complex analysis of the relationship between subject culture and pedagogy than if I had completed a comparative analysis of the many and varied teaching approaches employed by the participating teachers. In selecting the themes I
felt that it was important to represent this relationship as a mediated one, where the teacher, as a cultural member, is an actor and agent in interpreting, perpetuating or shaping cultural traditions and norms.

5.4. Summary

This chapter has begun the unfolding of the teachers and their personal pedagogies. I selected snapshots of each teacher’s practices and reflections to signal key ideas that will be elaborated in the themes. The next chapter includes two themes that examine aspects of the teachers’ practices that make the subject teaching identifiably mathematics or science.
Chapter 6. Aspects of the subject culture at the core of mathematics and science teaching

The previous chapter began to introduce the diversity of teaching orientations, commitments, strengths, and emphases inherent within the teachers’ conceptualisations of what it means to teach the subject. “The diverse cultivation of diverse talents” (Schwab, 1969, p. 198) is necessary for an innovative school community. Schwab states that a complex culture, such as a subject culture, requires both diversity and unity when conceiving of the tasks of teaching and learning. Unity as common goals amongst teachers within the subject area is important in establishing “shared traditions, shared experience, shared problems, values and idiom” (p. 198). This unity makes the subject identifiable.

In this chapter I highlight common or shared practices that may be characteristic of the subject cultures of mathematics and science. In doing so I situate the subject culture—its subject matter and prevailing pedagogies—as a major actor in shaping teachers’ practices.

Two themes speak particularly to the different ways in which the subject cultures of mathematics and science shapes the practices of these teachers. The first theme compares the effect of the arrangement of mathematics and science curriculum content on teachers’ conceptualisations of the teaching task. The second theme explores how the focus of instruction shapes teachers’ conceptualisation of practical learning experiences in the subject.

The chapter is organised into four sections. The two themes are presented in the first two sections. In the third section, I consolidate the basic assumptions underpinning the views represented in these themes. In the fourth section, I draw comparisons across mathematics and science in both themes in order to highlight subject differences in teachers’ assumptions about what was central in their teaching. I refer to these common assumptions as “subject pedagogies”, and then recast these subject pedagogies in light of views emanating from the research literature.

6.1. Curriculum content organisation as a shaping influence on pedagogy

Representing curriculum is a difficult task due to differences of opinion about what constitutes curriculum (Bishop, 1991a). One perspective is that curriculum is perceived of as an object that is transmitted to schools (Schwab, 1969). This
conceptualisation of curriculum as content is subject to continual debate, research and reform, and is impacted on by many interested parties, including schools and teachers, politicians and curriculum developers, researchers and members of the wider community who have an interest in education (Romberg, 1992). Grundy (1994) refers to this as an “input” view of curriculum, or as an “object” perspective on curriculum (Grundy, 1998). Curriculum as object equates to the defined syllabus guiding practice, for example, the Victorian Essential Learning Standards (VELS) describe what is essential for students to achieve. More widely, curriculum as object is also referred to as the intended curriculum (Groundwater-Smith, Brennan, McFadden, & Mitchell, 2001; Romberg, 1992), or the ideal or formal curriculum (Goodlad, 1979; Van den Akker, 1998).

Another perspective on curriculum encompasses the complex task of teaching and learning. According to this view, curriculum is

a particular form of specification about the practices of teaching and not...a package of materials or a syllabus of ground to be covered... [A] curriculum is a means of studying the problems and effects of implementing any defined line of teaching. (Stenhouse, 1975, p. 142)

Consistent with this more complex view of curriculum, Schwab (1969) describes curriculum as arising out of the interaction between the “four commonplaces of schooling”—teacher, students, subject matter, and milieu. Schwab’s structure presents “the curriculum as an outcome of any pedagogical moment” (Grundy, 1994, p. 10). The specification of school curricula, therefore, is not only a question of what subject matter students should be exposed to, but is also dependent on the teacher’s understanding of the relationship between the social context and the subject matter, and how students respond to the subject matter. Inherent within such specifications of what students should know and be able to do are assumptions about “what knowledge is, how it is produced, how it is demonstrated and how we make judgements about it” (Grundy, 1994, p. 13). Also referred to as curriculum as “action” (Grundy, 1998), this perspective on curriculum equates to what actually happens in classrooms, also called the enacted curriculum (Tobin & McRobbie, 1997), the operational, experiential or attained curriculum (Goodlad, 1979; Van den Akker, 1998), or the reality (Groundwater-Smith et al., 2001).

My analysis focuses on curriculum as action, the enacted curriculum, because my discussions with teachers were the product of teacher reflection on classroom interactions that were juxtaposed with their beliefs about practice.

The following analysis depicts a perspective on mathematics and science curriculum that reflects pedagogical intentions and needs. It reflects interaction between the various commonplaces of schooling as described by Schwab (1969), that is, between the teacher, students, subject matter, and subject culture as milieu. I focus on the nature of curriculum content organisation as arising from the nature of the
foundational disciplinary knowledge, and shaped by the pedagogical imperatives surrounding the school versions of the disciplines. In Section 6.3, I also use the commonplaces of schooling as an organising framework for examining teachers’ basic assumptions.

I probed teachers’ ideas about the nature of the curriculum during the Sequence 2 Reflective Interviews and Focus Group Discussion. Drawing on these reflections and significant classrooms events, the following sections contrast teachers’ experiences of the nature of curriculum content organisation in mathematics with that in science. Commonly occurring beliefs and experiences provide the foundation for developing basic assumptions underpinning this aspect of the subject culture in Section 6.3.

6.1.1. Teachers’ experiences of mathematics curriculum content organisation

I became aware of issues relating to the organisation of curriculum content during a lesson by Rose (lesson R2) as part of a unit on fractions and percentages. While students were working privately on textbook problems, Rose directed one student to complete an earlier exercise. I asked her about this incident in the interview:

LINDA: I noticed with the Year 8 group that there was one student who was having trouble with the work … You said, “OK what I would like you to do is go back and do this part again.”

ROSE: Or actually finish it, yes. Because Tom is a slower student. [An absent student], whose mathematics is good usually sits with Tom and he helps him all the time... Tom couldn’t do, he really wasn’t up to that, so I just put him back. And I will often do that, make them go back or give them some examples that are at their stage rather than what we are up to. Because there are about four of them that struggle with a lot of the content.

LINDA: Well it is often said about school maths, that it is very sequential.

ROSE: Well it is, and that is the problem, and if they haven’t got these down here, they can’t do this. I don’t know whether you knew but we started percentages and then all of a sudden the kids said to me “How do you do this, this is the multiplication, how do you do this?” And I said “You have done that before.” “No.” So we did a lot of multiplication and division of fractions and then we came back on to percentages. [S2AR:37-40]

Rose’s actions and commentary suggests a curriculum content that is sequential and hierarchical in nature, building on previous concepts and skills, and dependent on students grasping each step to enable them to move successfully through the curriculum. Such sequencing places demands on teaching and learning. When asked about how she saw her role as a teacher of mathematics, Rose stated, “I want them to enjoy maths. Because maths is a threatening subject, it is so threatening because it is so sequential” [S2AR:62]. Her response was to meet students at their level: “And often it is just going back to their level, to fill in the gaps, but sometimes you can’t fill in the gaps, there are just too many gaps to fill” [S2AR:279].
Simon’s view supported that of Rose. The school’s syllabus was considered an important guide for teachers in moving their students along the trajectory: “That is why the syllabus is so important. We rewrote it just on Monday, just to make sure what you have done in Year 7 and 8 [leads into Year 9 so that it] flows” [Simon, S2AS:158,160]. Rose’s pedagogical response in mathematics is reflected in Simon’s aim to ensure students have enough of “those concepts in their heads ready to go and to build on next year, and build on those for the next year and follow that process the whole way through” [Simon, S2AS:239].

Rose demonstrated this last with an example of a normally high achieving student, Jacinta, who missed some foundational concepts:

ROSE: When we did this, Jacinta had heaps of trouble with the triangle because she was away over the next week, and she was away a lot over the next two weeks and she just never ever got – she’s a really good student, but she never ever got that area bit. It’s interesting like I helped her a bit there but not as much as perhaps I should have because as the topic went on, she got further and further and further behind because she wasn’t there in the beginning. [S3AR:134]

James from School B attributed this imperative to move students along the sequence to pressure from the senior years. He explained that the junior years, as the preparation ground for the senior years, are marked by a densely packed curriculum, placing higher demand on, and giving priority to, more efficient pedagogical approaches over potentially more engaging approaches:

JAMES: VCE dominates maths teaching so incredibly. You’ve got all these skills that your students have to have by Year 12 so all that stuff just percolates down and influences what we do. So there’s always this time pressure or tension between having activities which are realistic based on reality but don’t cover all the syllabus and doing stuff from the textbook which tends to cover everything in the syllabus. [S2BJ:102]

Top-down pressure is often experienced by teachers. A finding of the Education and Training Committee (2006) was that a relatively stable curriculum at the senior level exerts pressure on the junior years to adequately prepare students. In the case of science, the Committee found also that “While the Victorian curriculum provides for the pursuit of a generalist science course until Year 12, a number of stakeholders argued that the division of science into specialised streams in Years 11 and 12 is driving the same division down through the curriculum in the compulsory years” (pp. 38-39). Even though this top-down pressure is felt in science, the teachers recognised that preparation for future learning was more strongly felt in mathematics. James’ commentary on the reality for him as a mathematics teacher reflects an approach to curriculum that moves students towards a level of mastery that will prepare them for their senior studies. This view reinforces the ideas coming out of School A.

Teachers’ experiences of sequential mathematics content support Siskin’s (1994) research into subject cultures. Apart from saying that mathematics teachers employ stringent assessment and tracking procedures, Siskin (1994) does not
elaborate on the pedagogical responses that result from such organisation. I questioned teachers regarding the pedagogical imperatives behind the use of such strategies. The clearest message was one of concern for the student. The sequential nature of mathematics content was seen to affect students in a particular way, and this required a particular pedagogical response, that is to support students to successfully move through the content.

6.1.2. Teachers’ experiences of science curriculum content organisation

Science had a similar adherence to a sequence of ideas, but the imperative focused less on student support, and more on coverage of science ideas. Donna demonstrated how the organisation of science content comes to bear on her practice during our conversation concerning her approach to teaching classification keys to Year 8. I observed two consecutive lessons. The first lesson (lesson D9) introduced the concept of grouping using three activities: students grouped lollies in multiple ways; the teacher grouped the class based on different characteristics, for example, girls or boys, red or brown or blonde hair, long or short hair; and students worked in pairs to group a list of organisms from the board. In the second lesson (lesson D10), Donna used the textbook and a worksheet to explain the reasoning behind grouping objects, and gave students a chance to use keys to classify a selection of wet specimens and live animals. During these sessions I had expected Donna to introduce dichotomous keys, which I had previously taught at this level. In the Reflective Interview I asked Donna about the focus of the unit and where dichotomous keys are introduced. Donna explained that the restructure of the science course at Years 9 and 10 had implications for the Years 7 and 8. Some parts of the Year 8 course were moved to Year 9. Despite the textbook remaining the basis for unit content, teachers made decisions about “what level to do it in Year 8” to limit repetition of content covered in the Year 9 subject, Standard Biology.

DONNA: At Year 8 we do basic classification in a short unit of two weeks. It looks at why we classify using the button or lolly activity that we did. Definitely the kingdoms then basic keys. Then in Year 9 we take it to another level and we talk about living and non-living things. A little about cells as the basis of all living things, then get into the five kingdoms, get the kids to think about what fits where and why… There is some overlap just because you can’t expect kids to remember it. “Remember when we did this last year?” and they go “No.” So there is definite overlap. And some kids will not pick Standard Biology in Year 9 … So you try to cover some sort of chemistry, physics and biology so they’ve got some idea of what’s on offer at Year 9 and 10.

Donna described curriculum content as being sequential within topics or disciplines (that is, chemistry, biology or physics) and building on students’ ideas from their prior studies. This is consistent with Siskin’s (1994) description of the science curriculum in Section 2.1.3. Students are introduced to different areas of content that
they are likely to encounter and use during higher year level studies. Donna also implied that the subject matter increases in complexity over the years, explaining that she was comfortable teaching light to Year 8, but would struggle at Year 10 due to the greater degree of difficulty and abstraction: “at Year 9 [explaining light] can get really tricky, like I wouldn’t want to teach physics at Year 10 or Year 11, to explain it even more than that would be, unless you are physics trained, I think it would be really hard” [S2AD:69]. The sequential nature appears at first to mirror the nature of increasing complexity in mathematics, but the difference lies in there being less of an imperative in science to prepare students as thoroughly for future studies as in mathematics. Donna accepted that students tend not to remember ideas from the previous year so that some overlap of content is required. Conceptual knowledge is the focus here, where the distribution of various parts of the topic across the year levels is based on the premise that concepts can be understood at a number of levels.

Despite downplaying the need to prepare students for future learning, Donna was aware that a focus on conceptual knowledge in science poses difficulties for students. When assisting students with their subject selections, Donna found that mathematics and science were often recognised as being intimidating and difficult:

DONNA: I even find that Year 9s now with their subject selections, they are really like “oh, not maths science, no, they are the really hard ones.” And for some reason that attitude is still coming through. They are either hard or boring unless kids are really maths/science students… [S2AD: 57]

Donna refers to her own experiences of learning science to explain these perceptions:

DONNA: I like that whole zoology/ecology type area, and even for me chemistry, physics, that was a bit more, I mean, I’ve got a science mind and it was always a bit more of a struggle, so I suppose I can actually see where that attitude comes from. [S2VSRÖM:59]

Student difficulty and disinterest are important comparisons to draw between mathematics and science. Both Rose and Donna present the subjects as being potentially threatening for students. For mathematics, the threat is associated with inadequate preparation for the next level of mathematics; but in science, the threat is associated with not being able to understand difficult concepts.

Donna’s experiences demonstrate a different pedagogical imperative guiding curriculum content organisation in science than what was observed in mathematics. The fact that I was expecting Donna to cover dichotomous keys in Year 8 suggests that the sequence is not necessarily determined by difficulty and whether students can cope with the complexity of ideas and skills, as is more the case in mathematics, but is structural in terms of what makes sense for a sequence of ideas spread over Years 7 to 10. The conceptual demands are not so specific, nor structured. As Donna suggests, the content covered in Years 7 and 8 was not necessarily a prerequisite set
of knowledges that must be understood to succeed in Years 9 and 10, but was more of a smorgasbord of ideas to introduce students to the different science disciplines.

Ian from School B commented on this distribution of content in relation to his frustrating experience of a constantly changing science syllabus. One example he gave was of science topics that he refined over years of teaching, but which were disrupted by curriculum reform that reshuffled the order and spread of content. According to Ian, students at different year levels have different learning needs, which is why moving a unit from Year 7 to Year 8 requires redeveloping the unit with appropriate teaching strategies and approaches. “Let’s say astronomy, you’ve got to do it quite differently for the next year level, so every one of those changes just makes a huge difference to getting a syllabus working properly” [S2BI:163]. This movement of topics across year levels is provided for in state curriculum documents (see, for example, Victorian Curriculum & Assessment Authority, 2005b) where Level 5 prescribes topics that can be applied at any point across Years 7 and 8 at the discretion of schools. Textbook writers also have a guiding hand in the arrangement of subject matter. For example, an analysis of different Year 7 and 8 science texts will show a difference in the order of content across the two years, for example, electrical charges and the atom occurs in the Year 8 ScienceWorld (Stannard & Williamson, 2007) text and the Year 7 Science Links (Cochrane, Devlin, & Coffey, 2005) text. Ian’s attitude reflects the pedagogical implications of topics being shifted. Not interruption to the progressive building of science ideas, but the compilation and sequencing of appropriately targeted activities is the basis of Ian’s concern.

A second example that Ian gave related to his experience of a constantly changing teaching load:

IAN: You’ll do a course one year, get the Year 7 science course right. Next year you find you’re not teaching junior science, you’re teaching Year 8 maths, and you come back in two years time and the course is all over the place, and it makes a huge difference [S2BI:93]

For Ian, disruption of the syllabus is not necessarily a problem for students’ ability to understand at different levels, but interrupts the development of units that “work,” meaning developing units that have a sense of coherence and age appropriateness in terms of activities that expose students to the particular knowledge and skills. From his perspective, the enacted curriculum in science is relatively dynamic and subject to reshuffling and refining. As such, a particular sequence of ideas and skills or processes is not regarded as vital for student success as it is in mathematics.

In summary, the experiences discussed above describe how curriculum content organisation came to bear on teaching and learning in both subjects. School mathematics was characterised by an adherence to highly specific and sequentially
arranged curriculum content. School science was characterised by movement through sequential content where the conceptual demands are less specific and structured, and where the concept can be understood at a number of levels.

6.1.3. Subject culture shaping the pedagogical response to curriculum content organisation

Underpinning these views about the nature of the curriculum content are assumptions about the nature of the subject matter and the relative importance afforded to the subject. Evident also were the type of pedagogical responses by teachers as they make the subject accessible for their students. Each of these issues is explored below drawing from interview data and relevant literature.

The nature of the subject matter

Curriculum content organisation depends on the nature of what is being taught. Subject matter differences were a defining element of their practice:

ROSE: Well, I haven’t taught science since my first year out, but I believe there are different demands, absolutely, and if a child is absent from maths, it’s really hard to catch them up. Whereas if they are absent from science, it’s a topic and it really doesn’t matter. Because it doesn’t matter in the next year if they haven’t done—

SIMON: Maths is continuous whereas science is topic based.

PAULINE: Its discrete, that’s right. [FGD:2-4]

When asked if there were sequential elements in science, Pauline and Simon identified certain skills that were ongoing, such as “mathematics skills, reading graphs” (Pauline, FGD:11), and “measuring, analysing” (Simon, FGD:12), which, if “missed in the junior years makes it harder in the senior years. But I don’t think content, not until you get to the senior levels does it matter too much if you miss content” (Pauline, FGD:13).

Pauline and Donna compared the sequential and hierarchical nature of the two subjects, signalling a difference in the relative focus on skills and procedural knowledge, and conceptual knowledge:

PAULINE: There are basic tools in mathematics and if you can’t utilise those tools as part of your tool box then the more complex stuff becomes impossible. It’s like trying to build a house without a hammer. If you don’t know how to use that hammer or that power-saw, then later on when you’re doing really complicated stuff putting the bathroom together, you’re lost.

LINDA: Are there some bits in science that are like that too then?

DONNA: I think there probably would be but I don’t think it’s as dramatic or as noticed as it is in maths. Because in science we do revisit certain topics, I mean you can do Year 12 Biology without having done it in Year 11. I mean I went to uni with students who hadn’t done biology at all. So, that would be hard, they’d probably have to work harder, but you can do it. I mean I wouldn’t want to take university maths and have didn’t done it at Year 11 and 12. [FGD: 40-42]
A topic-based science curriculum consists of some skills that develop over time (some of which are mathematics skills). While concepts provide a foundation for the next year’s study, they can be easily picked up and understood if missed in earlier years. As expressed by these teachers, movement through the science content involves students encountering different concepts and skills that may or may not be adequately acquired at any year level. Teachers gave greater weight to skill and procedural development in mathematics than in science. Pauline captured this imperative when she described mathematics as a “tool” subject, implying that mathematics is something that students use and do. Being able to do mathematics is the focus, which invariably requires a strong conceptual base. On the other hand, the notion of being able do science is perhaps overshadowed by the notion of being able to understand science, where the focus is more on the acquisition of conceptual ideas.

**Relative importance afforded to the subject**

In mathematics, the imperative of filling the gaps has the potential to dominate a teacher’s perspective on student learning. This imperative stems from mathematics being one of the “core skills for life” [Donna, FGD:46], along with English, that “go over different [subjects]” [Rose, FGD:47]. “They’re skills, numeracy and literacy are skills that spread throughout the curriculum, whereas science is a content based subject and its not as essential” [Pauline, FGD:48].

Two traditions have led to such beliefs about mathematics. The first tradition relates to the degree of importance afforded to mathematics. For example, Connell (1998) describes schools as being traditionally constituted by a Competitive Academic Curriculum in which there is a hierarchy of subjects, with mathematics sitting at the top. The second tradition arises from the first, and that is that the school versions of the disciplines have been sculpted in a particular way and for a particular purpose (Niss, 1994; Romberg, 1992). Although science is often seen in educational literature as being an “enabling” subject (Education & Training Committee, 2006) the development of numeracy skills (Siemon, Virgona, & Corneille, 2001), along with literacy skills, have traditionally received a higher level of immediacy and importance in the curriculum (see Niss, 1994). Ensuring success in these areas becomes a fundamental goal for teachers. Success as presented here by these teachers relies on building new knowledge and skills on a solid foundation. Rose mentions earlier that this has resulted in the development of a sequential curriculum. What arise also are pedagogical approaches that emphasise the support given to students to move successfully through the subject matter.
Pedagogical response

The third issue relates to teachers’ pedagogical response to these two issues. The experiences of teachers highlight certain pedagogical responses arising out of the organisation of curriculum content. Teachers compared the need for a variety of supportive practices in mathematics and science.

In mathematics, the metaphor of filling the gaps that Rose used in Section 6.1.1 highlights the “continuous” nature of the mathematics curriculum content. Learning builds upon, and relies on, prior learning and, therefore, requires “catching up” when a student has been absent. The potential of missing content makes a subject “threatening” for learners if the content requires keeping on top of what is taught. This experience of mathematics has been described in research. For example, one of the challenges facing the teaching and learning of numeracy, according to Siemon et al. (2001) is the significant number of students that experience failure or a sense of disconnectedness, and, consequently develop into “reluctant learners” (p. 7). The Education and Training Committee (2006, p. 165) found similarly that “maths anxiety” is a common response by mathematics learners due to a fear of mathematics and a lack of confidence resulting from gaps in student understanding. Such anxiety and reluctance can ultimately lead to student disengagement. Because of the sequential nature of the mathematics curriculum content, and the demand that this places on student learning, the need for student support became central for these mathematics teachers. An assessment regime that monitored students’ understanding was mentioned by Pauline as being more important in mathematics than science to ensure students do not get behind:

PAULINE: in science I’ve been known to say to a kid who has been away, ‘I won’t test you in that topic’, or just give them an assignment and use that as their assessment rather than the full test. But with maths I feel the need to make sure they have understood that topic because they’ll need it further down the track. [FGD:32]

A review into middle years numeracy (Siemon et al., 2001) found that success is a major component in student preparedness to engage with mathematics in the middle years. Early diagnosis and intervention were considered critical factors. Siemon et al. recommend the identification and elaboration of numeracy-related growth points, and the scaffolding to help students move through them. Individualised student support allowed teachers in my study to attend to students’ needs at their level so that students could achieve success, as well as be more optimistic about their own abilities: “there are all different levels, and if you can help them at their level then you are building up their self-esteem and they will feel better about it and therefore they enjoy it more” [Rose, S2AR:64].

The struggles that students experienced in mathematics were seen to have more significant consequences, and require closer individual attention than those in
science. For example, in relation to his son’s mathematical ability, James said that “like so many kids when it comes down to thinking maths, it just doesn’t click”. He confessed that he has not “worked out a magical way of helping out those kids” [S2BJ:126]. This is contrasted to his view of the support needs for science learners: “students ‘cotton onto’ science pretty readily because of the tangible nature of much of the science that students study in junior science” [S2BJ:128].

A non-threatening classroom environment where students felt safe to take risks in exposing their limited knowledge was a pedagogical response that was mentioned in relation to both subjects, but particularly mathematics. Rose developed an environment that reduced student anxiety by ensuring that the learning experience was enjoyable and personal:

ROSE: I have set the environment, I hope to make it non-threatening because maths is such a threatening subject… And I hope the kids will have the confidence to ask and that no-one gets left out because if you don’t know things, there will be other kids in the class who don’t know. [S2AR:249, 251]

Ian recognised that genuine student engagement with mathematics and science ideas requires a safe environment where students can expose their ideas. Classroom discussion provides such a forum: “A bit like in the maths…it’s possible by that type of discussion technique to point out what’s wrong with that answer without trying to put the kid down” [S2BI:115].

Subject matter differences are manifested as pedagogical differences in the above examples. Generally, teachers afforded a much higher demand for support to mathematics. At the centre of each of the above pedagogical choices in mathematics was the need to support students as they build firm foundations and extend their existing knowledge. In science, the need for support was evident, but was mentioned less in interviews. The message from this research is that, when compared with the support needs in mathematics, those in science are diminished.

In summary, a number of issues were raised by teachers in relation to the structure of the curriculum content in both subjects. Stodolsky (Stodolsky, 1988; Stodolsky & Grossman, 1995) asserts that the nature of the subject matter and its organisation is unique to any subject and likely to determine teaching practices. While this assertion is supported by my data, also evident in the data was a difference in the degree to which student support is a central pedagogical imperative. Curriculum content organisation plays an immediate and critical role in shaping the practices of the mathematics teacher because of the demand that the nature of the content, the progressive nature of student learning, and the traditions of status and importance, place on student learning. The shaping effect of the curriculum organisation appears less central in the minds of the science teachers, who are guided by an imperative to plan units “that work”, that is, units that are age appropriate and that provide opportunities for students to engage with science concepts at various
levels. This comparison arises out of differences in the degree of specificity and sequencing of the subject matter—mathematics to a higher degree than in science.

6.2. Learning experientially through hands-on activity

While teachers of mathematics discussed the imperative of support and sequencing of content as an overarching pedagogical concern, many of the science-related discussions centred on the generation of student interest in topics and ideas through engaging with the objects of science. Throughout the data, practical activity was recognised by teachers of science as supporting a form of activity that they characteristically associated with the subject.

Experiential education is based on the idea that active involvement enhances students’ learning (Kolb, 1984, 1993; Kolb & Fry, 1975). Kolb, along with Bruner and Piaget, maintain that learning through experience is needed for intellectual development. In fact, learning through experience is an ancient pedagogical tradition:

Tell me, and I will forget. Show me, and I may remember. Involve me, and I will understand. (Confucian proverb, around 450BC)

The notion of “activity” can be regarded in two ways: a form of action, or a structure that is intended to direct the action. Christiansen and Walther (1986), for example, distinguishes between “activity” and “task” on the basis that a task relates to what a teacher has in mind, and the “activity” is students’ response to the task. The activity may align with or be tangential to the teacher’s set task, so that a range of possible activities may result from the one task. This refers to activity as a form of action.

Alternatively, teacher resource materials often refer to “tasks” as “activities”. For example, textbooks commonly label tasks as “activities” (see, for example, Lofts & Evergreen, 2000). My use of the term activity resembles Christiansen and Walter’s “tasks” in that I am focusing on the way the teacher provides experiences to direct and shape student learning. Hence my research focuses on activities as the intended structures that direct student actions.

At the secondary level, activities used by teachers to actively involve students in any subject area reflect the teacher’s assumptions about the nature of the content, teaching, and learning, in that subject (Cripps Clark, 2006). Assumptions may be based on long-standing traditions, and hence what occurs in the classroom reflects traditional discourses. Alternatively, assumptions develop in response to a shifting subject culture, where the teacher embraces more innovative discourses.

This section is based on a discussion between teachers at School A that signalled their desire to actively involve students in their learning in both subjects through the use of activities that engage students with the ideas, objects, artefacts, processes or tools of the subject. Through the analysis I draw out differences in
teachers’ pedagogical approaches and beliefs across and within the subjects. I also examine the role of the context of school subject departments in perpetuating certain practices, or challenging assumptions as more innovative discourses make their way into the school subject culture.

6.2.1. Teachers’ experiences of using activity-based teaching approaches

A key excerpt from the Focus Group Discussion introduces those types of activities that teachers recognised as providing important experiences to assist learning in secondary school. These experiences principally focused on the “hands-on” kind. The discussion signals practical activity as a normalised, culturally-accepted practice in science, while mathematics is considered lacking in this type of experience. This exchange was prompted by the question: “What science teaching practices would benefit the teaching of mathematics?”

Taking part in this discussion were two teachers who preferred mathematics, Rose and Simon, and two who preferred science, Pauline and Donna. All teachers recognised differences in the pedagogies employed in the two subjects. All recognised the value of “hands-on” experiences in the two subjects. But by reflecting on the cultural expectations and traditions surrounding the incorporation of such activities, Pauline and Donna, as less experienced teachers, recognised their need for guidance in knowing how to use such activities in mathematics. Rose, as the only experienced mathematics teacher, appeared to be singled out as the enabler because of her breadth of experience and knowledge of resources and activities. Pauline and Donna, the two science-devoted teachers, seemed more confident in knowing how to incorporate activities in science.

PAULINE: As Rose said, finding the practical applications and demonstrations. In science we can do the pracs, we can show videos, we can do demonstrations, we can tell stories, we can relate to kids’ lives. These are all things that are harder to do in mathematics. If we could, if we knew ways of doing it, it might make mathematics less frightening. Yeah, it’s not always easy.

DONNA: Maybe the whole visual idea. I know you see some kids you can explain it as theory but once they see it through a demo or a prac you see the light bulb go off. I think it would be kind of good if you could do that visually, like you do that fraction walls.

SIMON: For every topic

DONNA: Yeah, where you could maybe show it a bit more visually. I mean, look at all those activities you’ve got Rose. Great hands-on sort of stuff.

SIMON: Open-ended tasks.
DONNA: Games that you’ve got that you can do with them. They can actually see it. What was that meeting last year where they were actually physically moving blocks across? The fraction walls where they were actually building on top of it and you could actually see, OK you take the four little blocks and you put them on top of this one and you’ve got a whole. Like I think if they can see it, it helps.

PAULINE: The primaries do that a lot better than we do.

ROSE: Because they’re in the same room all the time and they have everything there that opens and shuts. Whereas we’re moving around. How many different rooms are you in for your junior classes?

PAULINE: And see, in science, that’s the thing, we have science rooms and we have Shamus [the lab tech], and Shamus can bring out equipment and you can just ask. Imagine if we had a maths lab assistant: “I’d like you to bring all this stuff to my maths class so that I can…”

DONNA: Have a look at these (pointing to hanging 3-dimensional shapes on the ceiling). You could explain these shapes.

PAULINE: This room’s a show piece though. We need more of them.

DONNA: But some kids will visualise that in their head and go terrific. But some kids need to see that and go, oh. You can do that in science a lot, look what happens when I put this with this, this happens, and the kids see a colour change, you can tell them the colour change happened, but it’s not the same as watching them go to their benches and go “Oh!! Look it’s fizzing, it’s coming up!!” Whereas if you could do that a bit more in maths that would be good. [FGD: 62-73]

Figure 6.1. Science teaching practices benefiting the teaching of mathematics.

Two key points are raised by this excerpt. One is that, in science, instruction appeared to be quite firmly centred on phenomena, which can be experienced, observed, manipulated and made sense of. Teachers believed that students gain understanding through such practical encounters. Another point is that, in mathematics, incorporating hands-on, visual and aesthetically compelling experiences was desirable but constrained for various reasons. Other teaching approaches such as open-ended problem solving were mentioned.

Each of these points warrants exploration in understanding the basic assumptions that underpin teachers’ observations about what teaching approaches tend to “characterise” mathematics and science. In the following analysis I examine the influence of the subject culture in perpetuating certain teaching practices. I then juxtapose the views of these teachers against a changing cultural landscape depicted in the research literature.

6.2.2. Phenomena as the focus of instruction in science

In Figure 6.1, Pauline signalled reliance by science teachers on a diversity of teaching approaches, all of which allow students to engage with natural phenomena
either through first hand experiences (practical experiments and demonstrations), second hand experiences (videos), or other personal experiences (telling stories). This section examines how teachers positioned experiential learning in the form of practical-based activities as being culturally embedded in science and an integral part of science teaching.

Experiential learning is epitomised in school science as practical work, both by these teachers and the literature. Despite questions raised in the research literature about the role and effective use of practical work (see, for example, Hofstein, 1988; Hofstein & Lunetta, 1982, 2004), such experiences are widely recognised as fundamental and unique to science learning (Atkinson & White, 1981; Beatty & Woolnough, 1982; Christensen & McRobbie, 1994; Garrett & Roberts, 1982; Gough, 1998; Hofstein, 1988; Hofstein & Lunetta, 1982; Jenkins, 1998; Turner & Turner, 2000; Wardle, 1998; Wellington, 1998; Woolnough, 1991). The Education and Training Committee (2006, p. 179), for example, states that “experimentation is a central pillar to science education.” Similarly, Bennett (2003) claims that “Practical work is one of the prominent features of the science curriculum in many countries, and its place in science lessons often goes unquestioned” (p. 73). As an empirical way of knowing, science seeks to explain those things that can be experienced, tested, and modelled within the natural world (Victorian Curriculum & Assessment Authority, 2005b, p. 5). It follows that the ideas in school science are about natural phenomena. Concrete, visual and objectified concepts are placed at the centre of the learning process.

Generally speaking, as a form of activity in the science classroom, experimentation or “practical work” refers to those hands-on experiences where students are actively and physically engaged with concrete materials. Researchers interpreting the Trends in Mathematics and Science Survey (TIMSS) (Lokan, Hollingsworth, & Hackling, 2006) describe practical activities as “opportunities for students to observe and/or manipulate science-related objects” (p. 91). They define practical activities in science as:

- traditional laboratory experiments and other hands-on interactions with objects such as producing and observing phenomena, building models, designing and testing technological solutions to problems, classifying materials and drawing observations of objects. (p. 91)

Hands-on or direct experiences are well regarded as being essential for the acquisition of new concepts (Butts, Hoffman, & Anderson, 1994). Meinhard (1992, p. 2) explains that “hands-on activities mean students have objects (both living and inanimate) directly available for investigation”. Consistent with the literature, teachers in this study placed practical experiences at the centre of students’ learning experience. Concrete materials, as objects, were often used as the conduit for actively engaging students with the phenomenon under instruction. The objects were either:
• the natural phenomenon itself (such as chemical reactions in the lessons of Donna [lesson D6] and Simon [lessons S6, S7]);
• representations of these phenomena (such as the use of the Van de Graff generator to model the static electric discharge of lightning in Pauline’s lesson [lesson P2]); or
• equipment that enabled manipulating or experiencing natural phenomena while learning about and participating in the processes of science (such as using filters to separate mixtures whilst determining the best filter in two of Ian’s lessons [lessons I2, I3]).

The central nature of practical work to science pedagogy was also evident by the proportion of time devoted to practical work. As can be seen in Chapter 5, 18 of the 27 science lessons included activities that can be regarded as being “practical” in nature. Six of the nine lessons containing no practical experiences were used, at least in part, to either prepare students for practical work in the next lesson, or were following up on ideas emerging from practical work in the previous lesson. Evidently, experiential learning, where students experience those things that science is attempting to explain, was promoted as being a fundamental pedagogical tool.

Of primary interest in this analysis of how the subject culture shapes teachers’ practice are the assumptions that underpin teachers’ pedagogical choices. Above all, teachers believed that participation in practical work promoted understanding of theory.

**Practical work and theory**

Teachers identified practical experiences as being a distinctive part of the science culture, recognisable within a lesson, and distinguishable from theory: “because sometimes there are just theory lessons” [Donna, S2AD:59]. But even when a lesson was theory based, Simon found that it was important to allow students to experience the phenomenon. Simon labelled lesson S2 as a theory lesson “because they didn’t do any prac” [S2AS:96]. He explained that “the theory side of things, I am not a big fan of it to be honest, but I suppose that has to be done” [S2AS:92]. “I hated those periods [when I was a kid] and I always used to get into trouble because I’d be like, this is boring, and I would be the trouble maker in the class” [S2AS:100]. As a result of these learning experiences, allowing students to experience the phenomenon rather than simply accept a textbook or teacher explanation was important for Simon. In lesson S2, students used magnetic filings, magnets and other equipment related to magnetic fields to supplement the “theory” thereby setting up a hands-on experience where “they are still asking questions like why does this happen. They’re theory ones that I like” [S2AS:96].
This distinction between practical-based and theory-based teaching approaches is consistent with large scale analyses of science classrooms. For example, TIMSS researchers distinguished between “practical activities” (as previously defined) and “seatwork activities” on the basis that the former involved “objects and related phenomena” and the latter did not. Seatwork activities referred to “those activities … that did not involve the use of objects” (Lokan et al., 2006, p. 42).

**Multiple purposes of practical work**

I identified three broad purposes of practical work that teachers referred to when providing commentary on, or justification for, using practical experiences. These views emanate from both schools, and represent a collective account of the various purposes of practical activity.

The first was to *motivate* students at both emotional and cognitive levels, and that both levels were required for students to learn. For example, Donna believed that “fun” experiences were important for motivating students to learn. She mentioned that including practical activities reduced the intimidation that students experienced in science by making the subject “fun” and “interesting”, and “not scary” [S2AD:59].

Also: “It’s making sure they’re having fun because they won’t learn it as well otherwise” [S3AD:34]; and “it’s a fun way to learn and it reinforces all the theory” [S3AD:58].

Pauline understood that students could be carried away by the more superficial practical elements of a learning experience: “they love chopping things up, not so happy with drawing it after” [Inf:22]; and “we had this wonderful double prac where we had been exploring static electricity and the kids really got into exploring, more than was written in the prac” [S2AP:2]. Motivational advantages associated with the practical activities, therefore, do not necessarily translate to the written work.

Simon also believed that practical work has motivational dimensions, saying that “if it’s a fun activity they might want to ask questions” [S3AS:92]. According to Simon, this propensity to make science “fun” was a widespread move within the science department at School A in response to falling student interest in senior science:

SIMON: In science particularly we had, our numbers have dropped in science... So our KLA coordinator puts a bit of emphasis on trying to make it fun, as fun as possible. But that doesn’t mean you do games for no reason. Like doing that friction blow game was all about the fun side of it, but the friction fun side of it. But that’s our real main focus in science at the moment, trying to make things fun. [S2AS:18]
Simon seemed to plan for personal engagement with the activities for the purpose of motivating student learning through fun and activity-based experiences. He was careful to emphasise that he is not talking about using activities just for fun, but for the “friction fun side of it”: that is, how the activity demonstrates the concept of friction as experienced through the activity. The danger, of course, is that the science concepts can be relegated to a context for fun activities. The link between theory and the activity can become tenuous when the activity itself is the intended outcome at the expense of understanding the concepts, or when the nature of the activity is a distraction to student understanding (Appelbaum & Clark, 2001). Despite this problem, practical experiences were regarded by Simon, and the other teachers, as being potentially compelling and motivating, and providing opportunities to actively engage at kinaesthetic and multi-sensory levels.

A second belief was that practical work enabled students to participate in the processes of science, thereby enhancing students’ skills and scientific thinking. In her Reflective Interview, Donna recognised that students “see” the concepts better, but she also aligns students’ participation with the work of scientists:

DONNA: They see for themselves what we’ve been talking about. I told them it’s one thing for us to hear these things, or get told they happen, or for a scientist to do an experiment and say this is what I got. But I said it’s another thing to go out there and prove it. A lot of science is about coming up with these ideas and then proving it. [S3AD:56]

Donna’s comments relate to a lesson that I did not see. In comparison, I saw a strong emphasis in Ian’s separating mixtures lessons (lessons I1, I2 and I3) on science processes, particularly fair testing. This type of activity, Ian believes, both engages students and gives students a glimpse at the core of the scientific endeavour:

IAN: designing their own experiments is the one thing that really works … that’s the thing that makes it science. It’s not the content so much as the thought behind it or the scientific process. What makes an experiment? What’s a valid experiment? What can you draw out of this data? And if you can manage to put the two together you’re doing really well? [S2BI:59, 63]

A third common belief was that practical work assists in student understanding of science concepts. To achieve this depth of understanding, Pauline believed that students needed opportunities to develop explanatory understandings from their practical experiences. As mentioned in Section 5.2.3, observing things and explaining them was a natural part of Pauline’s approach to her own learning. Opportunities for class discussion based around students’ experiences, was, in her view, one of the main differences between her mathematics and science teaching: “in maths we don’t discuss enough. It is really hard to get kids to talk in maths… I need to do more on exploring what they know already” [S2AP:36].

Donna referred to concepts that required physical demonstration (see Figure 6.1). She appreciated that learning from a practical experience requires
understanding “why we are doing it”, which was why she tended to “go over the prac a little before we start so that then while they’re out there having fun they can at least hopefully remember what I said” [S3AD:34]. Both Donna and Simon talked about ensuring students understood the purpose of the practical by getting them to write the aim in their own words: “so they understand the prac” [Simon, S2AS:64], and so that they see the “relevance” [Donna, S2AD:61]. Ian’s experience suggests practical work can impede learning when the presence of equipment provides distraction and allows for student activity that is tangential to teachers’ intended aims: “if you’re doing an experiment, they’ve got that much equipment they can’t see the actual activity. The best activities are the ones with the smallest amount of equipment” [S2BI:83].

The effective use of practical activity involves conceptualising the complex relationship between the practical activity and conceptual learning. The above purposes are dependent on teachers distinguishing between pedagogies that perpetuate superficial learning from those that promote real engagement with ideas and evidence. This means knowing how to motivate in conceptually meaningful ways, how to represent the processes of science authentically, and how to use practical work to develop deep understandings. While practical work was seen by these teachers as assisting students in gaining understanding, they understood that careful structure and preparation was necessary for students to achieve the intended outcome. The motivational dimensions of practical work were seen by teachers to be beneficial for engaging students with the science concepts, although, whether a teacher achieves such deep engagement depends on their beliefs and knowledge associated with learning, teaching, and content. In the following section I look more closely at the relationship between teachers’ individual beliefs and their approach to their use of practical activity.

**Variation in using practical encounters for learning**

Teachers appreciated the theoretical dimension of any practical experience; however, they varied in how they related practical learning experiences with science ideas and practices. What follows is a characterisation of how each teacher approached this relationship.

*Donna: Tell, then show*

Donna’s lessons had a typical pattern of presenting theory through lectures and discussions and, usually, individual bookwork and other written work, often with worksheets. This was often followed by practical work sometimes with a demonstration of how to do the experiment, then a summarising lecture and discussion at the end or in the next lesson. This sequence was particularly evident in
lessons D1, D2, D3, D6, D7 and D9. Hence, Donna demonstrated a reliance on the practical experience to give meaning to the science theory, often sandwiching the practical experience between theory-based approaches. When asked “What sort of things do you tend to tell, and what do you tend to let them work out?”, Donna replied:

DONNA: Some basic theory I will tell them, like light moves in straight lines. I like to tell them the theory that they then could have to be able to tell me what they think is happening. So I like to give them enough information, like I think with those work sheets I gave them, how we talked about light, how it moves in straight lines. We talked about how it bends and it bends when it changes mediums and stuff. I was actually hoping that they might be able to use that to then go “Oh, OK.” [S2AD: 62]

In a later interview Donna stated that practical work “reinforces all the theory” [S3AD:58]. The theory was the main game for Donna, and the practical work provided another way for students to understand it. To Donna, different “learning styles” are catered for because “There are the ones that need to move around to see things or the ones that can take everything in and they don’t need to see it” [S3AD:12]. The sequence of segments for many of her lessons moved largely from theory to experiencing the theory through practical work. Hands-on activities provided confirmation and consolidation of potentially abstract or unfamiliar concepts, such as the difference between physical and chemical changes. These experiences allowed students to explore the phenomena and engage at an individual and personal level. Donna relied on the practical experience to give meaning to the science theory. But also, the theory prepared the ground for understanding the practical experience. By immersing students in the language needed to interpret and explain their observation, her hope was that their practical experience would be purposeful and lead to an enhanced and multidimensional understanding of the science concepts.

Pauline: Show, then tell
I noticed no regular pattern in Pauline’s lessons; however, in the second and third data sequences Pauline provided opportunities for practical work first then lecture and discussion. In these instances, the theory was introduced after the practical work and largely in consultation with students by drawing on their experiences from practical work rather than relying largely on textbook or worksheet explanations. One sequence (lessons P2 and P3) involved eliciting students’ experiences of various static electricity activities from the previous lesson, from which Pauline extracted three rules about static electricity. During this discussion, Pauline used the story of Benjamin Franklin’s discovery and postulations relating to static electricity, and students’ prior experiences with magnetic forces, attraction and repulsion. This segment lasted for 30 minutes. On reflection, Pauline felt that this lesson was
unrepresentative of her practice because it resembled a lecture rather than a
discussion, and because students were uncharacteristically compliant\(^6\). Another
lesson sequence followed a similar pattern of practice to theory. For ten minutes
(perhaps a more representative length of time) Pauline discussed students’
observations about a heart dissection from the previous lesson (not observed) from
which she constructed a diagram of the mammalian heart on the board (P6). This led
to teacher explanations about relationships between blood and the heart, and
relationships between different body systems.

In both of these examples, Pauline used the practical work as a springboard to
theory building. Pauline explained that “I like to spend, and I do spend at least 50% of
my time doing prac work because I am into observing things and then talking
about them” [S2AP:36]. This pattern was evident in her classroom. Explanations are
immediately contextualised through visual images that are familiar to students.
Pauline stated that having a visual and concrete component to an explanation is her
ideal: “A really top explanation would have something physical that I could use to
demonstrate…[I like to include] something physical, a diagram, a written, and a
verbal discussion, something that is going to appeal to everyone’s learning”
[S2AP:184]. A sequence of hands-on experiences followed by theory provides
opportunities for students to be actively involved during the hands-on activities, but
also in the social construction of theory through classroom discourse. Students’
experiences form the basis and logic of the formal scientific explanation. During
classroom discussion students could be seen to be actively involved in this
knowledge construction.

**Simon: When to tell**
For Simon, when to tell also amounted to how much to tell students. In his lesson
relating to everyday reactions (S6), Simon grappled with this tension between
preparing students with the theory beforehand and allowing students to discover the
information through the practical experience.

**SIMON:** Some things I would have improved on. I should have probably discussed the
background of the prac first. Like a little bit more information on hydrogen and
all that sort of stuff. Because I did give it to a few kids as we were going around
but I should have maybe introduced where hydrogen is used before that, but then
we did that after it. Like we talked…

**LINDA:** …yeah talking about the zeppelin.

**SIMON:** Yeah. But we could have maybe done that at the start and talked about densities
and stuff like that but I did it throughout so that was okay…I ran out of time to do
the summary because by the end kids were packing up…And a few kids had said,
“Oh I found out some things.” But I didn’t get enough time to do a whole group
discussion about it. [S3AS:72-74]
Students’ intrigue during the activity motivated them to ask Simon questions in search of information to explain their observations, but this raised a predicament for Simon for two reasons. One was that only some students asked those questions and participated in the sharing of ideas. Secondly, a follow up discussion was not possible before the lesson ended, so students were unable to share their observations and new ideas. Within this lesson, many students lacked the opportunity to be actively involved in the social construction of knowledge through discourse involving the teacher, although it may be assumed that some level of social construction of understanding may have occurred within the student groups. However, Christensen and McRobbie’s (1994) investigation of interactions of a highly motivated group of students doing traditional practical work questioned this assumption, showing that rarely did the understandings that resulted from such collaboration focus on the intended concepts.

Simon’s predicament raises the importance of ensuring that the role of practical work is not relegated to a motivational activity, divorced from theory.

*Ian: Do and discuss*

As discussed in Section 5.2.6, Ian always appreciated the need to give students experiences where they could make their own discoveries and draw their own conclusions. Ian had come to appreciate that well constructed questions following a practical experience, or during a teacher-led demonstration, are important for students to make sense of their observations. Class discussions, according to Ian, provide the space for productive dialogue that allows for a social construction of knowledge, but which also has the potential to expose naïve or incorrect conceptions.

Ian’s approach is consistent with constructivist approaches to teaching and learning, which suggest that “students construct their knowledge of scientific laws on the basis of their own experiences” (Geelan, 2002, pp. 25-26). Geelan makes the point, however, that a large part of the science syllabus is not capable of being experienced because it is based on sophisticated and highly abstract models. In Ian’s candle demonstration, students could not personally experience the effect of sound at the atomic level, and Ian felt that they may not have made adequate sense of their observations without his lead. While it may seem unreasonable to expect students to “discover” laws and theories that took scientists years to construct (Roth, 2002), Ian gave students scope to develop, or “discover”, their own representation of the effect of sound waves on air particles, enabling them to begin to make sense of the theoretical framework explaining this phenomenon. Ian’s teaching experience enabled him to appreciate the importance of using practical work as a means of reasoning through explanations.
Establishing consensus across the science subject culture

Five points arise from this analysis. One is that there was consensus amongst these teachers that the value of practical work lies in the fact that the nature of science knowledge is phenomenon based. They relied on practical work as a pedagogical tool to make links between theory and natural phenomena.

The second point is that, while the school science subject culture (at least in the western tradition) makes practical work central to the learning experience (Education & Training Committee, 2006), managing the relationship between the activity and theory appears to depend on the teacher’s epistemological position. Different epistemological perspectives are evident in these snapshots of teachers’ practice. Donna’s perspective represents a position that experience enhances understanding of concepts; Pauline’s represents a position that understanding emanates from experience; Simon’s represents a position that experiencing the practical side of science dominates the learning experience; and Ian’s represents a position that practical experiences provide opportunities for reasoning and inquiry.

This variation is consistent with that found in other research into teachers’ beliefs and practice. Research into teachers’ beliefs about practical work shows that teachers hold many, varied beliefs that may to a certain extent be manifested in classroom practice. Kang and Wallace (2004), for example, examined the beliefs and practices of three science teachers in relation to practical work and found that not only were there variations across teachers, but that a single teacher’s epistemological beliefs about science can be multi-dimensional and manifest different, and sometimes contradictory, goals and actions in the classroom.

A fourth point emerges when teachers’ views are compared with the literature. While teachers agreed on the important role of practical work, no such consensus occurs within the science education research community. Practical work receives both justification and critique. Justification is based on the premise that such experiences, for example, reflect the nature of the work of the larger science community in that they use empirical evidence to build knowledge; they promote the image of science as inquiry; they provide opportunities for students to build and understand scientific ideas through first-hand data and observations of phenomena; and they stimulate and maintain student interest and engagement (see Lokan et al., 2006, for a review of these and other justifications in the literature).

Criticism of practical work is based on trends in the structure and application of practical work that counteract the justifications for their use. The Education and Training Committee (2006) reported that there has been a tendency in the science education to perpetuate the image of science as theory, rather than science as practice. In addition, various science education researchers take issue with “the easy
assumptions that science educators make about the meaning of ‘experience’” (Wallace & Louden, 2002, p. 33). The mismatch between students’ experiences and theory make experience-based approaches problematic at times (Wallace & Louden, 2002). Recipe-style practical experiences have been described as uninspiring and unchallenging (Education & Training Committee, 2006; Goodrum, Hackling, & Rennie, 2001). Kesson (2003) comments that “hands-on classroom activities are most often carefully structured, and designed to teach students how to follow directions and promote a number of process skills” (p. 54), including observation, hypothesis formation, prediction and recording results, but that “there is little opportunity to engage in the exploratory processes that involve conceptualising problems and planning experiments” (p. 54). Further to this, Roth claims that “School laboratory activities are largely ill conceived, confused and unproductive in that many students learn little of or about science and do not engage in doing science” (Roth, 2002, p.43). The use of recipe-style laboratory experiences, coupled with an out-dated, canonical curriculum, have tended to remove school science from the central aspirations and interests of young people (Aikenhead, 2006; Tytler, 2007).

The fifth and final point is that, while the science subject culture plays an important role in perpetuating conservative traditions in the Traditional Subject Culture, it also has a role in supporting change towards more effective practices. Given that practical activities are culturally embedded and unlikely to be stripped from a science teacher’s tool box, others in the science education research community focus their attention on how to structure activities to produce better learning outcomes. For example, Lokan et al. (2006) list factors that research regards as important for effective practical work. These are that practical work should: be first-hand inquiry activities that increase student interest and improve understanding of the nature of science; increase student responsibility by having them ask and investigate their own questions; use project-based “authentic” inquiry activities; and have an increased emphasis on “minds on” in practical work, where students predict, analyse, represent, and interpret first hand data to build scientific arguments and support the development of scientific concepts.

Ian’s emphasis on supporting reasoning and inquiry is an example of how students use their observations and carefully guided questions to develop meaningful representations of the particle model. His emphasis on inquiry and reasoning goes beyond the purposes of motivation and visual support for conceptual development, although Ian still considers both of these important. The question remains as to whether Ian’s perspective is simply the result of years of experience that has given him an increased understanding of what science learning involves, or whether a shift in the subject culture, either at the broader level or at the subject department level,
has prompted him to question his assumptions of what is effective. I explore the effect of the culture of the school and subject department on the practice of individual teachers in Section 6.4.2.

An important message from this section is that, despite the different epistemological positions amongst these teachers, a common assumption that science knowledge is phenomenon based means that interaction with such phenomena is placed at the centre of the learning experience.

6.2.3. Making the abstract concrete in mathematics

Applying the idea of experiential learning to mathematics is not as straightforward as in science, partly due to the abstract nature of mathematics. Unlike science, which focuses on tangible objects or phenomena that can usually be readily observed or modelled, in mathematics the focus is on “mathematical objects, structure and relationships [that] do not depend on a particular context for their existence, but are interpreted to model key features of these contexts” (Victorian Curriculum & Assessment Authority, 2005a, p. 5). As a result, a pedagogical imperative in school mathematics is to make the abstract concrete. Daniels, Hyde, and Zemelman (1993, p. 9) assert that

as often as is possible, school should stress learning that is experimental. With mathematics it means working with objects – sorting, counting and building patterns of number and shape; and carrying out real-world projects that involve collecting data, estimating, calculating, drawing conclusions and making decisions.

Ian made links between the abstract nature of mathematics and the tendency for teaching approaches to be “less hands-on”:

IAN: No matter what you say about subjects I think maths is far less hands-on. When you’re dealing with numbers you’re not dealing with objects. You’re dealing with properties of things and that already removes it one degree from any science thing that you’re doing where the kids can see what’s happening. It’s one more degree of abstraction in maths. [S2BI:17]

Pauline described mathematics as “thought experiments” [FGD:60], suggesting that mathematical inquiry is much less steeped in concrete experience, and is an activity for the mind rather than the hands. According to this view, abstract subject matter does not immediately demand concrete representations. At the same time, it is because of this abstraction that such concrete representations are necessary to increase students’ conceptual understanding.

Teachers saw the benefit of incorporating alternatives to textbook exercises, which are marked by repetition and low level mathematical thinking. In Figure 6.1, Pauline mentioned practical applications, Donna mentioned visual activities and objects such as the three-dimensional shapes, and Simon mentioned open-ended tasks. Two main strategies are highlighted here: the use of concrete visual materials,
and higher order and complex problem-solving tasks. The former refers to the use of visual and practical experiences in mathematics that can be compared to practical activities in science. The latter relates to activities that promote higher order thinking. These activities sit outside of the experiential learning emphasis I am focusing on in this theme, unless they involve materials that support the development of problem solving skills (Durmus & Karakirik, 2006; Sowell, 1989). The emphasis that the school places on complex problem solving represents the school’s commitment to move away from “a focus on learning that is on repetitive problems and memorisation of mathematical facts and formula” (Education & Training Committee, 2006, p. 164) towards a focus where students are “engaging in more complex problem solving that challenges students to make connections between mathematics concepts and to utilise mathematical reasoning” (p. 165).

In order to compare the role of practical experiences across mathematics and science, in this section I discuss teachers’ use of equipment and materials, such as manipulatives, to support student learning. According to Durmus and Karakirik (2006), one practical route for bringing experience to bear on students’ mathematical understanding is through the use of “manipulatives”. This comparison offers useful insight into two aspects: firstly, the assumptions of individual teachers as to the role of practical experiences in mathematics based on their beliefs relating to mathematical knowledge, teaching and learning; and secondly, the effect of the subject culture in shaping opportunities for providing such experiences. I begin by presenting an analysis of the use of materials in the observed lessons. I then compare the cultural traditions and expectations across the two subject cultures that afford or constrain the use of practical activities to support learning.

**Using concrete materials to teach abstract mathematical ideas**

The TIMSS analyses provide a useful framework for examining teachers’ use of concrete materials. Stigler et al. (1999) analysed the 1995 TIMSS video data mathematics lessons for phases where equipment or materials were used or manipulated by students or for demonstration of conceptual ideas. Equipment or materials were classified as either: mathematical tools, manipulatives, or posters. Equipment excluded from the analysis included textbooks, worksheets, calculators, whiteboards, and overhead projectors. The analysis of the 1999 TIMSS data by Hollingsworth et al. (2003) used similar categories, and gave the following examples for mathematical tools and manipulatives:

- **mathematical tools** - specialist mathematics materials, for example, graph paper, graph boards, hundreds tables, geometric solids, base-ten blocks, rulers, measuring tape, compasses, protractors, and computer software; and
• **Manipulatives** - real world objects and concrete tools, for example, cans, beans, toothpicks, dice, newspapers, magazines, springs.

Heddens (n.d.) describes manipulatives in a similar way to the TIMSS researchers:

> Manipulative materials are concrete models that involve mathematics concepts, appealing to several senses, that can be touched and moved around by the students (not demonstrations of materials by the teacher). The manipulative materials should relate to the students' real world… They can be moved and touched by the learners. (electronic source)

Other researchers also call some of the specialist mathematics materials manipulatives, such as base-ten blocks, algebra tiles and Unifix cubes (Durmuş & Karakirik, 2006; Howden, 1986), which do not, as Heddens (n.d) states, relate to the student’s real world. More recently, “virtual manipulatives” are attracting the attention of researchers (see, for example, Durmuş & Karakirik, 2006). These are “interactive, web-based visual representations of dynamic objects that present opportunities for constructing mathematical knowledge” (Moyer, Bolyard, & Spikell, 2002, p. 373). I adopt this broader view of manipulatives that subsumes some of the mathematical tools.

Generally speaking, manipulatives provide concrete representations of an abstract mathematical concept: “Manipulatives are objects designed to represent explicitly and concretely mathematical ideas that are abstract” (Moyer, 2001, p. 176). Research suggests that manipulatives are useful in helping students move from the concrete level to the abstract level, particularly when they are used before formal symbolic instruction (Clements, 1999). Moyer (2001) warns that “the physicality of concrete manipulatives does not carry the meaning of the mathematical ideas behind them. Students must reflect on their actions with the manipulatives to build meaning” (p. 177). When used correctly, manipulative materials act as an intermediary between the real world and the mathematical world. The gap between the concrete and abstract is known as the transitional iconic level (Heddens, n.d.). Heddens divides this level into the semiconcrete and semiabstract level:

> The semiconcrete level is a representation of a real situation; pictures of the real items are used rather than the items themselves. The semiabstract level involves a symbolic representation of concrete items, but the pictures do not look like the objects for which they stand. (p. 14)

Howden (1986) claims that bridging the gap between the concrete and abstract forms of a problem requires careful selection of the manipulatives and direction by the teacher.

I saw five instances in the 20 mathematics lessons where students used materials or equipment as part of the learning experience:

1. a poster detailing the problem solving process in Marg’s lesson while students were completing an open-ended problem relating to powers of seven (lesson M3);
2. counters to assist with working through directed number problems from a worksheet during Marg’s revision lesson (lesson M1);
3. paper to represent pavers and shrubs in the “Garden Beds” MATHS300 activity7 in Rose’s lesson on algebraic equations (lesson R1);
4. paper for making three-dimensional shapes for a textbook activity, “Investigation involving construction of solids”, which was used as an extension activity for advanced students in Pauline’s lesson (lesson P5); and
5. paper for manipulating two-dimensional shapes in Rose’s lesson (lesson R7) where the paper shapes provided concrete proof of the area of a triangle as being half the area of a rectangle: “Nearly all of them know the area of a rectangle. Next thing you do is the area of a triangle and make it into a rectangle and cut it so that they can see it is half a rectangle. Then the formula makes sense to them” [S3ID:95].

Two purposes for the use of manipulatives are evident in these examples.

The first purpose is to support the problem solving process. Stacey and Southwell (1996) support the use of materials during problem solving because they provide a concrete representation of the parts of the problem, and thus make the problem easier to solve.

The second purpose is to introduce or support students’ understanding of mathematical concepts. Some teacher support materials put a high degree of importance on the use of concrete materials. For example, Hartshorn and Boren (1990) detailed the importance of using manipulatives “to introduce or reinforce a mathematical concept” (p. 1).

Both of these purposes are evident in these five occurrences in different ways.

The poster, although not really a tool in the same sense as a manipulative, provided the teacher with a referent to the problem solving process. This incident is included here because the TIMSS analyses included posters as a concrete tool.

In the second instance, negative and positive counters supported students’ understanding of the rules associated with adding and subtracting integers in multiple problems as part of revision activities. Some students chose to use them, others did not.

In the third instance, the pavers helped students visualise how algebraic equations can be derived from everyday situations. The pavers also helped to introduce the concept of generalizing algebraic patterns into rules through a problem solving strategy.

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In the fourth instance, the construction of 3-dimensional shapes allowed students to experience the geometry of solids through building and seeing the shapes. As an extension activity for the more capable students, Pauline used the manipulatives to reinforce the concept through an application.

In the last instance the paper cutouts were used to visualise the proofs for formulae used in calculating the area of 2-dimensional shapes. No problem solving context was introduced during this process as this was a concrete-to-abstract sequence that focused on developing the concept.

**Cultural expectations and traditions**

Practical experiences in mathematics were discussed in the interviews much less than in science, partly due to the limited number of occurrences in the lessons that I observed and video recorded. Teachers recognised such experiences to be valuable in mathematics but felt that they were peripheral to the main aim of mathematics instruction. A tradition of instruction based on a commitment to a skills-based curriculum that prepares students for senior studies, as discussed in Section 6.1, perhaps detracts from time that might be spent doing more time-consuming tasks like engaging with concrete representations of abstract concepts, such as “fraction walls” that Donna referred to briefly. Time constraints and an over-crowded curriculum were blamed for constraining the emphasis placed on these valued yet seemingly dispensable experiences. As stated by James in Section 6.1.1, getting through the syllabus overrides his desire to include more “realistic” activities.

Ian also felt the pressure of time. In the following response, Ian demonstrated how his personal commitment to using activities to reinforce students’ understanding of concepts was thwarted by time constraints. This excerpt was a response to a question about the difficulties that non-mathematics trained teachers might face when teaching mathematics:

IAN: There’s actually a lot more resources out there than most teachers are aware of that are available for reinforcing these kinds of concepts. But the way education is, you really never get a chance to look at all these done properly in the right way. Even some teachers don’t seem to twig to what some of these activities are trying to do. [S2BI:41]

Students, teachers and school contexts are actors in perpetuating certain types of teaching approaches. The comparative roles for these three actors are discussed below.

**Student as actor**

In earlier research on year 7 student perceptions of engaging pedagogy (Darby, 2002) I found that students expected to be actively involved in science through
experiments. In the current research, James echoed this experience of student perceptions and expectations:

**JAMES:** They come into the classroom with the perception that maths is, sit down, copy the examples from the board, answer the problems on the left hand side, that’s sort of built in. They come in with the expectation of a science classroom that they’re going to do chemistry, and they’re going to see videos. They’re going to have discussions. They can talk a bit more. [S2BJ:116]

He describes a difference in students’ expectations in the two subjects: in science, students expect to be more active because they are in an environment where hands-on experiences are permitted, normalised and preferred; while in mathematics, such experiences are less normalised and, I would extrapolate, a novelty.

**Teacher as actor**

In both mathematics and science, teachers either enabled or inhibited opportunities for students to engage in more practical experiences. For example, it was evident in the excerpt from the Focus Group Discussion in Figure 6.1 that Rose was seen by the other teachers as the store of good ideas. She had knowledge of what worked, what activities were available and how to use the activities to support student understanding. Donna, on the other hand, positioned herself less of an expert because of her limited experience and knowledge:

**DONNA:** I don’t have a big maths background, so I have to spend a bit of time thinking about what could be available and what I could do, whereas with a science background, I think of things just because I’m experienced in that area. So I suppose it might depend on how much maths you’ve done or what resources you’ve been exposed to. [FGD:91]

Donna is an example of a teacher who is not “maths-trained.” While a lack of experience is an understandable constraint in terms of knowing what can work, Rose exhibited frustration with experienced teachers who choose not to incorporate activities that she promoted as valuable learning experiences. Evidently, a range of discourses operate within the subject culture that position activity-based learning experiences differently.

Rose reported a classroom incident where she came to realise that a Year 8 activity-based shapes unit that teachers were encouraged to use was not making its way into some Year 8 classrooms:

**ROSE:** There’s a space unit there and I thought everyone in Year 8 was doing it. I know one person who doesn’t do it, and I thought he was the only one. But I’m discovering that other people haven’t either. And I just think it’s a lost opportunity because it’s such a terrific unit. And then I thought, well, I’ve got to do something about it, knowing the stuff is in the cupboard first, and then knowing you can take it into your class and explain something that it’s not related to, you can relate it to another topic that you’ve got. And I think that’s part of the problem.

…
ROSE: We have to have a Year 8 meeting. And I just think there’s a lot of ideas out there, but to get them so that everyone is using them is another step. And that’s where we’ve got to go. [FGD:77,80]

This incident raises two issues. One relates to teachers’ knowledge of how to make use of the materials. Rose indicated that she needed to raise teachers’ awareness of the availability and usefulness of the equipment in the mathematics storage cupboard. The second issue relates to the importance placed on the resources. The use of activities appeared to be considered negotiable and, thus, peripheral to the main business of mathematics teaching.

A lack of knowledge is a known contributor to the reduced use of manipulatives by teachers. Marshall and Swan (2005) noted that in the upper primary levels, teachers’ apparent reduced use of manipulative materials was a function of not only “a lack of knowledge of how to manage and how to use the manipulative [but also] a lack of knowledge of the associated mathematics being developed” (p. 144). Despite relating to the primary level, this finding is significant to my study where teachers exhibited similar reservations about their ability to access and effectively use these types of materials.

Context as actor
Rose’s scenario speaks to a cultural tradition at School A where the hands-on, visual, activity-based learning experiences are not instituted as a necessary practice in mathematics. Consistent with this view, investigating, self-discovery and practical experience provide an alternative, attractive, yet unfortunately peripheral imperative for mathematics teachers. A commitment to mathematics as skill- and process-based, stable, and ordered dominates. As a consequence of this tradition, the privileges of funding for resources, supportive infrastructure (laboratories, preparation and storage rooms), and personnel (laboratory technicians) that science has traditionally enjoyed remain largely out of reach for mathematics departments. Swan (2001) found similarly that lack of funding for the purchase of, and training in the use of, manipulatives is a significant impediment to their use. In his observations of numerous schools, he found that mathematics storerooms were often in disarray, with equipment poorly or incorrectly labelled, and with pieces missing or in disrepair.

James experienced frustration at the lack of consideration to suitable learning environments for mathematics lessons. In comparison to the infrastructure commitments to provide suitable learning spaces for science, James complained that mathematics is timetabled in any room, including needle craft rooms (something I had previously witnessed at School A). As a consequence, mathematical equipment and artefacts are not visible to mathematical learners, nor readily accessible for mathematics teachers:
JAMES: It really belittles maths. It denigrates the work of mathematics and it again makes it even harder to have practical applications because you haven’t got a proper lab or ten labs set up with maths equipment with the proper computers where you can engage the students and do real things. I’d much rather students be out there measuring how far a beam deflects or measuring with the theodolite some angles … So, until that sort of idea percolates to the administrators in schools so that people like our head of department are able to implement the ideas that they really want to, it’s going to be very hard to do practical activities in the classroom.

Teachers at School B were under strong direction from the mathematics head of department to employ more activity oriented teaching approaches. Ian described the situation in this way: “he has been encouraging us to use the standard discovery learning things like RIME and a few others of those because they’ve been well tried methods of expanding kids out of the textbook” [S2BI:27]. As a result, the lessons I observed at School B contained a greater proportion of activities and open-ended problem solving than those at School A. Ian and James described a shift in the culture of teaching at their school away from a textbook-dominated approach limited to skill and process development, towards an emphasis on developing deeper understanding:

JAMES: The maths department was in a real slump. It just didn’t have any real leadership for a variety of reasons and he was a real breath of fresh air and ideas to change the presentation style to make it a bit more scieney if you like so the kids would have activities maybe for the first time rather than textbook driven. Your boring stuff. So they do a lot about problem solving. And the idea is that they’re thinking about thinking. Trained to go through the logic of a scenario rather than just finding, just teaching the process, which is a lot of what happens in maths.

In spite of this new direction and invigoration, James remains somewhat ambivalent to the apparent prominence attributed to activity based approaches: “If you were seeing mostly problem solving I would suggest they’re putting on a show for you” [S2BJ:114]. He believes pressures imposed by the curriculum tend to limit opportunities to incorporate these potentially time-consuming tasks, so that their use is conditional on teachers adequately getting through the curriculum.

Despite this, both Ian and James expressed support for moving forward with the new direction set by the head of department. This reflects not only a valuing of practical experiences, but a willingness to prioritise them on the agenda of school change and teacher development.

6.3. Teachers’ basic assumptions

Evident in the experiences and reflections of these teachers are some internal consistencies in the ideals and perceptions about curriculum content organisation and the use of practical experiences. According to Schein (1992), the essence of a group’s culture is its pattern of shared taken-for-granted basic assumptions. Schein likens these basic assumptions to Argyris and Schöhn’s (1974) theories-in-use that
prescribe how to act, think, and feel about things, and that operate as “unwritten scripts” for members of the group. These scripts internalise a routinised approach to performance on the job: “Potential courses of action are evaluated in terms of internalized socially constructed theories-in-use” (Schein, 1992). Like theories-in-use, basic assumptions are internalised perceptions of the world, objects, ideas, and how to relate with others.

Some basic assumptions are evident from these teachers’ descriptions of school science and mathematics. In the following sections I use Schwab’s (1969) commonplaces of schooling—subject matter, student, teacher and milieu—as the framework for constructing these basic assumptions. These basic assumptions are developed to expound the relationship between the structure of the subject matter and the pedagogy of these teachers, as well as the epistemological, pedagogical and cultural demands associated with hands-on activity. The perceived learning needs of their students and other broader influences from the cultural milieu factor into these aspects of the subject cultures.

### 6.3.1. Teachers’ basic assumptions relating to curriculum content organisation

The basic assumptions listed in Table 6.1 represent the on-ground experience of these teachers: the enacted curriculum as it emerges out of the interface of the students’ learning needs in the classroom, teachers’ beliefs about what needs to be learned and how this is best made available for students, the imposition of a school system and its

<table>
<thead>
<tr>
<th>Subject matter</th>
<th>Science</th>
<th>Mathematics</th>
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<tbody>
<tr>
<td>Basic Assumption 1: Junior school science subject matter is organised in topics that are relatively discrete, but there is some sequencing of ideas within the disciplines of science. Topics tend to be iterative.</td>
<td>Basic Assumption 1: Junior school mathematics subject matter is organised as a carefully sculpted sequence of skills/processes and concepts, moving to greater degrees of abstraction and complexity.</td>
<td></td>
</tr>
<tr>
<td>Students</td>
<td>Basic Assumption 2: Missing science content at the junior level has limited bearing on future success with science learning. Students’ willingness to engage with future learning experiences, however, is dependent on coherent and suitably targeted</td>
<td>Basic Assumption 2: Poor skill development can result in insecure foundational understandings, posing a threat to future success. This can result in students feeling threatened by the learning demands of school mathematics.</td>
</tr>
<tr>
<td>Teacher</td>
<td>Basic Assumption 3: The imperative for the science teacher is to add more pieces to the puzzle for students so that they develop a coherent picture of the knowledge and skills of science, and move them on to more complex concepts.</td>
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<td>--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
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</tr>
<tr>
<td>Milieu</td>
<td>Basic Assumption 4: Science curriculum content is subject to reshuffling, reflecting an acceptance that there is no single trajectory through the subject matter required for students to achieve success in their learning.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basic Assumption 3: The imperative for the mathematics teachers is to support students in developing firm foundations to allow them to move successfully to the next level of complexity and abstraction.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Basic Assumption 4: Mathematics curriculum content is relatively stable because there is general acceptance about the steps that students should take as they move to greater degrees of complexity. The imperative to ensure student success comes from the importance given to mathematics for school, university and life.</td>
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</tr>
</tbody>
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expectations and demands associated with different subjects, and the nature of the school version of the disciplinary knowledge.

Whether these assumptions about the nature of curriculum content organisation align with best practice is not the issue here. However, it is useful to consider how these assumptions compare with other accounts that critique the status quo of current practice and provide alternative perspectives and methodologies. In Section 6.4, I discuss some of these issues in response to the basic assumptions listed above.

### 6.3.2. Teachers’ basic assumptions relating to hands-on activities

The basic assumptions in Table 6.2 represent teachers’ experiences of using hands-on activities when teaching mathematics and science: demands imposed by the subject matter, teachers acting within a context that enables or constrains the use of hands-on activities, and expectations of students and teachers to incorporate such activities in supporting conceptual development.

Whether a teacher incorporates practical or activity-based experiences in mathematics and science is not simply a matter of having a filing cabinet full of activities, but requires an awareness of the purpose and nature of the types of activities appropriate for the subject. It also requires a particular epistemological stance, which is underpinned by a web of beliefs, knowledge, and experiences that provides some logic to the pedagogical decisions that are made by a teacher.

In science, teachers showed a firmer commitment to students experiencing natural phenomena because the nature of the subject traditions demands it. Teachers
relied on such experiences to engage students at both an aesthetic and motivational level, and at a deeper conceptual level.

In mathematics, while teachers considered practical experiences as pedagogically beneficial, teachers experienced resistance and constraints born from a traditional commitment to pedagogical approaches more appropriate for supporting students’ progress through a tightly structured curriculum.

Not obvious in these assumptions are the subject cultural shifts that I saw at the school level, particularly at School B where teachers reported on a directive from the head of school to embrace more engaging and meaningful pedagogies in the middle years. The assumptions in Table 6.1 tend to reflect what might be considered a traditional position on what it means to teach and learn. In the following sections I characterise the subject pedagogies that arise out of these basic assumptions.

Table 6.2

<table>
<thead>
<tr>
<th>Basic Assumptions Relating to Hands-on Activities</th>
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<tbody>
<tr>
<td><strong>Subject matter</strong></td>
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<tr>
<td><strong>Students</strong></td>
</tr>
<tr>
<td><strong>Teacher</strong></td>
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</tbody>
</table>
6.4. Subject pedagogies arising out of what is central

The cultural expectations captured through the basic assumptions above appear to have a strong influence on practice, and in some senses teachers’ pedagogical responses are clear. These common responses are what I am calling “subject pedagogies” (see Ball & Lacey, 1980) because there was general agreement about what was central to the teaching task. The basic assumptions underpin what I have called a “Pedagogy of Support” in mathematics, and a “Pedagogy of Engagement” in science. My use of the term pedagogy implies not just an adoption of methods of teaching but a rationale and certain philosophical assumptions. They represent strong discourses that I saw characterising the pedagogical imperatives of these teachers.

Below I explore each of the subject pedagogies. I then draw on the research literature to show how the research community is advancing the thinking encapsulated by these subject pedagogies. The evolving ideas from the research literature come to bear on schools and, therefore, teachers, in varying ways. Teachers at both schools were responding to these shifts in ways that demonstrate their epistemological and pedagogical commitments.

6.4.1. “Pedagogy of Support” in mathematics

The nature of the curriculum content organisation was a defining feature of school mathematics for these teachers. Responding seriously to the relationship between a hierarchy of ideas and student success was considered central. The curriculum was seen to be more sequential than in science and moving to increasing degrees of complexity, and this appears to result in a particular response by the teacher—to make it less threatening for students, and to take the responsibility for student progression as a central part of their role. Of fundamental importance is that students are given the best opportunity to be successful in the subject, therefore, support for learning dominated these teachers’ approach to teaching and learning.

Teachers recognised that the impetus for this view stems from a longstanding tradition of school mathematics being viewed as both an “entrance” subject and preparation for life. As such, school mathematics enjoys an elevated position of
importance, more so than for science. Subsequently, pedagogical choices are shaped by the relative importance given to the subject. If the aim of teachers is to move students through a sequential curriculum and the mastery of increasingly complex and abstract key ideas and skills, then student support becomes paramount. If parents and students consider mathematics as having intrinsic worth and purpose and mathematics is considered fundamental to students’ futures, then promoting enrolment in the subject by focusing on student engagement is less of an imperative. Following this way of thinking, it is easy to see why teachers adopt support mechanisms in mathematics.

Teachers emphasised support above engagement, although engagement was implied. This was evident in the relative difficulty that Rose experienced in encouraging some teachers to adopt an activity approach in the algebra unit, and by the limited use of manipulatives and specialist mathematical materials in School A. I am not, however, implying that attention to engagement and support are mutually exclusive. A mounting body of evidence is showing that well-designed support in the middle years has a significant impact on a child’s future educational development (Pogrow, 1998). A student who feels supported in their learning is more likely to be engaged if they are learning within a positive learning environment.

Lockart (2002) claims that two factors impact on student engagement with mathematics: the autonomy students have over their learning, and a classroom environment where teachers have faith in their ability to succeed. Autonomy in problem solving can be behavioural (an appropriate environment for exploring through problem solving), or cognitive (freedom to grapple with the conceptual complexities of the task). Williams (2005) states that finding a healthy balance between these two when supporting students is difficult. For example, a teacher may offer emotional security by offering cognitive support, but do so by telling students rather than allowing students to struggle with unfamiliar ideas.

The nature of the support that a teacher gives in mathematics is therefore, central, but also complex. Williams (2005) uses the notion of flow (Csikszentmihalyi, 1997) to develop the “Engaged to Learn Model” to represent the relationship between challenge and conceptual level. The model explains why tasks that are too easy for a student breed apathy and boredom, and tasks that are too difficult can result in anxiety and lead to panic. Williams asserts that success through challenging situations breeds optimism, that is, the perception that success is a consequence of personal characteristics, and that failure is temporary and overcome by personal effort. Optimism is linked to a student’s inclination to explore unfamiliar mathematical ideas. Teacher support has an important, but complex, role. In establishing a supportive learning environment, teacher-student relationships based on care can contribute to increasing or reducing optimism. For example, Rose’s
sense of care was central to her approach to student learning, with many of her reflections demonstrating her commitment to meeting the student learning needs. A teacher-student relationship based on trust enabled her to approach students openly, at their level, and with the knowledge that she can move them forward in their understanding.

Relationship issues in relation to student achievement are reported in research by Boaler (1997b). In her study of “top set” students she found that a group of previously high achieving girls became unproductive and unhappy when moved into the higher stream. Applying a Care Perspective (Noddings, 1992) to this scenario, Ocean (2005) suggested that poor relationship formation between the girls and their mathematics teacher may have contributed to students’ low productivity: “I suggest that the lack of connection with the teacher was one reason that their participation and achievement had plummeted” (p. 147).

Therefore, a pedagogical imperative to support students in their learning is fundamental to mathematics teachers, both at the relational level, where teachers makes themselves available, and at a cognitive level, where teachers support the development of optimism by judiciously offering support for problem solving. An imperative to engage students is also important. Engagement arises out of a careful balance between challenge and success for the student, where the supportive role of the teacher can make the difference between apathy, panic or full engagement.

Moving forward: Directions from the broader mathematics subject culture

According to Romberg (1992), the American mathematics curriculum of the 1980s was a collection of hierarchically arranged concepts and skills where the “acquisition of information and the ability to demonstrate proficiency in a few skills have become ends in themselves, and students spend their time absorbing what others have done” (p. 763). Romberg referred to scope and sequence charts that identified the procedural objectives that students must master, which subsequently resulted in the segmentation of mathematics into “literally thousands of segments, each taught independently of the others” (p. 764). The student’s role was to master each skill or concept one after the other. Romberg believed that this method of segmentation resulted in the “assumption that there is strict partial ordering to the discipline” (p. 764).

This segmentation of the 1980s mathematics curriculum appears to be consistent with the teachers’ views of curriculum content structure in this study. Rose, as a mathematics specialist, presents a subject centred on content requiring mastery at each level. The emphasis is on an “absolutist perspective” (Romberg, 1992) where skill and concept acquisition is the main aim. The school syllabus is carefully sculpted to help students build their knowledge so that they can move
successfully through the year levels, and travel along a trajectory that is determined by skill level and proficiency. Certain measures are taken by Rose and the other teachers to support students through this progression.

How can teachers and schools move subject pedagogy based on student support forward? The broader mathematics subject culture provides alternative curriculum structures and perspectives.

Krainer (1993) provides two extreme positions on the organisation of mathematics content and the pedagogical demands that are imposed by each. The first extreme is based on the perspective of “mathematics as a highly complex and highly developed science which offers, however, polished and stable ideas and theories in areas understandable for pupils… Therefore, it is easy to build up well-established (‘secured’) courses for mathematics” (p. 66). This perspective strongly echoes the experiences of the teachers in this study. Krainer makes the point that such a position demands economic efficiency and well-developed pathways.

As in science, mathematics textbooks are influential actors in maintaining this status quo because “the actual topics taught in classrooms are those that appear in the textbooks that are used” (Romberg, 1992, p.764). Indeed, research into the influence of mathematics textbooks on teaching strategies has shown that textbooks convey pedagogical messages and provide curricular environments conducive to particular teaching strategies (Fan & Kaeley, 2000; Valverde, Bianchi, Wolfe, Schmidt, & Houang, 2002). According to Romberg, publishers, along with curriculum developers, administrators and political pressure groups, make decisions about what is included in the mathematics curriculum (see Section 2.1.4). Textbooks, therefore, have a capacity to perpetuate certain pedagogies and curricula, but also have the capacity to lead curriculum and pedagogical reform. Lappan (1999) targets textbooks as an important vehicle in revitalising and refocusing the teaching of mathematics.

Krainer’s (1993) second extreme advocates a reconceptualisation of mathematics teaching, advancing the perspective that students bring a variety of relevant practical experiences, associations, intuitions, and so on to mathematics instruction. If the spontaneity and creativity of the pupils are taken seriously it is—from a psychological point of view—necessary to have a certain insecurity of mathematics courses. (p. 66)

Such a conceptualisation of the subject matter demands a commitment by teachers to “investigate and discover for themselves and have the freedom to ‘pave’ their own ways” (p. 66).

Both extreme perspectives deal with issues of the nature of the subject matter and issues of pedagogy. However, where the commitments lie differs. Where the first perspective focuses on what students should study, the second perspective places more emphasis on how students should learn. The second perspective shifts the pedagogical imperative from preparing students adequately for the next level of
abstraction and complexity, to engaging students in the reasoning, reflection and creativity of mathematical inquiry. Differences between these two extremes are illustrative of the gulf between reform agenda in mathematics education and current practices in the average Australian classroom. The results of the TIMSS analysis show that Australian classrooms are characterised by excessive repetition, an emphasis on problems of low complexity, and an absence of mathematical reasoning (Hollingsworth et al., 2003). In her response to these results, Stacey (2003) recognised two directions for teachers: the “reform ideal” that emphasises learning through “deep engagement with rich problems”; and a more traditional agenda that “seeks to maximise outcomes obtained by emphasising standard sets of mathematical procedures” (p. 122). Stacey asserts that, regardless of the approach, “greater emphasis on explicit mathematical reasoning, deduction, connections and higher-order thinking” (p. 122) is needed.

In a tightly scripted curriculum, support is paramount. In a curriculum emphasising rich problem solving, support also plays an important role, as demonstrated by Williams’ research into optimism during problem solving. The issue of support remains constant, but the focus of instruction shifts, as does the nature of the support. Moving forward from the Pedagogy of Support means shifting the focus towards the reform ideal mentioned by Stacey. This agenda calls for teachers to “create supportive learning environments, to utilise worthwhile mathematical tasks, to manage students’ mathematical discourse, and to promote sense making” (Jones, 2004). School B appeared to be moving in this direction. Activity-based approaches that focus on problem solving and mathematical reasoning are part of the reform agenda of the head of mathematics department. While Ian and James saw this as admirable and important, they nonetheless felt the pull of the demands of the senior years so that movement away from the tight sequencing of content was not without challenge. School A most strongly represented an agenda to maximise outcomes through emphasising mathematical procedures. Activity-based approaches provide an alternative to the textbook, but in a way that make them optional or in addition to the main focus provided by the textbook. While Rose was seen as an agent for change, there appeared to be no common agreement or comprehensive reform agenda with which teachers could align.

While extant research impresses the need to promote greater complexity and depth in the way mathematics is taught, Australian classrooms continue to be lagging behind other countries (Hollingsworth et al., 2003). The extent to which teachers can move away from these less effective traditions and expectations, such as the cultural shifts being experienced at School B, remains to be seen. Messages coming from the literature suggest that it will not be easy. In her research comparing two schools, one
utilising activity-based and open approaches and another relying on more traditional approaches, Boaler (1997a) expressed concern that the school with an open approach to teaching mathematics was showing signs of reverting to a more traditional approach, despite students being more positive towards mathematics and more able to see the relevance of mathematics in their lives.

6.4.2. “Pedagogy of Engagement” in science

In science, the analysis points to a reliance on a Pedagogy of Engagement where the artefacts of science and natural phenomena are used to engage students with science ideas and ways of thinking. The science teachers at School A in particular claimed to rely on students experiencing the practical work to draw students into the subject, to promote interest in science ideas, and to make students’ science experiences both meaningful and understandable.

In order to understand how a Pedagogy of Engagement emerges in science, it is important to understand the relative importance afforded to the cultural artefacts of the subject and discipline. Cultural artefacts, according to Becher’s (1989) theory of academic tribes, are important for developing and maintaining a sense of community. Along with idols and language, cultural artefacts manifest the tribalistic nature of these communities. Although Becher’s theory pertains to academia, school subject departments may exhibit such tribalistic behaviour. These practices include the reliance on defining cultural artefacts. These artefacts metaphorically become embodiments of those ways of relating, thinking and acting that are considered sacred in that culture. For the science teacher and learner, the laboratory, the scientific equipment, and the phenomena explored during science lessons are science artefacts. Also, the specialist scientific language, the scientific processes and methods experienced through practical activities, and the tools by which one learns the science, such as the textbook with its pictures, stories and ideas, are artefacts that students come to know as characteristic of science. The defining artefacts represent multiple meanings that are associated with traditional practices of science and science education.

Certain expectations are perpetuated. Students expect to do experiments, teachers expect to include practical work as part of their teaching repertoire, and schools expect to have to provide the appropriate cultural grounds and artefacts to enable this practice to take place. The artefacts, both as objects (phenomena and equipment) and practice (practical work), are central to this cultural view of what defines science teaching and learning.

Teachers understood that practical experiences that utilised these artefacts provided students with positive experiences that are both cognitive and affective. Teachers recognised the aesthetic dimension (Wickman, 2006) of practical activity
and the positive effect they can have on engaging students in the processes of science. Donna and Simon talked about practical work as fun and enjoyable. Simon considered it as the key to boosting student interest and enrolment in senior science courses. Ian saw it as an important tool for promoting reasoning about science ideas. Engaging students is a central pedagogical imperative.

The role of the objects and practical activity in meeting this pedagogical imperative is supported by the existence of the laboratory in schools. Socio-cultural forces, such as the subject department and school administration, affirm this by the provision of specialised equipment that accommodates the empirical nature of school science. Consequently, in science, dealing with the compelling nature of objects, which relies on particular infrastructure and availability of resources, is a critical driver of a teacher’s pedagogical moves.

**Moving forward: Directions from the broader science subject culture**

According to my analysis, engagement for these teachers is dependent on practical experiences. A Pedagogy of Engagement remains unquestioned as practical experiences are regarded by these teachers as aesthetically compelling and motivating, and providing opportunities to actively engage at kinaesthetic and multisensory levels with science ideas. However, the purported links between practical experiences and theory, the affective opportunities often associated with science, and the authenticity of the practical experience are questioned in research. Moving forward from the Pedagogy of Engagement requires an examination of alternative ways of thinking about the curriculum content and how to deliver it, particularly the role that practical experiences play in learning and teaching.

Students often describe science as “fun” and “interesting” because of the opportunity for hands-on activities (Darby, 2002). Lemke (2002) challenges the acceptance that experience-based approaches are automatically “fun” and that they “produce genuine emotional engagement and personal identification with science” (p. 31). Appelbaum and Clark (2001) interrogate the role of “fun” as part of school science discourse. They question the need for teachers to make science fun, as this perspective suggests that science holds little intrinsic value and thus has to be made fun to make learning it and doing it a worthwhile activity. Student learning, they assert, is achieved when students are supported to make sense of their experiences. Raizen and Michelsohn (1994) state that

> Without a well-organised session in which students are asked to summarise what they have experienced and relate their experiences to the concepts they already understand, a hands-on activity becomes time to “play” with science materials; the well-meant demonstration becomes only an entertaining show. (p. 93)

Another perspective is that fun is used as the “hook that will draw the students into being interested in the material (which will therefore be defined as ‘non-fun’)… as
far as [the students] are concerned, the fun is what they are doing” (Appelbaum & Clark, p. 585). The hook precedes or follows, and can be distinguished from, the content, or “real stuff.”

Appelbaum and Clark (1994) offer an alternative, where science pedagogy is thought of as a “self-perpetuating construction of meaning and problems that need to be solved within the discourse of motivation” (p. 596). They promote student generated topics and activities grounded in what students perceive as science, with the teacher emphasising the wonder of knowing. Similarly, Kesson (2003) emphasised that messing about by kinaesthetically engaging with the world is an important “phase of discovery…which can spark the thirst for inquiry that characterises genuinely ‘good science’” (p. 56). In these environments students are more likely to experience what Clifford and Friesen (1998) call “hard fun” where the nature of power and learning in classroom contexts shifts as teachers put the power of adult tools in the hands of children: “Instead of ‘fun’ as the reduction of pain, fun can be the marker of a serious engagement” (as cited in Appelbaum & Clark, p. 597).

Moving forward from a Pedagogy of Engagement could therefore mean using the practical experience to promote wonder. This situates the learner as a doer of science, rather than a learner.

Lemke (2002) situates the student in a similar way in relation to science. But he takes the argument further by challenging the assumed relationship between theory and practice. He asserts that experience-based approaches misrepresent the role of theory. He challenges the view, which is consistent with that coming from teachers in my research, that theory is the “summary and generalisation of what experience and experimentation show. It is represented as the end-product of empirical research. It’s also acknowledged as a practical tool for setting up experiments” (p. 30). Ignored in this empiricist view of theory is the alternative idea that theory is “a realm of imagination where we can leap ahead of all possible experiments and generate impossible possibilities” (p. 30). As a result of this omission, the affective dimension of human learning, that of “joy and desire, imagination and caring” (p. 31), tend to be neglected in schools. Real engagement with science, Lemke believes, occurs when students are able to “make a link, to identify, to engage some part of themselves with something in science” (p. 33). In his view, this is not necessarily achieved through practical experiences. Engaging with science in this way places the emphasis on the mysteries and possibilities that science produces, rather than on objects themselves, or the theory that arises out of scientific investigation.

Moving forward from the Pedagogy of Engagement could, therefore, mean a shift from a taken for granted acceptance of practical work as the tool to engage to a
focus on the mysteries of science and questions that students have that can spark
deep interest.

Part of the issue raised by Lemke is the nature of what is being taught and
how the content is being organised to suit the educational setting. The tendency for
content to be organised as discrete, mono-disciplinary topics has come under scrutiny
in recent years. Researchers are concerned that the segregation of the science
disciplines in school science presents a distorted picture of science (Down, 2007;
Education & Training Committee, 2006; Goodrum et al., 2001; Tytler, 2007).
Science is often presented in schools as “a bundle of disciplines rather than as an
integrated, self-consistent account of the world” (Education & Training Committee,
a variety of disciplines believed that school science represents an outdated and
discipline content-bound view of science, and that a curriculum concentrating on
“knowledge structures” is misconceived.

Donna presented science as being sequential within the different disciplines,
therefore, accepting this disciplinary image of school science. The advice from the
Education and Training Committee (2006) is to have an integrated approach. Other
than one unit developed at School A (by teachers not participating in this study) that
integrated mathematics with biological and physics-related aspects of sound, little
evidence from the classroom observations or the interviews indicated the
development of interdisciplinary science units. Even with the curriculum restructure,
Donna explained that the new syllabus continues to be mainly based on topics
defined by the textbook. Textbooks, therefore, impose an organisational constraint
for schools and teachers when they are used as the basis for unit design. “Textbook
science”, traditionally and currently, tends to present science as topic-bound and
mono-disciplinary rather than trans-disciplinary (Souque, 1987). The textbook is,
therefore, an important actor in perpetuating the disciplinary image of science.

Looking beyond to innovations occurring at other schools, research has
shown that more schools are moving away from topic-bound (for example, states of
matter), towards more thematic approaches to curriculum development (see, for
example, Crawford, Krajcik, & Marx, 1999; Tytler, 2007). Thematic units, such as
“wine making”, draw in multiple science disciplines and even multiple subject areas.
Part of the imperative behind such moves is the development of curriculum content
that is more relevant to students’ lives. This flexibility to the curriculum supports the
earlier view espoused by teachers that there is a certain amount of local variation
across schools.

Given that there is a degree of flexibility in how science content can be
thematised and contextualised, moving forward means finding opportunities for
engaging with a science that more authentically represents science in community, both in terms of science ideas and science practices.

6.5. General agreement leading to a picture of variation in the subject cultures

This chapter explored two aspects of the subject culture that appeared to be central for these teachers in shaping pedagogy: content organisation and hands-on activities. A review of the literature indicates that there are multiple perspectives associated with these two aspects. There are moves within mathematics and science education to develop more meaningful pedagogies that move away from what might be considered “traditional”.

Based on these two aspects I developed two subject pedagogies that arise from the fundamental assumptions guiding teachers’ practices. They represent, at least with respect to these seven teachers, what it means to teach the subject. These perspectives do not necessarily reflect what researchers, policy makers and educators understand as “effective” teaching, but the reality of mathematics and science teaching as it is enacted and experienced by these teachers. These subject pedagogies make the subject teaching identifiably mathematics or science.

What are the consequences of having general agreement about these aspects of teaching? What happens when the prevailing pedagogies resist moves towards alternatives that are underpinned by other basic assumptions? How do these general agreements on what it means to teach the subject affect how teachers negotiate subject boundaries? Teachers moving between the subjects are expected to understand how the curriculum content is organised and how to engage students actively in their learning. Grundy (1994) suggests that in circumstances where teachers are expected to develop a curriculum that explores cross-curricular practices, “it isn’t sufficient that each learning area simply acknowledges the knowledge production processes of other learning areas, each learning area needs to be understood and respected” (p. 13). This need for respect applies also to situations where teachers are teaching a subject with which they are unfamiliar. These teachers may not be as aware of the demands imposed by the subject culture. They may be ill-equipped to filter, respond to or seek alternatives to the subject pedagogies, that is, the “Pedagogy of Support” and the “Pedagogy of Engagement”, which are underpinned by basic assumptions about how the subject should be taught.

Teachers in this study talked about strong traditions of practice in each subject. In science, an expectation that practical work is part of a teacher’s repertoire is apparent. But the teacher will determine whether practical work is used effectively by creating an environment that fosters deeper levels of engagement, or alternatively
rely on the activity to “hook” students and focus purely on an affective response in
the hope that students will be engaged and retain a positive disposition towards
school science.

In mathematics, there is an expectation to support learning in order to prepare
students for future learning success. A danger is that this imperative may be
interpreted in a way that restricts the learning experiences to skills and processes as
laid out in textbooks. Another danger is that teaching focuses on coverage rather
than depth of understanding, resulting in superficial student learning, difficulties in
translating mathematics to real-life contexts, and poor attitudes and self concept in
relation to mathematics.

While there is some flexibility within the traditions to accommodate
variation, breaking away from those traditions to embrace emerging traditions
emanating from the research literature requires an appreciation of what is possible
within the epistemological and pedagogical constraints of the subject. A number of
factors, such as teaching backgrounds, subject commitments, and beliefs about
teaching and learning, mediate a teacher’s capacity to interpret the traditions, and
degree of autonomy to challenge or move forward from those traditions.

The reality is that a teacher brings with them their own perspectives on these
basic assumptions that shape the way the basic assumptions will come to bear on
their teaching. The next two chapters examine this personalised pedagogical
response from two angles.

Chapter 7 examines how teachers situate the learner and themselves in the
subject as they respond to and translate a generic push to make school, and in
particular, the subjects of science and mathematics, relevant to students. I
problematisate what teachers mean when they talk about and go about “relating the
subject to students’ lives.”

In Chapter 8 I delve more deeply into teachers’ personal response to the
subject to examine how this personal response shapes their pedagogical response.
Drawing on the insights gained in the previous chapters I use the framework of
aesthetic understanding to examine how teachers situate themselves as part of the
subject cultures.
Chapter 7. Translating relevance into mathematics and science

In this chapter I turn to the culture of schooling to focus on a generic school imperative to relate the subject matter to students’ lives that teachers felt compelled to respond to, and, therefore, translate into their subject teaching. I examine teachers’ individual pedagogies to understand the subject pedagogies that arise in response to this school imperative. Analysis of the interview and the observation data revealed different approaches to making the subject matter relevant, for example stories that the teacher or students told to show how the subject matter linked with students’ lifeworlds. I discuss teachers’ views of what could be made relevant in the subject, and how the demands of the subject shape their pedagogical response. This analysis exposes teachers’ insights into the nature of the subject matter, and the value that the subject matter has for students. The chapter also explores how the effect of subject culture in shaping pedagogy is mediated by the personal aspects of teaching, including teachers’ beliefs, values, commitments and experiences with the subject and the discipline. Implications for how teachers negotiate their movement between subjects are discussed.

7.1. A rhetoric of relevance in school

In recent years, there has been a push to reframe curriculum and pedagogy in ways that ensure that students’ experiences at school are meaningful and relevant to their lives and perceived needs. A focus on the middle years of education in the 1990s prompted research into the needs of young people (Eyres, 1992). Research has shown that a curriculum that fails to recognise the personal and social lives of young adolescents results in student alienation and disengagement (Australian Curriculum Studies Association, 1996; Eyres, 1997). Some educators claim that part of the problem is the fragmentation of the curriculum into distinct “subjects”. Beane (1995), for example, argues for an integrated curriculum that is more representative of students’ life experiences. The Queensland New Basics (Education Queensland, 2001) blurs boundaries between traditional subjects in order to provide students with “rich tasks”, which are integrated problem based learning experiences that tackle real life multi-disciplinary issues and problems. Rich tasks are informed by educational theory, including Dewey’s emphasis on “integrated, community-based tasks and activities [that] engage learners in forms of pragmatic action that have real life value...
in the world” (p. 4); and Freire’s emphasis on the solving of problems that have “relevance to the immediate worlds of students” (p. 4).

This chapter explores how relevance, as an imperative coming from the wider educational setting, is translated into subject teaching.

Such a focus is important in the contemporary climate of declining student interest in mathematics and science. Despite reforms in Australia in science and mathematics education, the disparity between the science and mathematics being offered and the needs and interests of students continues to be of concern. A number of recent inquiries into the state of school science and mathematics in Australia (Department of Education Science & Training, 2003a; Education & Training Committee, 2006; Goodrum et al., 2001) report on falling enrolment in post-compulsory science and mathematics, and student disenchantment with curriculum that they often consider to be irrelevant. For example, the Education and Training Committee (2006) found that one of the major factors contributing to student disengagement in secondary mathematics is the lack of connectivity between students’ lives and mathematical problems. Similarly in science, the Committee recognised a need for curriculum approaches that focus on, among other things, relevance to students’ lives, as well as making strong links between future education and career pathways. One reason proposed for the disjunction between students’ interests and the science curriculum is that the latter continues to consist largely of canonical science knowledge that is removed from the lives of students (Aikenhead, 2006; Tytler, 2007).

In 2006, Victoria introduced the new Victorian Essential Learning Standards (VELS) as the guiding curriculum document. Relevance to students’ lives features as one of the premises of the Discipline-based learning strand: “students develop deeper understanding of discipline-based concepts when they are encouraged to reflect on their learning, take personal responsibility for it and relate it to their own world” (Victorian Curriculum & Assessment Authority, 2005b, p. 3). Teachers’ ability to respond to this imperative will depend on them understanding how relevance can be incorporated into mathematics and science classrooms in meaningful and appropriate ways.

This chapter draws on interview data and critical incidents from classroom practice to explore how six of the teachers attempted to make the subject matter meaningful for their students by relating it to students’ lives. These attempts are referred to as “stories” because it was through discussions with me about stories that many of these ideas emerged from teachers, and as “stories” they “help students organize their knowledge into explanatory frameworks which serve them as interpretive lenses through which to comprehend their experiences” (Milne, 1998, p. 178).
In this chapter I address the questions:

- how is relevance thought of in mathematics as compared with science?;
- how does the subject and its associated pedagogies shape how a teacher can make links between subject matter and students’ lifeworlds?; and
- what issues relating to relevance arise for teachers as they move between mathematics and science?

7.2. Finding links to students’ lives in the classroom

The realisation that stories and storytelling can provide insight into differences between mathematics and science emerged during one of Simon’s Year 7 mathematics lessons (lesson S4). Simon taught this group for both mathematics and science, and he was encouraged by the school to integrate mathematics and science where possible.

This mathematics lesson (lesson S4) was immediately followed by a science lesson (lesson S3). The lesson began with a discussion between Simon and the students focused on developing rules for solving algebraic equations from a set of problems. Students were then instructed to work through some student generated problems, at which time two boys at the back attracted Simon’s attention and asked what they were doing in science today. Simon said they were doing an activity about friction. Immediately, the boys responded with a story about what they had done at home. In the interview, I asked Simon about this interchange:

Simon: The two boys, they’re my whiz kids. They said, “Me and Jack, we did an experiment at home” and I said, “What did you do?”, and they said “We burnt plastic” and I said “What sort of plastic?” and they said, “Oh, some Ronald McDonald figure of his sisters”. And they said, “You should have seen the fire!” And they put it on DVD for me and they brought it in…So I took it home the other night and I watched it and they were rapt. [S2AS:206]

On seeing this play out in the classroom, I was alerted to the personal and informal interaction that these students had had with science, albeit destructive rather than productive, that they could relay to the teacher as a story of personal engagement. I had not observed such stories being told in relation to mathematics in any of the mathematics lessons up to this point. Yet, when the conversation between Simon and the boys turned to science, the boys were able to immediately relate stories about experiences that they considered to be appropriate in the science context. This raised the question for me as to whether the subject and what it had to offer students influenced the way these students related to it.

Subsequently, during my classroom observations I became interested in how teachers and students were presenting and engaging with science and mathematics through the use of stories that situated themselves or their personal experiences within the dialogue about the subject matter. I noticed that in science these stories
were commonly introduced by either teachers or by students and they appeared to have a purpose of situating the subject matter, and sometimes the scientific endeavour, into students’ lives. I also noticed that in mathematics, fewer stories were used to explicitly connect students’ lives to the subject matter. This raised the question as to whether stories in mathematics took different forms, possibly suggesting a different dynamic of engagement in mathematics and science.

During interviews I questioned teachers about the nature of, and potential for, telling stories in mathematics and science. Teachers recognised that stories were used, and were important in both subjects, but that science generally had more opportunities for story telling. Also, the teacher and students had different roles to play in contributing stories. For example, Simon stated that “there is no spectrum for [using stories in mathematics], whereas in Science you can do anything like that” [S2AS: 209]. On prompting, Simon was able to offer situations where he could use real-life applications of either science or mathematics. In mathematics, however, his experience was that, “most kids can’t do that, like I have to lead that” [S2AS:211]. When asked whether stories were as common in mathematics as in science, Dona said “Probably not, no” [S2AD: 140], but she related this more to her limited mathematics background. Pauline believed that there are fewer stories in mathematics than science because “This is our world, this is what we live in, and explaining it, the science is all about explaining it. You just don’t get stories like that in Maths, do you?” [S2AP: 44]. These differences suggest that stories play a different role in mathematics and science teaching and learning.

While analysing the differences between stories in mathematics and science, my attention turned not to whether stories were being used, as this appeared to be much more of a science phenomenon, but to the pedagogical assumptions underpinning their use of stories: teachers referred to an imperative to link the subject matter to students’ lives. By broadening the notion of “story” to include the notions of meaning-making, relevance and connectivity to students’ lives, there was greater scope to explore in the data the various ways that teachers made the subject matter meaningful for students. The analysis presented in this chapter targeted meaning-making in terms of being meaningful in the lives of their students. The notion of “story” is, therefore, referred to in this chapter in both a typical narrative sense, where stories about people, objects and experiences are “told” and become part of the teaching and learning experience, and in a metaphoric sense, where the lifeworld experiences of the teacher or student and the subject matter are not necessarily woven into a narrative but are linked in order to demonstrate the cultural and human dimensions of mathematic and science. Storying the subject in these ways reveals something of the “teller’s” understanding of how the subject can link with human experience.
In order to demonstrate the different orientations of teachers to the subject and what they perceive as relevant, in the following sections I explore how individual teachers made connections between students’ lives and the subject matter. I then present a categorisation of “meaning-making” approaches that teachers use to emphasise the familiar and human dimensions of science and mathematics.

7.3. Snapshots of three teachers’ approaches to making the subject relevant

All teachers involved in the research said that relating the subject matter to students’ lives was important; however, what they chose to relate, and how they did this, differed. In this section I use the stories of three teachers — Pauline, Donna, and Rose — to show that these differences are not just style differences but are borne out of different views of the subjects in terms of perceived purposes and values, and that these views stem from teachers’ experiences of science and mathematics as disciplines, in real life, and as school subjects. The following snapshots illustrate how teachers made the subject matter meaningful by making it relevant to students’ lives. The snapshots emphasise not only teaching strategies and approaches, but also teachers’ personal experiences of, and beliefs about, the subjects and disciplines.

7.3.1. Pauline

Pauline demonstrated a strong appreciation for the human side of both mathematics and science as she talked about the effect of mathematics and science on students’ lives, their prevalence in society and how they impact on decision making. Thus, Pauline placed a strong emphasis on humanising science:

PAULINE: Science [provides an] understanding of how your world works and I find my knowledge of Science extends to everything. It extends to when I go to the Doctor and I talk about my health … Everything I do is informed by my science knowledge, and I just think that scientific literacy is so important for kids to get the most out of themselves, out of their world … I just think scientific literacy informs everything that we do, personally, and the way we interact with the world and being more responsible. [S2AP:80]

In this quote, science is made part of what it means to be human and a global citizen. Science becomes something that is constructed by people in an attempt to understand and explain the world we live in, to improve our lives, and to take some control over the decisions we make.

Pauline valued stories as a part of her own learning, and endeavoured to express these in the classroom where possible. In the following quote she explained that, when she was a learner, a science teacher had stirred in her an interest in science through his use of stories. She reflected on the role of stories in her developing interests and subsequently in her teaching:
PAULINE: I like collecting [stories]. I don’t think I have enough. I like telling stories and getting the kids’ stories out as well. And I have found that when I studied science they were the things that got me excited when a teacher told me a really interesting story and I don’t know if mine are interesting or not, but I know that they were the sort of things that got my interest going in science and why I wanted to do more. It is unfortunate but it is true that sometimes it is the teacher’s personality, rather than the content that they are teaching that gets kids engaged … like I had a fantastic Year 10 teacher who revved us girls into doing physics and chemistry in Year 11 and Year 12 and that was more his personality, the way he told stories, his passion for science, that got us into it. [S2AP:48]

The way Pauline became interested in science is of interest here. The teacher’s personality, rather than the content, had been instrumental in shaping her perception of science as personally interesting and worthy of attention. The teacher’s “passion for science” that was transferred to students through engaging stories resonated with Pauline on a personal level. A subsequent interest in science led Pauline to a career in physics and a commitment to science as a way of thinking about the world and informing life’s choices.

Her commitment to science was conveyed through the stories she used in the classroom. Stories were a major component of her teaching repertoire. She was able to convey through story her passion, her experiences and her appreciation for what science offers. An example of her use of stories was when she introduced the theory surrounding static electricity with the story of Benjamin Franklin’s discovery of electrical charge during lesson P2:

PAULINE: I want to talk about what we did see. Now, Benjamin Franklin conducted a lot of experiments with electricity, his most famous one of course, flying a kite in a thunderstorm with a key attached to the string and having lightening strike that string and then come out of the key. Now he was really lucky that it hadn’t rained yet and that the string he was holding wasn’t wet because another scientist tried to replicate that experiment only a couple of months later and was killed because of the large amount of electricity going down the string. Benjamin Franklin was really really lucky. So Benjamin Franklin postulated, he came up with this idea, a model, that these, he’d done these types of experiments as well, that there was something that he called an electrical fluid that you could put onto substances and that if you took it away from substances that had one type of charge, and if you added it, it had a positive charge, if you took it away it had a negative charge. We can pretty much say we experienced that charge. Something, the most spectacular thing we did with the van de Graff when we did the discharge rods, what did we see?

STUDENT: Sparks!

PAULINE: Sparks. I always thought that sparks were the most impressive evidence of static electricity… We’ve got evidence for it. Benjamin Franklin postulated that there were two types, positive and negative. [lesson P2]

Here Pauline tells a story about a scientist’s search for understanding natural phenomena. She represents part of the scientific process—Benjamin Franklin postulated, developed a model, experimented, and another scientist replicated. She also provides a positive aesthetic response to the phenomenon of static electricity by
using such terms as “spectacular” and “impressive”, thereby modelling a fascination with science.

Pauline was confident that her style of teaching is effective and suitable for the science classroom. She used examples and illustrations to link the subject matter to students’ lives, as well as humanising stories, such as the Benjamin Franklin story, to bring the subject to life; stories about people and events, the development of ideas, and connections with her own and students’ lives.

Pauline professed that she was less confident in mathematics than science because she knew less about engaging students in mathematics, even though her teaching allotment had always included both mathematic and science. As discussed in Section 5.2.3, Pauline was frustrated that she struggled to translate this personal approach to mathematics, and felt disempowered by her lack of stories in mathematics.

7.3.2. Donna

Donna referred to the use of stories to provide contexts for investigations in order to make the subject matter relevant. She selected learning experiences that she thought would be meaningful for students, focusing particularly on making connections between science ideas and students’ interests: “If you’ve got an idea of where your kids’ interests are you can use things like, because in that Year 8 class there’s a lot of girls into horses so you can use different examples where that’s relevant. And the boys: football or cricket” [S3AD: 149]. Donna also referred to her use of phenomena that students would be familiar with that could act as contexts for student investigations, such as the local lighthouse for investigations into light (see Section 7.4.2 for more detail).

As discussed in Section 6.1.1, Donna was involved in Year 9 and 10 subject selections and was aware that students often felt intimidated by science and mathematics, which were often regarded as the “hard subjects”. Donna appreciated that students would find the subjects less intimidating if they had a coherent and connected understanding of the subject matter. As a result, many of her pedagogical choices were based on providing students with a coherent set of experiences with which they could relate. Her stories and the way she constructed a narrative around the conceptual ideas testify to her commitment to providing a science experience that is meaningfully related to students’ lives.

7.3.3. Rose

Rose made pedagogical choices based partly on what she believed students needed in order to be successful in mathematics, and in preparation for future mathematics studies. She used stories that provided meaningful applications of the mathematics
processes and concepts, such as buying a present for a colleague and using percentages to work out value for money (see Section 7.4.1 for more detail). She used familiar objects, or more realistic representations of otherwise abstract mathematical ideas, in order to improve students’ opportunity to engage with the mathematics meaningfully. For example, she drew chocolate blocks to illustrate fractions. Also, Rose expressed the personal meaning that mathematics offers. She humanised mathematics by modelling her enjoyment of mathematics. “I tell them I love maths” [S2AR:64] was echoed throughout the interviews. “It appeals to my logical brain” [FGD:108].

Rose conveyed that she had a strong commitment to getting students to a point of understanding mathematical concepts and mastering skills and processes. Her experience with teaching across all year levels gave her an understanding of how to present the mathematics in meaningful ways, the difficulties students experienced, and how to overcome these difficulties. As discussed in Section 6.1, she appreciated the connection between student confidence and student success. As a result, her attempts to situate the subject in students’ lives were aimed at supporting skill development and conceptual understanding.

Rose’s sense of care for students is played out in a particular way in mathematics classes. She wanted students to enjoy mathematics, to be comfortable with mathematics, and to recognise that it is preparation for senior mathematics and “preparation for life” [S2AR:54]. Such beliefs and attitudes stem from her personal success and experiences with mathematics, and her years of teaching experience. As mentioned in Section 5.2.1, she regards herself as being “mathematics-trained”, which means having some degree of training that appropriately prepared her for mathematics teaching. She had no other career that involved mathematics, so her personal interest in mathematics, use of mathematics in the real world, success as a learner, and university education provided the basis for her teaching career in mathematics. Unlike Donna, James and Ian who have work experiences to draw stories from, Rose’s examples emanate from her experiences of mathematics in life, learning and teaching. Such stories illustrate her commitment to ensuring students have a strong foundation in mathematics, both for life and to support future mathematics learning.

7.4. Pedagogical approaches as Categories of Meaning Making

The above snapshots give a sense of how each teacher emphasised the relevance of the subject. Their approaches reflect to some extent the teachers’ beliefs about the purpose of the subject and the value that the subject can have in students’ lives.
Using the notion of story in both the narrative and metaphoric sense, four story types are exemplified by the snapshots. These are:

- Illustrations of relevance;
- Exploration of familiar contexts;
- Humanising stories of historical and contemporary “heroes”; and
- Representations of the human response.

For Pauline, stories were important in capturing students’ interest through the use of humanising stories of historical figures that represent the human dimension of scientific discovery, thereby making the subject worthy of attention. For Donna, investigations of familiar contexts were pivotal in making connections between ideas. Rose made direct links to students’ lives by illustrating how the mathematics can be used, but she also expressed her love for mathematics as a way of thinking, thereby modelling the human response of appreciating the subject.

The stories serve to situate the subject matter historically, culturally, socially or personally, that is, they essentially humanise the content in order to make it meaningful. Four types of “story” are evident in these snapshots, which I refer to as Categories of Meaning Making. In the following sections I describe each of the categories in detail by comparing teachers’ use of stories in mathematics and science. These four categories capture the variety of approaches that these teachers took to making meaningful links between subject matter and students’ lives. The categories also show how the subject defines what can be made meaningful and relevant. The assumption underpinning the analysis is that providing links to students’ lives serves to make the subject relevant. These categories provide the basis for a later broader discussion on the nature of relevance in mathematics as compared with science.

### 7.4.1. Illustrations of relevance

This category of meaning-making relates to the ways teachers and students used familiar things to illustrate how the subject matter connected with students’ lives. They are stories in the metaphoric sense because they emphasise the human dimension of the subject matter. They were the most prominent and recognisable attempts to relate the subject matter to students’ lives. They generally involved applying concepts, skills or processes to contexts familiar to students. They were evident in both mathematics and science as examples that gave shape, meaning, and relevance to explanations given in class. Simon described the nature of these illustrations:

Simon: Yes, I suppose you can [provide real life examples] in all [areas of mathematics]. If you’re doing graphs you can talk about how the weather in Australia is not a linear graph. Petrol prices sometimes go in a linear function. And then you can talk about if you are doing simple calculations. Like, $10, I went to the footy and they charge you $5 for pies. You try and bring it in as much as possible. But most
kids can’t do that, I have to lead that. Kids aren’t switched on enough
mathematically thinking to go “oh is that sort of like when I gave you $6 for
basketball and you gave me 50 cents back,” that transactiony sort of stuff. Where
Science is more, “Jeez that’s like cooking” or “that’s like what Dad does out in
the back shed.” Mathematics is all around them, but they don’t realise it. Whereas
science, Dad might go “that’s science son” and they would go “I’ll remember
that,” or Weird Science on TV. [S2AS:211]

In mathematics, the examples illustrate how the mathematics provides a tool to
represent patterns recognisable in society, such as graphs to explain weather patterns
and the linear nature of increasing petrol prices. The examples also relate to
particular ways of thinking that students may carry out or encounter in their lives,
such as transactions that students may recognise as mathematics.

In comparison, the science examples illustrate how science explains natural
phenomena. According to Simon, these examples emanate more naturally from
students’ experiences. Consequently, where the presence of mathematics is more
invisible for students and the teacher acts as the prompt for making connections to
students’ lives, in science students can more readily draw on personal experiences as
they make sense of science ideas. The teacher, then, plays a more active role in
making connections for students in mathematics than in science.

These illustrations generally provide limited opportunity for deeper level
engagement with the mathematics or science, and they generally do not demonstrate
the deeper purposes and values of mathematics or science; however, the focus of the
illustrations exemplifies the difference between the subject matter in science and
mathematics.

In science, the illustrations include examples of phenomena or objects, such
as discussing familiar examples of translucent, transparent and opaque materials
(Donna’s Year 9 lesson on light, lesson D5), corrective lenses as an application of
lenses (referred to during an interview with Pauline), and the melting of chocolate
and ice-cream as examples of physical change (Donna’s Year 7 introduction of
chemical reactions, lesson D7). The illustrations were usually visual, required little
personal engagement with the concepts, were offered by teacher or students, and
were selected based on teachers’ understanding of what students would “recognise”,
“have an interest in” and “relate to”, and how to “provide links that were relevant to
students’ lives”. For the teacher, this meant being aware of not just the concept under
study, but also the various phenomena or objects that students might be familiar with,
and have an interest in, that would give the abstracted concepts a concrete form and
“hopefully the concepts will cement a bit more” [Donna, S2AD:132].

In mathematics, the illustrations refer students to thinking processes that they
may have experienced or where they can see the application. For example, in the
context of real life applications of algebra at Year 9, Simon tried to incorporate
“worded questions that are world use sort of questions” [S2AR:32] that apply.
contextualise, and illustrate where this thinking might occur in real life, “questions that they would come across in actual life rather than just ‘do the left hand side’” [S2AS:32].

All teachers recognised that there were areas of mathematics that were easier to directly link to students’ lives, such as percentages, fractions, statistics, and graphing. Others, such as algebra, were recognised often during interviews as being more difficult to relate. Rose exclaimed in regards to algebra: “We do these complicated equations. Where will it ever go? I just say I have no idea where you are going to end up with it and I have no idea whether you would use it not” [S2AR:90].

At the junior level, Rose tried to present mathematics as something that is relevant and enjoyable. Recognising that students have difficulty with the abstracted nature of parts of mathematics, Rose tried to make mathematics more understandable by illustrating an operation using recognisable objects, such as the sharing of chocolate to illustrate fractions, as is mentioned in the following excerpt:

ROSE: I am always drawing boxes of chocolates on the board and cutting it up or whatever and trying to relate it back to ‘well if you have a cake and there are 6 of you, how are you going to cut it up into equal parts?’ … I relate it back to what they can identify with. [S2AR:88]

Rose used the “fruitbowl” analogy for algebra, such as $a$ and $b$ “standing for something” [S3AR:59] such as apples and bananas, thereby illustrating reasons for adding and subtracting like terms only. In these cases, the familiar objects (apples and bananas) are used as representations of abstract symbols ($a$ and $b$), rather than helping students understand the actual objects themselves, as is usually the case for science.

This is a difference between mathematics and science. The object or phenomenon stands in a different relation to the concept in mathematics than it does in science. In science, the object or phenomenon is the object under study and the meaning of the object for the person is bound up in the explanation. There is a natural relation between the explanation and the object. The stories are examples of these objects and how they behave. In mathematics, the object of these illustrative stories itself is not under study, but is used to give meaning to some concept that has no natural relation to the object. The purpose of junior school mathematics is not so much to explain phenomena, but to develop the mathematical skills required to recognise and make sense of patterns, and solve problems. Identifying these problems in nature and the social world, as indicated by Simon in Section 7.2, is quite challenging, particularly for students.

I propose that examples of this type edify the narrative that the teacher is building up around a concept. Certain ideas are selected and sequenced with a view to develop a particular understanding of the concept. The stories themselves are like simple snapshots rather than necessarily representing the complexity of mathematical
or science ideas. In the example of fractions, the narrative surrounding the concept is enhanced by personally relevant and familiar processes, that is, the sharing of chocolate. Simon illustrates below how he is aware of the need to consider what would be familiar for students when sequencing for conceptual understanding. When questioned as to his reasoning for introducing reactants and products before atoms, he said:

SIMON: If I started with terms that they have heard and real life instances like the bread one, cordial and cement, kids go, “Oh yeah, I’ve seen dad do that or I’ve seen mum make a cake.” And then we talked about how everything is made up of those little atoms and when we put them together, that’s what this is. And then they started to be able to write the formulas. If I’d have gone into atoms with symbols straight away, kids would have been going “Oh, what’s this chart? As if I’m going to know all this sort of stuff!” [S3AS:47]

Students’ experiences were tapped into immediately in order to give some reason for the more abstract notions that were to follow. Within this sequence students recall prior experiences of the familiar and observable process of reactants forming products, then the more abstracted concept of the atom is introduced. Simon’s use of stories of observable reactions acts as a tool for edifying explanations. There is richness to the development of conceptual ideas.

7.4.2. Explorations of familiar contexts

This theme encompasses Donna’s use of contexts to challenge students to think more deeply about the subject matter mentioned in her snapshot. These contexts were built around students’ interests, or were generative of new interests. Story in the narrative sense is appropriate here as the exploration of a context, for example can be built around a web of events and experiences. The story is the context and the application of the concepts under study.

The power of the story lies in the way a complex series of ideas are pulled together and given meaning through an application. Connections are made between the subject matter and ideas or phenomena that are already understood by the student or that hold intrigue. The result is a coherent and deeper understanding of the subject matter. The application therefore takes on a narrative structure where events are selected, sequenced and related. There is continuity of content and connectivity of time, so the events are not simply listed (Milne, 1998). Although I did not directly observe teachers using this approach in the classroom, Donna and James spoke about how they incorporated contexts that related the subject matter to the real world in mathematics and science classes.

Donna emphasised the connective nature of these stories. In particular, she focused on situations where students were given time and opportunity to investigate their own questions. When asked about the way she saw the role of stories in science and mathematics, she replied:
DONNA: I think they are pretty important, because I think it actually connects the kids better to actually do their work and it gets them thinking about something. I think [they learn more] if they want to find out the answer instead of just being told you’ve got to answer these exercise questions, off you go. Whereas, like I actually want to find this out, I want to know the answer. And if you can do that in terms of connecting into a story, I think it is good, I think it helps them.

... So I try and do it because I think if the kids can get connected to the mathematics, I mean we did a little thing on statistics, and that was great because the kids could go off and research all their favourite topics—who watches the TV, or who barracks for who. And I found that all of them breezed through that topic, and I thought ‘yes, that is because that is really connected’. [S2AD:138,140]

Donna indicates the fundamental essence of these stories: connections between ideas, and connections between student interests and learning.

In mathematics, such stories can be used to develop “problem solving activities” (School B) or “open-ended tasks” (School A). In some of Donna’s mathematics examples, students investigated something of interest, for example, investigating fractions using a context that was of interest to them, such as sewing, sales or football.

In an attempt to generate interest, James used student investigations that incorporated mathematical skills required to build a house and design a vineyard:

JAMES: I’ve designed and built a couple of houses so I was able to incorporate the mathematics skills. So I worked out a project based on that and I was able to show them photographs of the houses. And they had to do—this is in year 10—they had to do some calculations similar to what I did. And similarly, for Year 7 I was able to use a couple of programs to get them to design a vineyard. I’ve got 10 acres and I had planned to put a vineyard on there. Luckily I didn’t. So they had to work out the spacing of the vineyards to maximise the profit. So you can incorporate things like that. And they find that quite useful. Again if you can show photographs this is what the land looks like, this is what’s on the land now, then it’s a bit more real. [S2BJ:100]

In these examples, the mathematical skills are applied to a realistic problem. The story here is the situation that demands building the house or designing the vineyard, and the problem arises out of the story. The task requires a selection of processes and concepts in order to complete the task.

In science, Donna replaces “regurgitating questions” with student generated questions; for example, exploring refraction by investigating “the distance that light comes out of a lighthouse in terms of where the boats are coming, how they work out where to put the lighthouse, does the light run out at a certain point?” [S2AD:126]. Lighthouses are prominent in the lives of these coastal students. In both mathematics and science, such stories are “favourite topics” [S2AD:140]. In the case of James’ design investigations, he evokes students’ interests by showing photos that make these more “real” situations. As with Illustrations of Relevance, these stories are familiar to students. Knowing the interests of her students was emphasised by Donna as being pivotal in providing meaningful experiences.
Positioning students’ interests and developing their serious commitments as the basis for education stems back to the late nineteenth century (Kilpatrick, 1951), and was an important part of the progressive educational movement in the early twentieth century. Dewey (1963), for example, stressed the importance of students defining the “purposes which direct [their] activities in the learning process” (p. 67).

More recently, Tytler’s (1992) research into student participation in independent research projects was a response to teaching practices that negated students’ life experiences. He found that projects carried out by students that were based on their interests were not necessarily an efficient way of students learning new formal science knowledge, but that much of the knowledge learned had special meaning for students for a number of reasons. For some students, such projects produced practical knowledge that served a particular purpose. For others, “ownership and worthwhileness of knowledge had become part of an explicit personal philosophy” (p. 406).

Donna’s lighthouse activity has some common features with the independent research projects explored by Tytler (1992). Students conducted investigations by drawing on a number of ideas, which Donna believed resulted in meaningful understanding. As students proceed with such tasks, they have some autonomy over the storying of the concepts—the ideas that are selected, how the ideas are sequenced, and what questions are posed. As identified by Tytler, personal investment is driven by student interests, and generative of student interest. The emphasis here is on developing more meaningful science understandings.

A scan of the literature showed that the use of contexts for investigation and in-depth study is supported within both mathematics and science education. For example, Stevens (2000) reported on the relative successes of a program focusing students on project-based mathematics where students worked on extended projects “organised around fields of inquiry other than disciplinary maths” (p. 105), such as architectural design or science based contexts. This strategy was shown to be successful at connecting mathematics to situations where mathematics is used as a resource, “though only one among many, for making sense of that experience” (p. 139).

Researchers have explored the integration of mathematics with other subjects in order to connect teaching and learning with the real world (Jones, 1997; Nagel, 1996), or across mathematics and science (Herrera & Damian, 2000). Others present problems that show how mathematics processes are used in everyday life (Cohen et al., 2000; Goo, 2002). In science, materials that support teachers in relating science ideas to real life are readily available, for example, Walker and Wood’s (1994) publication of hands-on general science activities is designed to “help students understand concrete scientific applications that are interesting and relevant” (p. 1).
A form of meaning-making using contexts that I did not see in either mathematics or science was the use of “real” story telling, such as stories where “mathematical ideas are integral to the setting, characterisations, plot, and theme of the story” (Borasi, Sheedy, & Siegel, 1990, p. 174). Borasi et al. assert that mathematics stories are “bound up with context, value and illustrate the process of searching for meaning; emotions are a part of the texture of these stories as well” (p. 188). *The Number Devil* by Enzensberger (2000) is an example of how mathematics can be woven into a story. Similarly for science, Malcolm (2005) used story as the basis for a unit called *There’s an Emu in the Sky*. The story describes the journeys of three children of different cultural backgrounds as they try to understand the motions of the sun, moon, and other celestial bodies of the night sky. They seek the wisdom of their elders and traditional legends in their communities to see scientific explanations in the context of making meaning and generating understanding.

Student story telling was less mentioned by teachers, apart from students telling Simon the story of their crude experiment in Section 7.2. The use of narrative, such as explanatory stories, is becoming firmly entrenched in curriculum recommendations (Millar & Osborne, 1998). Research by Boström (2006) examines how students and teachers used stories of their lived experiences to make sense of science ideas. She found that narrative discourse in the classroom opens up possibilities for connecting theoretical chemistry with real life. Such story telling could be easily integrated into the Explorations of Contexts.

**7.4.3. Humanising stories of historical and contemporary “heroes”**

The third and fourth categories of meaning-making emphasise the human side of mathematics and science. These stories were used to humanise the subject. The third category, humanising stories, provide windows into the disciplines of mathematics and science, and include stories about historical and contemporary figures who have contributed to the development of scientific and mathematical knowledge.

James and Pauline used historical stories of science in the classroom. Both of their examples were in science. I observed no stories about the development of mathematical knowledge or about mathematicians. Since much of the discussion about stories during the interviews focused on how teachers related the subjects to students’ lives, there were few references to heroic figures in mathematics and science. However, two references were made to these types of stories in the classroom and during the interviews.

Both stories I saw were part of class discussions about conceptual ideas. The first was Pauline’s story of Benjamin Franklin’s discovery of static electricity (see Section 7.3.1 for more details). The Benjamin Franklin story was used by Pauline to
engage students in the stories surrounding the discovery of static electricity. The story is intriguing because Franklin went to such extremes in his search for understanding about static electricity.

James used a story about “spontaneous creation” in his Year 10 genetics unit, where he explained to a student who had been absent how scientific experimentation had falsified the previously accepted idea that life was created in a spontaneous manner:

JAMES: That was how maggots appear in meat that has been hung there. It used to be that they didn’t understand that the blow flies were laying eggs in the meat. So this guy did an experiment where he put some meat in a jar, covered it with cloth and did a control with a normal situation with some meat in there so the blow flies had access to it. So he was able to show that where the blow flies didn’t have access to the meat there were no maggots coming out. That worked against the age old concept of spontaneous creation of life or starting of life where maggots would appear or babies would appear in women when the time was right or the gods blessed them.

…

You know that anecdotes of any sort, whether personal ones, which are always great to include, or anecdotes about science in history, it works well [S2BJ:73, 81]

James’ experience has been that students accept these types of anecdotes in science, partly because they counter the typical science-as-fact and unproblematic story of science that students would normally encounter: “everyone gets tired of the notion of science being some sort of fact so if you can show that what people thought was fact at one stage has been proven to be wrong time after time” [S2BJ:77]. He liked to introduce historical stories during class discussions to illustrate the dynamic nature of science and the “progression of ideas” [S2BJ:75]. Other examples of where he does this include various models of the universe in astronomy and early theories about atoms. Science is presented here as using current understandings to best explain natural phenomena.

Stories in school mathematics can offer an alternative message about the meaningfulness of mathematics to those based on the utilitarian purposes of the knowledge. Doxiadis (2003), for example, disagrees with limiting the purposes of school mathematics to a foundation for future mathematics studies, preparation for the invisible use of mathematics in society as part of technological advancement, and learning to think. He presents a more complex and meaningful purpose through the investigation of contexts as stories based on mathematics as a “form of fascinating intellectual history of ideas” (p. 22). “Mathematical biography and history with a paramathematical slant” (p. 22), says Doxiadis, allows students to identify with the human context of mathematical research:
Embed mathematics in the soul by embedding it in history, by embedding it in story. By showing how it is lovely and adventurous – the stuff of the best quest myths. By showing how it was created by complex, adventurous, brave, struggling human beings. If you cannot teach or even show much of its beauty directly, for technical reasons, show it by showing the light it reflected on the faces of its discoverers. (p. 24)

Hence, stories about the heroes of the discipline have the potential to demonstrate how science and mathematics ideas are generated out of human exploration. They are included here because they give insight into teachers’ understanding of how the historical and biographical nature of the disciplines, and disciplinary knowledge as a way of thinking about, and understanding the world, could enter their classrooms. The fact that no such stories were mentioned by these teachers in relation to mathematics suggests that the historical development of mathematical ideas is perceived to be peripheral to the main purposes of mathematics learning.

7.4.4. Representations of the human response

These representations related to the ways teachers modelled, or emphasised in their teaching, a person’s response to science and mathematics. They included examples of how mathematics and science affect our lives, and teachers’ personal encounters with mathematics and science. They also demonstrated for students how mathematics and science provide the means by which we can live our lives as functioning human beings and citizens. Their use in the classroom depended on the extent and quality of teachers’ experiences with, and knowledge about, the discipline (this issue of teachers’ backgrounds is discussed further in Section 7.6).

These stories represent what it means to:

1) be passionate about, and committed to, either the discipline, the products of the discipline, or the subject;
2) participate in the generation or application of mathematics or science knowledge by engaging in disciplinary practices; or
3) be a user of mathematics or science ideas, processes and skills.

Stories exemplifying each of these human responses are discussed below.

The first aspect, teachers’ passions and commitments to the subject, was represented by Rose, who modelled an enjoyment and love of mathematics by being enthusiastic in her approach to mathematics: “I said to them ‘I love maths’ and I said ‘I want you to really like maths too, by the end of the year I really want you to like maths, that’s my aim’” [S2AR:62]. This issue of teachers’ passions is explored further in Chapter 8.

The second aspect, engagement in disciplinary practices, was exemplified by teachers through their references to their previous employment experiences. Donna
referred to her use of stories about her participation in dolphin research during biology lessons. James told stories about when he worked in a laboratory conducting research in order to illustrate safety in the laboratory and how things can go wrong, such as mercury from a broken thermometer falling through the cracks in the floor, and piercing his finger as he pushed a bit of glass tubing into a stopper.

JAMES: If you’re able to relate those to the students, you can see the eyes are saying, oh, things happened to him and he was being careful. He’s had acid burns and pieces of glass. Breathed mercury vapours and things like that. So you know all of a sudden it’s a bit more real than it would be otherwise. [S2BJ:95]

These stories make the concepts, disciplinary practices, or in this case the safety concerns, seem more real. They are intriguing for students. The purpose of these stories for James is to make science more real, and to bring to life the work of scientists, thereby making what students are doing in the classroom more authentic. He also tells students about his previous experiences with “spontaneous combustion of iron ores” [S2BJ:98] and how students can then relate this to their previous chemistry studies. Science as a process of human discovery and investigation is emphasised. Science becomes something worthy of attention.

By comparison, James explained that similar stories in mathematics, such as his use of sophisticated mathematics in the design of bridges when he was a civil engineer, are generally poorly received by students:

JAMES: I was originally a civil engineer and so yes I was using maths all the time. The maths was a different level of sophistication. What rate would you use here? So the best I’ve been able to do in maths basically is talk about how maths is a tool subject and use it for higher order functions. That sort of goes down like a lead balloon really. [S2BJ:96]

James’ inability to capture students’ imagination with this story of mathematics in use emphasises the inaccessibility of the more sophisticated formal or applied mathematics.

Teachers also made explicit the nature of science or mathematics by providing opportunities for students to participate in disciplinary practices. For example, Donna explained why scientists do a number of trials during a controlled experiment, and why scientists use chemical symbols as shorthand for chemicals (lesson D7). Rose emphasised mathematics as “making you think” [S2AR:92], and Pauline said that she liked to model this thinking process as she solved problems with students: “I really like to verbalise and write down: this is how I am tackling this problem, this is how a problem is solved, step by step” [S2AP:62].

The third aspect, being a user of mathematics or science ideas, relates to the usefulness of the subject. It centralizes the development of scientific or mathematical literacy as an aim of teaching. For example, in mathematics, Simon wanted students to understand how to work with numbers. He referred to the need for students to appreciate significance in mathematics to make sense of everyday events, such as
appreciating the significance of being a member of an Olympic team with only four people and winning a medal, compared to being a member of a large Olympic team. This involves contextualising higher-order mathematical skills that are applicable to all kinds of measuring, estimating and calculating problems (Jablonka, 2003).

Some of the mathematics illustrations mentioned in Section 7.3.1 come close to humanising mathematics because many of the examples given by teachers represent the usefulness of mathematical thinking in students’ lives. For example, when Rose illustrates how percentages are used in real life she continues the story to model her personal response:

ROSE: My story about going into town, the 30% sale, it was a shock to me and I went “Oh what’s this?” and I said that to the kids. So you can relate percentages back to “hey, this is what happened last night”. [S2AR:42, 295]

Rose assumes students are familiar with retail processes. Her story illustrates both the usefulness of mathematics and connects the abstracted and formalised processes taught in school with thinking carried out in what she calls the “real world” [S2AR:82,86,88]. The account also includes the emotive response that can be associated with developing insight into the mathematics behind sales—“it was a shock to me” [S2AR:295]. The mathematics becomes humanised. The narrative built around teaching fractions and percentages is enhanced and takes on meaning due to the connection she draws between processes in their abstracted and formalised form, and the familiar experience.

In science, Pauline emphasised the explanatory power of science in understanding our world, such as how static electricity plays a role in dust settling on televisions (lesson P3). As discussed in her snapshot (Section 7.3.1), Pauline expressed passionately her belief that “science informs everything that we do” [S2AP:80]. While appreciating the importance of mathematical literacy, Pauline expressed difficulty with demonstrating the more abstract areas like algebra, which students did not believe to be relevant.

Similarly, Ian held the view that having mathematical and scientific knowledge provides enlightenment and preparation for citizenship. He stated that he is passionate that “the kids see something that is relevant to them that they can take away from school, whether or not they become a research scientist or mathematician, and that it’s relevant to them becoming more enlightened people. Citizens I suppose” [S2BI:193].

The subjects are humanised through the use of stories that relate the subject ideas to daily living and citizenry. As a result, science and mathematics are portrayed as being constructed by humans in order to understand and explain the world we live in, to improve our lives, and to take some control over the decisions we make.
Representations of the human response to the subject, therefore, relate to the ways teachers represent for their students the human endeavour of understanding the world, constructing scientific and mathematical knowledge, and appreciating particular ways of thinking. The emphasis is on justifying learning of the subject matter for students. In this way, the nature of mathematics and science are represented in their many facets, especially their role in society and their meaningfulness as human endeavours.

7.4.5. **Summarising categories of meaning-making**

The previous discussion highlights a variety of approaches used in teaching to make the subject meaningful for students. Teachers referred to different teaching approaches when describing how they related the subject to students’ lives. For example, Donna was much more explicit about the use of contexts in science and mathematics than other teachers from School A, and Ian and Pauline were quite clear about school preparing students for citizenship. Different beliefs and orientations to meaning making are, therefore, evident.

Taken together these different approaches provide a sense of the subject pedagogies that characterise mathematics and science. In all categories, connections were made between the subject and students’ lives, used to engage students in their learning, and included by teachers to support the learning process. Other characteristics were specific to mathematics or science: the image of the subject that they present, their form in relation to the subject matter, from where and how they arise, and how students use and respond to them in their conceptual learning. These commonalities and differences are summarised in Table 7.1.
Table 7.1
"Characteristics of the Categories of Meaning Making"

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<thead>
<tr>
<th>CATEGORY 1</th>
<th>CATEGORY 2</th>
<th>CATEGORY 3</th>
<th>CATEGORY 4</th>
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</thead>
<tbody>
<tr>
<td>Illustrations of relevance</td>
<td>Explorations of familiar contexts</td>
<td>Humanising stories of historical and contemporary “heroes”</td>
<td>Representations of the human response</td>
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<td><strong>COMMON ELEMENTS</strong></td>
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<tr>
<td>These are applications of concepts, skills or processes that:</td>
<td>These are contexts for investigations built around student interest or generative of student interest that:</td>
<td>These are stories about how historical and contemporary figures have engaged with and developed knowledge over time that:</td>
<td>These are representations of the human endeavour of using, practising and being passionate about disciplinary ways of knowing and practices that:</td>
</tr>
<tr>
<td>• make connections between subject matter and familiar experiences for students;</td>
<td>• make connections between subject matter and familiar experiences for students;</td>
<td>• make connections between subject matter and the aims, practices and values of the broader disciplinary community;</td>
<td>• make connections between the subject matter and a humanistic response to the subject;</td>
</tr>
<tr>
<td>• offer surface levels of engagement with the concepts;</td>
<td>• offer deep levels of engagement with the concepts;</td>
<td>• offer deep levels of engagement with the nature of the discipline;</td>
<td>• offer deep levels of engagement with the human side of the discipline; and</td>
</tr>
<tr>
<td>• enrich the narrative built up around a concept.</td>
<td>• provide a context where conceptual connections are made.</td>
<td>• provide justification for learning about the discipline.</td>
<td>• models doing, using and appreciating a particular way of thinking.</td>
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</tbody>
</table>

**SCIENCE**
Science is presented as explaining natural phenomena that are meaningful to students. These illustrations:

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<tr>
<td>These are examples of phenomena, e.g., translucent, transparent and opaque materials;</td>
<td>Science is presented as a body of knowledge that can be used when explaining complex phenomena. These contexts:</td>
<td>Science is presented as subject to human interest, and a human construction that is constantly scrutinised, rather than objective, factual and unproblematic. These stories:</td>
<td>Science is presented as a worthwhile pursuit that can capture one’s imagination and interest. These representations:</td>
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<tr>
<td>• emanate naturally from students’ personal experiences of the natural world, e.g., bushfires to show the human impact of burning, which is a chemical change;</td>
<td>• provide a vehicle for connecting real life to science concepts, e.g., lighthouse and the behaviour of light;</td>
<td>• are exemplars of the way knowledge is constructed out of human discovery and intrigue;</td>
<td>• are explicit or implicit messages about what it means to be interested in and interact with scientific ways of knowing and phenomena;</td>
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<td>• assist students to recognise detailed aspects of the object under study, e.g., classify an object based on its characteristics</td>
<td>• arise out of student questions about phenomena, e.g., how do they work out where to put a lighthouse;</td>
<td>• emanate from teacher knowledge and resources that represent disciplinary practice and development;</td>
<td>• emanate from and are dependent on the extent and quality of teachers’ experience with scientific phenomena and ways of practising and thinking; and</td>
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<td></td>
<td>• require students to select the ideas and how they are connected and sequenced, e.g., what do I want to know about lighthouses?</td>
<td>• allow students to identify with the human context of scientific research.</td>
<td>• assist students to recognise the value of science in their learning and life.</td>
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<td>CATEGORY 1</td>
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<tr>
<td>Illustrations of relevance</td>
<td>Explorations of familiar contexts</td>
<td>Humanising stories of historical and contemporary “heroes”</td>
<td>Representations of the human response</td>
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<tr>
<td><strong>MATHEMATICS</strong></td>
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<td>Mathematics is presented as a useful tool for representing or manipulating abstracted patterns that occur in the real world, e.g., linear pattern of oil prices. These illustrations:</td>
<td>Mathematics is presented as a tool to solve problems or to make sense of data. These contexts:</td>
<td>Absent in these classroom observations. Use of these stories:</td>
<td>Mathematics is presented as a way of thinking that holds interest, intrigue, challenge and utility. These representations:</td>
</tr>
<tr>
<td>• are recognisable patterns and ways of thinking in the natural and social world;</td>
<td>• are contexts for problem solving or understanding patterns in society, e.g., designing a vineyard for maximum profit;</td>
<td>• are explicit or implicit messages about the intriguing nature of solving a problem, and the usefulness of being able to work with numbers;</td>
<td>• are explicit or implicit messages about the intriguing nature of solving a problem, and the usefulness of being able to work with numbers;</td>
</tr>
<tr>
<td>• emanate less naturally from students’ experiences as the presence of math is more obscure for students, e.g. money transactions;</td>
<td>• generally do not arise out of students’ questions about patterns, so are more teacher directed;</td>
<td>• are dependent on teachers’ conceptualisation of the purpose and potential for school mathematics; and</td>
<td>• are dependent on teachers’ knowledge, experience and attitude towards mathematics as an activity and educational pursuit; and</td>
</tr>
<tr>
<td>• assist in making an abstract concept concrete. However, the concept has no natural relation to the object, e.g., 4a is 4 apples</td>
<td>• require that students select the mathematical skills and processes appropriate for solving a problem</td>
<td>• can be of limited interest to students when the stories about the use of sophisticated mathematics to solve ‘real’ problems are too removed from students’ experience of mathematics.</td>
<td>• assist students to respond aesthetically to the challenge, order and utility of mathematics.</td>
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The first two categories focus on the direct links between familiar experiences and subject matter, while the humanising representations are more attitudinal and dispositional in nature. While teachers had initially stated that there were fewer opportunities to relate the content to students’ lives in mathematics than science, through closer examination of their practice they were able to find many instances where this could occur.

The diversity of ideas represented raises the question about the nature of relevance in mathematics and science teaching—what was considered relevant by these teachers? Table 7.1 outlines what teachers believed should be made relevant in both subjects.

According to these teachers, making school science relevant requires them to focus on science as: a way of explaining natural phenomena and familiar objects that are aligned with student interests; a body of knowledge used to explain the complexity of these phenomena in students’ lifeworlds; a human construction that developed out of a need to understand the natural world; and a worthwhile pursuit that can capture one’s imagination.

Making school mathematics relevant involves focusing on mathematics as: a tool, or system of thinking, that serves a recognisable need in everyday life and work; a tool for solving interesting problems or making sense of data; an intellectual pursuit that holds intrigue, challenge and utility. The development of mathematical ideas over time was not mentioned; however, Dioxiadis (2003) asserts that mathematics can also be portrayed as a history of ideas.

These differences are significant, particularly because they require a teacher to understand the subtleties of what the subject has to offer their students. How do these ideas compare with those emanating from the research literature? This question is discussed in the following section.

7.5. The nature of relevance in mathematics and science education

The question of relevance entails both content and pedagogy. This section addresses three questions:
1. What aims are associated with relevance in maths and science subject cultures?
2. What should be made relevant?
3. Is humanising the subject a way forward in making the subject relevant?
What aims are associated with relevance in mathematics and science?

Newton (1988) critiqued the construct of relevance as represented in science education research. He found that there were four categories of aims that underscored discussions about the relevance:

- **moral aims** are concerned with empowering people in their choices;
- **contextual aims** are those concerned with placing science in broader contexts so that students see the significance of science to people’s lives;
- **philosophical and epistemological aims** are concerned with presenting science as it is practised in order to present an appropriate image of the nature of science; and
- **psychological aims** are concerned with teaching that is considered relevant to students themselves, and which possesses some motivational value.

This framework offers an enriched way of conceiving of relevance in both mathematics and science. In Table 7.2 I have aligned each of Newton’s aims with the Categories of Meaning Making.

As can be seen in the table, psychological aims can be aligned with all of the categories because teachers considered that all of their attempts to make mathematics and science meaningful were underpinned by the psychological aim. The purpose of the Illustrations of Relevance, in particular, was to make spontaneous, relevant and purposeful links between students’ lives in order to make the subject matter more meaningful. As motivation for learning, the Explorations of Contexts are built around students’ interests, Humanising Stories are intriguing, and Representations of the Human Response demonstrate what it means to value the subject.

Contextual aims were associated with the use of Explorations of Contexts by teachers, such as Donna’s and James’ emphasis on using contextualising problems in mathematics and science.

Moral aims were evident in Pauline’s and Ian’s ideals about students becoming empowered citizens through their scientific and mathematical knowledge, and how this knowledge can be used in their lives as expressed in the Representations of the Human Response category.

Philosophical and epistemological aims were evident in the various attempts to humanise mathematics and science, linking with the Humanising Stories and Representations of the Human Response. Pauline and James shared stories of scientists to show the historical development of science ideas in Humanising Stories.

Table 7.2

*Alignment of Categories of Meaning Making with Science and Mathematics Goals*
Represented also in Table 7.2 are the goals for the Science and Mathematics VELS Domains as they align with the Categories of Meaning Making. In science, emphasis is accorded to preparing students for current and future citizenry responsibilities and participation. Similarly for mathematics, the emphasis on mathematics as a tool runs across most of the goals. Two goals appear to sit outside of the use and applicability of mathematics and focus more on connections between ideas and preparation for further study. These two goals are not mirrored in the science goals. This difference, I believe, reinforces the distinction between the basic assumptions leading to the Pedagogy of Support and Pedagogy of Engagement discussed in Chapter 6.

All students participating in the IMYMS Project completed a survey of perceptions of their lessons. In science, the items that scored poorly related to the relevance of the curriculum and their classroom activities to students’ interests and lives. Similar items scored poorly for mathematics, such as working on problems that affect their lives, and connections between school mathematics and students’
interests outside of school. Positive outcomes were received for items to do with teachers making science “fun”. In relation to mathematics, the subject was deemed useful, the teacher was shown to have high expectations of students, and students wanted to do well.

Although the results included all students who participated in the IMYMS project—not just the schools and teachers participating in my research—these results aligned with the views of my teachers. School A teachers emphasised activity oriented science in order to engage and interest students, confirming students’ perception that science is “fun”. Teachers’ attentiveness to linking science and mathematics to students’ interests was found wanting by students, which either confirms these teachers’ perceived need to make the content more relevant, or suggests that teachers’ espoused use of linkages to students’ lives and interests is underused or misperceived. It might also suggest that a focus on superficial engagement with the science activities through an emphasis on “fun” does not generate deep seated interest in science. Students’ appreciation of the usefulness of mathematics aligned with teachers’ perception of mathematics as a tool subject.

**What should be made relevant?**

These teachers’ pedagogical decisions are based on certain assumptions about what might be relevant for their students. Relevance, according to Newton (1988, p. 8) “requires a relationship in the presence of some need, aspiration or expectation”. He distinguishes between “external relevance” and “internal relevance”. External relevance is outward looking and refers to science that is relevant to life in some way. Internal relevance is inward looking and presents the knowledge as a neat, structured, coherent and unified assemblage of knowledge; pattern and unity is expected to be more attractive and makes the content easier to acquire.

Historically, mathematics and science favoured internal relevance in the selection of content. In science, intellectual knowledge acquisition provided a basis for student progression to the next level of a science course (Aikenhead, 2006). In mathematics, a building blocks metaphor (Lerman, 2000) provided the rationale for a curriculum where “Analyses of mathematical concepts provided a framework for curriculum design and enabled the study of the development of children’s understanding as building of higher order concepts from their analysis into more basic building blocks” (p. 22). According to Lerman, the result was teaching dependent on drill and practice, and positive and negative reinforcement.

In both subjects, a history of curriculum reform has resulted in movement towards greater emphasis on external relevance; however problems about what might be considered relevant to students’ lives and interests continue to be debated, and the pedagogies relevant to this have not been thoroughly researched.
In 1988, Newton distinguished between student and adult interests. Newton’s distinction is still applicable to a certain extent. If relevance is perceived as alignment with students’ interests, then catering for students’ current interests can be problematic. On the one hand students’ needs are transient and change over the course of their education. Newton believes that a student’s “limited experience and immaturity make him a poor arbiter” (p. 10) of what might be relevant for the future. On the other hand, “it may well enhance interest and encourage favourable and positive motivation” (p. 10). Alternatively, catering to adult needs may render the school curriculum irrelevant for students given the lack of immediacy to students. Newton advocates a healthy balance between meeting students’ immediate needs for motivation and casting the curriculum as knowledge needed for the future.

Newton’s distinction between adult and student needs is perhaps less clear in the current climate. Since the late 1980s, utilitarian aims for mathematics and science have developed into a drive to prepare students for citizenship and a transforming workforce. Science and mathematics education are being promoted as central to Australia’s economic and technological advancement (Department of Education Science & Training, 2003a). Citizenry needs are, therefore, increasingly impacting on both curriculum and pedagogy. Tytler’s (2007) casting of a re-imagined science curriculum perhaps finds the balance that Newton promotes:

the curriculum needs to seriously cater to all students and be set within contexts that will be meaningful to all students. The content of science needs to be set within these contexts, and introduced on a need-to-know basis but structured so that major ideas are covered… Content should be chosen to represent contemporary practice, and with a view to its usefulness in students’ current and future lives as citizens. Content should not be restrictive but needs to allow room for initiatives built around local conditions. (p. 64)

In mathematics, the debate has centred on how to maintain rigour and consistency in the canonical ideas, yet ensure universal access to mathematics for all of society (Gates & Vistro-Yu, 2003). For the past four decades, a call for “Mathematics for All” prompted curriculum reform to make the mathematics curriculum more relevant. In the 1970s, modelling and applications were emphasised. A move in the mid 1980s saw the mathematics education community approach this issue from two angles. One was to segregate the curriculum into “real” mathematics for the majority, and “core” mathematics for specialist studies. The other view was to maintain the current curriculum, which was somewhat canonical in nature, but to teach it more effectively to the majority, centralising the question of pedagogy over selection of content. Later in that decade, the problem of a universal curriculum was considered to be resolved as a new curriculum structure was introduced that provided alternative tracks, or streams – university track, vocational track, and non-formal track (Gates & Vistro-Yu, 2003).
In Australian schools, growing retention rates in the early 1980s led to the proliferation of alternative mathematics courses catering for different clientele, and for which there were different levels of acceptance by the community and for tertiary entry. By the late 1980s, an assumption that the majority of students would complete Year 12 before seeking further study or work led to what Stephen and Money (1993) reported as “an extensive top-down reform of curriculum and assessment arrangements across all subjects in the senior secondary years” (p.156). With the introduction of the Victorian Certificate of Education (VCE) in 1990, three mathematics courses with a comprehensive curriculum were offered to all students. In 2002, an alternative to the VCE was introduced in response to falling retention rates, and a growing proportion of students who performed poorly. The Victorian Certificate of Applied Learning (VCAL) provided pathways to work and further education via a more relevant curriculum based on practical work-related experience and learning.

The question of what is considered relevant by the broader education community continues to promote debate. Finding and creating relevance is an increasingly important part of the subject cultures of mathematics and science because it relates to current trends in student responses to the subjects. The negative stigma attached to the subject and declining student participation in advanced mathematics and science are symptomatic of school mathematics and science not meeting students’ perceived needs.

Is humanising the subject a way forward in making the subject relevant?

Aikenhead (2006) distinguishes between two perspectives on science curriculum, both emphasising the relevance of science. The first is a science curriculum that prepares students to appreciate science for its national importance. Students become “literate enough to receive scientific messages expressed by scientific experts” (p. 1). The second is a science curriculum that emphasises the “human endeavour” of science, which shifts the purpose of school science to developing “students’ capacities to function as responsible savvy participants in their everyday lives increasingly affected by science and technology” (p. 1). The former is based on the canonical ideas of science that present science education as enculturation into the scientific discipline. The latter is an “everyday approach that animates students’ self-identities, their future contributions to society as citizens, and their interest in making personal utilitarian meaning of scientific and technological knowledge” (p. 2).

Similarly in mathematics, Lerman (2000) maintains that mathematics education has changed to embrace a “humanistic image of maths…as a quasi-empiricist enterprise of the community of mathematicians over time rather than a monotonically increasing body of certain knowledge” (p. 22). Transmission of facts
has been replaced by problem solving (Lerman), applications, and modelling (Gates & Vistro-Yu, 2003). Lerman claims that “mathematical activity is identified by its heuristics” (p. 22) as pedagogies promote the use of readily accessible methods that lead to more or less the right answer. A shift towards “democratic tendencies for pedagogy among some schoolteachers” (p. 23) means that mathematical knowledge is being shaped to suit pedagogies favouring shared decision making amongst students, and more student-centred learning approaches. The needs of students, both in terms of their learning of mathematical concepts, skills and processes, and their assumed interests and future needs, are part of this shift.

All of the Categories of Meaning Making attempt to humanise mathematics or science at some level. The first two categories do this by raising students’ awareness of science or mathematics in society and relating it to their interests. If pedagogies are restricted to these two categories, indoctrinating students in the canonical ideas of science, and mathematics remains the agenda based on the assumption that there are particular bodies of knowledge that students need to know. Understanding the relevance of this knowledge is best achieved when this conceptual framework is situated within the students’ lifeworlds. The first of Aikenhead’s perspectives on science education could well be achieved by incorporating these types of stories.

The last two categories situate the person more deeply into the subject. They represent an agenda of humanising science, Aikenhead’s second perspective, with a focus on personally engaging with the subject, as well as the broader agenda of scientific literacy that prepares students for citizenship rather than “preprofessional training for the scientific world” (Aikenhead, 2006, p. 3). In these categories, relevance is associated with future use, appreciation of the impact of science and mathematics on students’ lives, and the role of humans in producing knowledge and understanding about our world. A sense of agency is given to students based on the assumption that they stand to benefit from what science and mathematics has to offer. Reconciling themselves as actors in society requires that the content stems from, and feeds back into, their lives.

Aikenhead’s (2006) proposal for a humanistic perspective in science education is a radical challenge to traditional science. While the teachers recognised the need to humanise the subject, their focus remained largely on canonical ideas. In order to move towards a humanistic perspective in their teaching, a number of barriers need to be overcome. Aikenhead asserts that, for teachers, a shift from a traditional canonical and conceptual based curriculum to a humanistic perspective requires substantial shifts in goals, values and ideologies surrounding mathematics and science education. Research has shown that it can take years to effect such change (see Gates & Vistro-Yu, 2003).
In mathematics, research has shown that there continues to be a divide between everyday uses of mathematics and the content of school mathematics (see, Abreu, 2002). Niss (1994) raises the problem of the “paradox of relevance”, which he believes is preventing students from seeing the need for learning mathematics. The paradox is that, as citizens, people need to know mathematics, but the use of mathematics in society remains largely invisible. The power of mathematics lies in its generality and transferability. However, generality leads to mathematics being disguised in contexts where those who apply mathematics, such as bankers and engineers, are not identified as mathematicians (Biehler, 1994). This was the case for James who, with his engineering background, had difficulty in translating the applied mathematics to anything that the students would comprehend or appreciate. IMYMS component 8.2 suggests introducing students to contemporary people working with mathematics in their professions. This is one way of making mathematics more visible, but the sophistication of the mathematics may exclude students from appreciating the role that they can play in advancing or utilizing the mathematics.

Kaput (1994) claims that there is a gap between what he calls the island of mathematical representations and the mainland of everyday experience. He calls this the “island problem in mathematics education”, and believes that it inhibits students’ ability to reconcile reality with the mathematics involved in problem solving. He states that solving this problem requires the use of authentic situations to understand the mathematics involved. Various representations of the same concept, and the use of traditional manipulatives can help students understand different aspects of the problem. Explorations of Contexts provide opportunities for these deep investigations to take place. Also, Humanising Stories that show how scientific and mathematical ideas have developed over time have the potential to add to an enriched sense of their possible applications.

Inherent in the assertions of Niss (1994) and Kapput (1994) is the need to raise awareness of, and to use, authentic and familiar contexts when teaching mathematics. Lave (1988) argues that there is a divide between the everyday uses of mathematics by students and the way mathematics is done in school. As a result, students have difficulty transferring acquired knowledge between contexts. For example, students might reason precisely and communicate persuasively in more familiar contexts, but struggle in a formal test situation. Lave proposes exploring variations in performance across different situations so that student successes and failures might be better understood in terms of relations between persons, their activities and contexts, rather than only in terms of cognitive structures.

The data have raised awareness of the increasing need for teachers to be attentive to students’ conceptual development, as well as to make science and mathematics accessible for their students. Part of this accessibility is justifying for
students the need to invest time, energy and interest in what is being learned. The teachers in this study appreciated this need, but found that incorporating students’ lives and interests in mathematics was more problematic than in science.

When juxtaposing these teachers’ perceptions of relevance with the directions that emerge from the science and mathematics education literature, I have two concerns. One is that a utilitarian view of curriculum that focuses only on the needs of future use will overshadow the depiction of science and mathematics as intriguing and the aesthetic experience of solving a problem. The other is that a fixation on canonical knowledge, even with the use of illustrations to enrich the learning experience, without the opportunity to explore ideas and problems at multiple levels, within different contexts, and from different angles, will present school science and mathematics as a “study of” disciplinary knowledge and process, rather than a “study for” enhancing one’s life and participation in society.

Incorporating all of the Categories of Meaning Making may help to meet the different aims associated with relevance. Doing so will also support students’ attainment of the various goals associated with the science and mathematics domains, with the exception of the mathematics goals that focus more on the internal relevance of the content. For both subjects, but perhaps particularly in mathematics, the goal of preparing students for future studies may take the highest priority for some teachers and thus overshadow the need to present a humanised mathematics and science experience.

7.6. Knowing the narratives of mathematics and science

Stories that teachers tell reflect something about themselves. Teachers’ backgrounds and experience with the discipline or subject provide the sum of their “lived experiences” (van Manen, 1990) from which teachers can draw. In their research into professional identity, Connelly and Clandinin (1999) refer to this as a person’s “professional landscape” on their professional lives, metaphorically described as a “storied landscape”. The landscape comprises multiple stories, “stories to live by”. As a knowledge base, this landscape can include knowledge of events, processes or conceptual understandings, but it also includes feelings, attitudes and values that stem from their experiences. Kerby (1991) states that a sense of self is generated through stories. The stories teachers tell are based on their experiences and the actual telling of stories shapes the self. For example, Ritchie, Kidman, and Vaughan (2007) explore the importance of telling stories of science during teacher education in order to bring identities relating to both science and teaching to the foreground.

This shaping effect of story telling is consistent with the way in which Pauline, Donna, James and Ian referred to themselves as science teachers, Simon
preferred the label of mathematics teacher, and Rose preferred to be recognised as a
teacher of students.

Teachers’ histories are evident in the stories that they tell. The influence of
the discipline is evident as they share about their experiences of learning at university
(for example, Pauline’s appreciation for physics and commitment to science
generally), working in the field (for example, James’ stories of safety in the lab),
personal experiences (for example, James’ experiences of designing a vineyard and
building a house), or a personal orientation to particular ways of thinking (for
example, Rose and Simon’s love of logical thinking). Their personal histories
predispose teachers to particular ways of talking about the world.

The type of experiences that the teacher has will shape what events,
understandings and dispositions they have to share or project. Donna and James have
work experiences that provide them with stories that they can bring into the
classroom. Pauline has a particular view of the subject that has developed over years
of studying science and enculturation into certain ontological and epistemological
positions, including an appreciation of the use of stories and the problems this creates
as she moves into mathematics teaching. Rose and Simon have spent most of their
working lives in the school environment, but they too have particular experiences as
learners and teachers that have led them to develop particular positions ontologically
and epistemologically.

The schooling imperative reshapes teachers’ experiences. When teachers
enter the teaching profession stories and experiences become pedagogical tools if the
teacher understands the subject well enough to know what is appropriate or what is
not for furthering student understanding. This knowledge base could be considered
more complex than “content knowledge”, or even “pedagogical content knowledge”,
as described by Shulman (1986) because their knowledge is impregnated with beliefs
about teaching and learning, the subject, and what it means to personally engage with
the subject. For example, Simon’s pedagogy is underpinned by a belief that a fun and
sometimes competitive environment will result in motivation to develop conceptual
knowledge. This psychological aim (Newton, 1988) of student motivation influences
how he makes science relevant for his students because his knowledge of how to
connect the science content to students’ lives is coloured by his assumptions that fun
activities will entice students into being interested in science.

But what happens when teachers have few positive experiences with the
subject or do not understand how their lived experiences can enhance learning
opportunities for their students? Both Pauline and Donna valued stories but lamented
having fewer stories to tell in mathematics because of their inexperience as
mathematics teachers. This restricted the way they connected the subject matter to
students’ lives. Donna explained this below:
DONNA: Probably not, no, and again I think that would probably be where I would find that, I’m predominantly a science teacher, and until I started here I hadn’t taught maths before, so I am new at maths teaching, which means I try and do it where I can and I am still trying to learn where I could actually, what topics I can do that in. Because sometimes I think “algebra, how am I going to—” Whereas then you actually hear what other people are doing or you go and research a bit and you go “oh, yeah I wouldn’t think of that”. So now I know from last year I know what I can actually do with algebra, or different concepts this year. [S2AD:140]

Donna is relatively new to teaching and is building up a repertoire of stories, examples and contexts that are appropriate for the content and relevant to the students. Donna finds her students’ lives and interests a wealthy source of contexts that she can draw on. Ideas also come from other teachers. Collegial sharing, especially within subject departments, was referred to in every interview with the teachers as being valuable for curriculum development and broadening the teachers’ pool of activities and resources. The teaching imperative, therefore, motivates teachers to seek out stories. The discussion between Pauline and Donna below emphasises this teaching imperative. The discussion begins with a reflection on how they tend to be attentive to stories in the media relating to their disciplinary knowledge and research, and how these stories feed into their teaching:

DONNA: I’d watch a dolphin documentary before I’d watch the new latest technology in optics. Like if it was dolphins, like this afternoon I could talk about what dolphins do in their prides and family groups because I’ve done dolphin research, like a report to the Council. Whereas if I’d walked in cold to an optics or lenses I would probably have to use what I know, what I’ve already researched myself or what I’ve taught in the past. I couldn’t just go off and give them examples from industry, or this is how the newest camera works, there’s this great new lens.

PAULINE: Yeah, its an interesting thing isn’t it. I’m doing optics at the moment, and I said to the kids, Did you know that the Hubble Telescope is about to be decommissioned and things like that, and I think you should go off and research that. Cos it is, its our interest. And I think, if you’re a biology person, then you go and watch a doco, actually I would watch a doco on dolphins too because I love dolphins, but if you’re a physicist your ears might prick up when there’s a story on, if you’re skimming through the paper you’d go, what’s this about the latest theory on how the earth was created, or whatever. And these things stick in your mind and you use them later when you’re talking to kids.

DONNA: But if I was teaching a unit on that, I would probably watch it. Because you’d help yourself out, you’ve got to know your stuff when you walk in class. But apart from that, with it not being an interest area, and you don’t necessarily have a need for it. [FGD:102-104]

These stories are different from those mentioned by Donna in the earlier quote where she used stories from the students’ lives to enhance her teaching. The above discussion talks about those stories that the teachers bring with them from their lived experiences with the discipline that they think the students might identify with. These are stories from the discipline that represent for both teacher and students something about the nature of the knowledge and the nature of the scientific endeavour itself. They represent the subject as being a part of the larger science culture because they draw on the same body of knowledge, and that science can
influence society such as through technology or social action. The teachers immerse themselves in these stories, depending on their interests. These are personal stories that have interest for the teacher, and come from the teachers’ lived experiences with the discipline rather than out of a pedagogical imperative, that is needing to have something to teach to students, “knowing your stuff” as Donna puts it. However, Pauline indicates that these stories find their way into the classroom because of their usefulness to teaching. When thinking about the effect of subject culture on teaching, there are two things operating here: one is an expectation to prepare oneself for teaching, a pedagogical imperative; and the other is the role that a person’s background and interests play in making a teacher sensitive to certain experiences and ideas.

7.6.1. Negotiating subject boundaries

What does a teacher need to understand when they cross the subject divide into unfamiliar territory? Teaching out of field is a growing reality in many secondary schools. For example, research has shown that the future junior mathematics teacher is likely to be a female biology graduate (Harris & Jensz, 2006). While this in itself is not problematic, the move from one disciplinary way of knowing, thinking and acting requires a shift in a teacher’s thinking and being.

A teacher without a background in the subject is in danger of not knowing how to use common or previous experiences to enhance the teaching sequence. For example, the research by Lave, and the ideas of Niss and Kaput discussed in Section 7.5, emphasise the need for teachers to appreciate how to use contexts meaningfully in mathematics. Based on my research, the same could be said for science. A new teacher or a teacher teaching out of field is in danger of not being aware of the difficulties associated with knowledge and skill transfer, as was the case for James who expressed difficulty utilizing his engineering experiences. Also, they may not appreciate that while students might perform poorly in one context, such as in a “test” situation, they may be successful in more informal contexts.

Alternatively, a teacher without these appreciations may attempt to bring in a style appropriate for a different subject with a different set of demands. As Pauline realised, pedagogy suitable for one subject will not automatically translate to another subject. For Pauline, movement across the boundary from science into mathematics was hampered by her limited understanding of how to use stories to make connections between the mathematical ideas and students’ lives. While she was fluent in explaining the presence of science in students’ lives, the impact of mathematics on students’ lives was more difficult for her to explain, maybe because of the culture that she is coming from (science, where connections between life and science are more recognisable for her) and the culture she is moving into.
(mathematics teaching, where mathematics is recognised as a tool for science and for life, and as a challenging process that makes you think).

7.7. Conclusion

Understanding how teachers of mathematics and science conceptualise relevance and how they connect subject matter to real life can inform teaching practice in three ways.

Firstly, comparing the role of relevance in mathematics and science illustrates various meanings that relevance can have for teachers. For example, the absence of historical stories in mathematics demonstrates a silencing and lack of appreciation within the subject culture for the historical development of mathematical ideas, and how this can inform and enrich the learning process.

Secondly, it demonstrates that expecting teachers to make the curriculum relevant is not necessarily unproblematic because the meaning of relevance is not collectively understood, nor is it the same for mathematics and science. For teachers moving between mathematics and science teaching, especially when moving into a subject where they have limited appreciation or experience, understanding how the subject can be made relevant for their students, and themselves, is an important aspect of their pedagogical content knowledge.

Thirdly, Elbaz-Luwisch (2002) describes the practice of teaching as being constructed when teachers tell and live out particular stories. Teachers “having stories to tell” is important, not only in terms of sharing anecdotes in the classroom that reveal the teacher’s view of the subject in an effort to draw students into the subject, but also as it fundamentally reflects part of their personal response to the subject. In this way, stories have a reflexive character as they have the potential to give the teacher a confidence and level of commitment that may be evident as a passion for teaching the subject to students.

This background, a storied landscape, acts as a mediator to how subject culture influences individual teachers. In the next chapter I develop further the personal aspects of teaching by overlaying a theoretical lens of aesthetic understanding over the data and interpretations I have used already.
Chapter 8. The role of aesthetic understanding in the relationship between subject culture and pedagogy

One of the important observations of Chapter 7 was that the teachers recognised the importance of humanising a subject in order to give it some level of significance in the lives of their students. How the teachers embraced and responded to this challenge depended on each teacher’s personal commitments to, and historical interaction with, the subjects and the subject cultures. Therefore, “having stories to tell” was not simply a cognitive issue, but also required a personal response from the teacher. It is likely that evaluative judgements about what might be of interest in the subject shape the teacher’s pedagogical choices; judgements arising from what the teacher knows and values, which are aesthetic in nature. For this reason it is important to examine the role of the aesthetic dimension of teaching in mediating the interaction between teachers’ experiences of subject culture and what occurs at the classroom interface.

In this chapter I focus on the role of aesthetic understanding in the ways that these teachers experienced, situated themselves within, and negotiated boundaries between the subject cultures of mathematics and science. To assist in this I draw from existing theory to construct a framework of “aesthetic understanding.” I then use this framework to re-examine teachers’ experiences and perspectives already presented in Chapters 5, 6 and 7 to emphasise relationships between the aesthetic, the subject and the teacher.

8.1. Aesthetics in education

I began thinking about the aesthetic dimensions of teaching when I noticed how these teachers constructed themselves in relation to the subject. Teachers recognised that their interest in the topic had a strong bearing on how they taught. Subsequently, I felt it was important to consider the idea that teaching, and knowing how to teach, involves both cognitive and affective dimensions. According to Zembylas (2005b), emotion and cognition are inextricably linked in the process of student learning. I assert that the same can be said for teachers in their development as mathematics or science teachers. “Aesthetics” provides a way of exploring the links between what teachers know about the subject and its culture, and their personal response to that knowledge.
Aesthetics is often restricted to the affective domain, along with beliefs, values, attitudes, emotions and feelings, self-concept and identity (Schuck & Grootenboer, 2004). In the last twenty years increasing attention has been given to the affective domain as researchers explore its centrality in the learning of mathematics (Bishop, 1991b; Sinclair, 2004), learning of science (Alsop, Ibrahim, & Kurucz, 2006; Chandrasekhar, 1990; Zembylas, 2005b) and learning in general (Beijaard et al., 2004; Ivie, 1999; Pajares, 1992; Schwab, 1978; Zembylas, 2005a). This growing interest in affective issues in educational research acknowledges the personal dimensions of teaching and learning; however, aesthetics is less represented, particularly in relation to the teacher.

While the aesthetic is often restricted to the affective domain, strictly speaking aesthetics addresses both the cognitive and affective aspects of human nature. The term “esthetic” was first used in the eighteenth century by the philosopher Alexander Baumgarten to refer to cognition by means of the senses, sensuous knowledge, and more specifically in reference to the perception of beauty by the senses (Goldman, 2005). Kant used the term to apply to judgements of beauty about art and nature. One of Kant’s four key distinguishing features of aesthetic judgements, known as “judgements of taste”, is that they are disinterested, meaning that we take pleasure in something because it is considered beautiful, rather than judging it to be beautiful because we take pleasure in it (Graham, 2005). This beauty behaves as if it were an inherent and an objective property of the object. Dewey criticised Kant for making beauty disinterested (Dewey, 1934/1980). Instead, Dewey preferred to adopt the term “aesthetic experience”, signifying “experience as appreciative, perceiving and enjoying. It denotes the consumer’s rather than the producer’s standpoint” (Dewey, 1934/1980, p. 47), and, therefore, is not an inherent quality of the object. The individual acts as agent in their perception of the experience, and this agency involves both cognitive and affective dimensions: “not absence of desire and thought but their thorough incorporation into perceptual experience characterises esthetic experience in its distinction from experiences that are especially ‘intellectual’ and ‘practical’” (Dewey, 1934/1980, p. 254). Dewey’s aesthetic integrates the mind and emotion so that the integrity of an experience is maintained. This is called aesthetic experience (Dewey, 1934/1980). This chapter uses a Deweyan perspective on aesthetics and aesthetic experience.

Contemporary educational research into the nature, and importance, of the aesthetic in education has centred predominantly on its role in learning (Gadanidis & Hoogland, 2002; Girod et al., 2003; Jakobson & Wickman, 2007; Wickman, 2006). Girod and Wong (2002) argued that “science can be taught in ways that borrow from aesthetic and artistic pedagogy to tap into the power of aesthetic experience” (p. 200). Wickman (2006) investigated the role of aesthetic judgements (that is,
expressions of pleasure and displeasure, or evaluations of taste) in science learning activities at tertiary level in Sweden. Aesthetic experiences, he claims, are inherent to science activity. Similarly, Jakobson’s research (Jakobson & Wickman, 2007) into elementary school learners found that aesthetic judgements occurred in moments of anticipation and moments when the science activities were brought to fulfilment. Her results support the contention that “emotions, values and aesthetic experiences are interrelated in children’s learning and also related to cognitive aspects of learning” (p. 65).

This interweaving of the emotional and cognitive is also described in relation to the process of teaching. Some researchers use an aesthetic overlay to describe the art of teaching (Eisner, 1979; Ivie, 1999; Rubin, 1985). For example, Rubin (1985) depicts the artistry of teaching as being more than motivation and dramatisation: “It is an extraordinary level of performance, bred out of personal commitment which elevates the state of the art” (p. 159). According to Eisner (1979), the experience of teaching is essentially aesthetic due to this artistic quality: “teaching is an art in the sense that teaching can be performed with such skill and grace that for the student as well as the teacher, the experience can be justifiably characterized as aesthetic” (p. 153). Both artwork and good teaching are made up of the coherence or unity of discrete and different parts. Dewey recognised this comparison: “In a work of art, different acts, episodes, occurrences melt and fuse into unity, and yet do not disappear and lose their own character” (Dewey, 1934/1980, p. 36). “It is an old saying that unity in variety marks every work of genuine art. Certainly the art of teaching bears out the saying” (Dewey, 1933, p. 53). The aesthetic of teacher’s work, therefore, is evident as a sense of unity that brings together different and discrete individuals through a dialogue between the teacher and their students (Eisner, 1979; Ivie, 1999).

Other research focuses on the role of the aesthetic in the activity, psychology and affective response of scientists and mathematicians to their discipline (Root-Bernstein, 1989; Tauber, 1996), often with the intent of informing mathematics and science teaching of that which provokes an aesthetic response (Burton, 2002, 2004; Sinclair, 2004; Wickman, 2006). In mathematics, for example, Sinclair (2004) explains that aesthetics has long been claimed to play a central role in developing and appreciating mathematics. Recognition of the beauty of mathematics stems from the Ancient Greeks who believed in the affinity between mathematics and beauty based on its order, symmetry, harmony and elegance. This is often called the aesthetic of mathematics. This aesthetic is often removed from the mathematics curriculum (Doxiadis, 2003) and the mathematics story is often shortened to a sequence of steps that can result in students failing to experience the pleasure of the process (Gadanidis & Hoogland, 2002). In science also, the words beauty, inspiring,
artful and passion are often used by scientists to describe their work (Girod, Rau & Schepige, 2003). “The scientist does not study nature because it is useful; he studies it because he delights in it, and he delights in it because it is beautiful…intellectual beauty is what makes intelligence sure and strong” (Poincare, 1946, quoted in Girod et al., 2003, p. 575).

These portrayals of science and mathematics as eliciting an affective response such as curiosity and the pleasure of the process are in contrast to the objects of science and mathematics that “are amenable to a rational and cognitive inquiry” (Wickman, 2006, xii). Educators draw from the disciplines the important ideas, behaviours and dispositions that should be presented to students. If science is characterised as being analytic, logical, objective and methodological, Girod et al. (2003) assert, this is then translated in classrooms as requiring students to be removed “critical observers of objects, events, and the world” (p. 575). By comparison, some scientists “portray science with an opposing personality—one that draws us in, begs our curiosity, passion, and emotion” (p. 575), which, if translated to the classroom can improve the quality of the learning experience.

Dewey’s theory of aesthetic experience helps to understand the relationship between the affective and the cognitive. Dewey rejected binaries, such as objective and subjective, logic and intuition, mind and heart, and thought and feeling. Wickman (2006) explains that in an aesthetic experience the inner emotional world is continuous with the outer world, meaning that one cannot think of one without the other. The cognitive (factual, what is the case) cannot be conceived of without the normative (values, what ought to be) in an aesthetic experience (which is evaluative). In keeping with this epistemology, Girod et al. (2003) claim that “from the perspective of aesthetic understanding, science learning is something to be swept-up in, yielded to, and experienced. Learning in this way joins cognition, affect, and action in productive and powerful ways” (p. 575-576).

According to Dewey’s principle of the “experiential continuum” (Dewey, 1938, p. 33), there exists some kind of continuity in every experience. This means that every experience affects for better or worse the attitudes which help decide the quality of further experiences, by setting up certain preferences and aversions, and making it easier or harder to act for this or that end. Moreover, every experience influences in some degree the objective conditions under which further experiences are had. (p. 37).

Dewey (1938) gives the example of a child who, on learning to speak, has a new “faculty” and new desire. The child “also widen[s] the external conditions for subsequent learning” (p. 37), such as learning to read.

In the context of teacher learning, Dewey’s ideas suggest that as teachers learn what it means to appreciate the subject, certain preferences and attitudes are
established that set the conditions for future experiences with the subject. For example, a teacher may have a history of developing the “faculties” they require to learn more complex ideas, and a desire to want to learn more. I am interested in how the teachers’ experiences with a subject shape their faculties and desires, and in turn, how these faculties and desires shape the way they engage with, and see themselves in relation to, the subject.

This chapter focuses on the role of the aesthetic, specifically aesthetic understanding, in the relationship between subject culture and pedagogy. I frame this in terms of not so much what and how the teachers learn, but how their aesthetic understanding relating to teaching mathematics and science can give insight into how teachers negotiate boundaries between the subject cultures of mathematics and science. I use the notion of aesthetics on the basis that a teacher’s personal experience of, and response to, the subject culture is aesthetic in nature, meaning that the cognitive and affective are inextricably linked in both their experiences of the subject culture, and in the way current experiences provide parameters and expectations for future experiences. The cognitive is continuous with the affective, and the experience is part of a continuum of experiences.

I found the framework of “aesthetic understanding” from Girod et al. (2003) useful when describing this personal response: “Aesthetic understanding is a rich network of conceptual knowledge combined with a deep appreciation for the beauty and power of ideas that literally transform one’s experiences and perceptions of the world” (p. 578). Girod et al. (2003) draw from Dewey’s epistemology to describe aesthetic understanding as being comprised of three aspects: that it is “compelling and dramatic”, “unifying”, and “transformative” (p. 578). While this reduction of aesthetic understanding into three aspects potentially fragments the wholeness of the aesthetic as described by Dewey, by focusing on each aspect, I am able to explore in detail the weaving of the cognitive and the affective during the teaching act, and as the teacher develops a sense of self in relation to the subject. In the following sections I expand on each of these aspects:

• Compelling and dramatic nature of understanding: teacher motivations and passions;
• Learning that brings unification or coherence to aspects of the world or the subject: knowledge of what and how to teach; and
• Perceived transformation of the person and the world: teacher identity in relation to the subject.

I draw together various contemporary theories about teaching, learning, subject culture and the individual. I also use data from teacher interviews (some of which
have appeared in Chapters 5, 6 and 7) to explore how a teacher’s conceptualisation of a subject shapes, and is shaped by, their aesthetic understanding.

8.2. Compelling and dramatic nature of understanding

This aspect of aesthetic understanding recognises that aesthetic experiences are steeped in emotion. Aesthetic experience “…quickens us from the slackness of routine and enables us to forget ourselves in the delight of experiencing the world about us in its varied qualities and forms” (Dewey, 1934/1980, p. 104). In such experiences, emotion, cognition, and action are fused.

So, when Rose says to her students at the beginning of the year “I love mathematics and by the end of the year I want you to really like mathematics too” [S2AR:64] (see Chapter 8) she is demonstrating her passion for mathematics, and that there is something about mathematics that compels her to further engage with it. Rose explained that she is interested in mathematics because it is logical and “it appeals to my logical brain” [FGD:108]. It is this that she wants to share with the students so that they can appreciate and delight in mathematics in the same way. A passion for the subject is evident here: a passion for the content matter, but also for teaching the content.

In the focus group discussion I asked the teachers what passion is and what it looks like in mathematics and science. Rose shared an experience she had during a lesson where she and a small group of students were working together on a different task to the rest of the class. “And I was so engrossed,” Rose exclaimed, “I didn’t realise the class had finished. And I turned around and they were all sitting back in their chairs, but my kids were so engrossed in what they were doing and really happy” [FGD:153]. Donna replied, “That’s what passionate looks like in mathematics!” [FGD:154]. Rose’s passion for promoting student engagement with the subject is recognisably an experience of “flow” where, simply put, a person is so engrossed in a task that they lose all sense of time (Csikszentmihalyi, 1997).

During the focus group discussion, various teachers explained how passion for the subject or discipline is evident in the classroom: “You’re interested in it. Enjoy it. If you enjoy something then you’re going to impart that enjoyment onto your students” [Rose, FGD:139]; and “You can see that [teachers] know their stuff and are passionate about mathematics” [Donna, FGD:143].

Teachers’ lack of passion about the subject was also seen by the teachers as being evident to students: “I think kids pick up on it when you don’t enjoy it. If you’re teaching something you don’t particularly enjoy, it seems like they muck up more. I dunno, maybe we’re all suffering together!” [Pauline, FGD:142]. Many studies assert that it is important for students to see their teachers being passionate
about their subject (see, for example, Darby, 2005b; Education & Training Committee, 2006; Lane, 2006; Palmer, 1998).

During the focus group discussion I asked teachers what happens when teachers teach outside of their subject area if passion for the subject is so important. In these instances, a general passion for teaching students is believed to be important. As Donna explains below, this passion is rooted in that which first lured them into teaching:

DONNA: What got you here in the first place, your passion for teaching. You may not be happy about it, but you’ve still got the basic passion for teaching to try and do the right thing by the kids and you go out of the way to make sure, no matter what subject it is, that you’re teaching them the best way you can…It comes down to [the fact] that you’re teaching people, not the subject. [FGD:181]

This suggests that a passion for teaching can be related to the activity of teaching, separate from the content matter under instruction. The passion emerges out of a desire to engage with students.

8.2.1. Aesthetic, passion, and the subject

In their research into individual teacher’s commitments, Crosswell and Elliot (2004) assert that teachers are emotionally committed to their work. Commitments that are external to the teacher (such as the school, students, career continuance, and subject commitments) are significantly linked to personal passions which include ideology, values and beliefs. In the previous section, the teachers expressed a need to be emotionally committed to their work. Emotional commitment is expressed as passion, which Fried (1995) states “is at the heart of what teaching is or should be about” (p. 6).

The teachers in this study expressed passions for three aspects of their work: a passion for the subject matter, a passion for promoting student engagement with the subject, and a passion for teaching in general. This multi-dimensional framing of what drives teachers is represented by Day (2004, p. 12):

To be passionate about teaching is not only to express enthusiasm but also to enact it in a principled, value-led, intelligent way. All effective teachers have a passion for their subject, passion for their pupils and a passionate belief that who they are and how they teach can make a difference in their pupils’ lives, both in the moment of teaching and the days, weeks, months and even years afterwards. Passion is associated with enthusiasm, caring, commitment, and hope, which are themselves key characteristics of effectiveness in teaching.

As indicated by Donna in the previous section, this sense of care can be perceived of as a passion for teaching in general. Rubin (1985), in his study of good teachers, found that teachers who gained satisfaction from their work tended to “view teaching not only as a job, but as a means of satisfying the demands of the spirit as well” (p. 20). Teachers in his study referred to the intrinsic rewards associated with
stimulating “children’s intellectual growth” (p. 6). This more general sense of satisfaction and passion that sits outside of the content is likely to be particularly important when teaching a subject where the teacher has limited experience, training and commitment. In such situations, the passion lies in the act of relating with students (as stated by Donna). A question remains as to whether a teacher can be effective at engaging students in the subject matter if she or he has little passion, or even appreciation, for the subject. Rose believes that teacher interest in the subject is vital: “If you’re not interested in something, you shouldn’t teach it!”.

Day (2004) also describes the importance of teachers sharing with students a commitment to the subject they are teaching:

When students can appreciate their teacher as someone who is passionately committed to a field of study and to upholding high standards within it, it is much easier for them to take their work seriously. Getting them to learn then becomes a matter of inspiration by example rather than by enforcement and obedience. (p. 15)

The Education and Training Committee’s (2006) inquiry into the promotion of mathematics and science education in Victoria supported this view saying that when promoting student engagement there is a “need for teachers to be passionate and deeply knowledgeable about their subject area” (p. 172).

My research has shown that a passion for teaching is coloured by a teacher’s commitments to the subjects they teach; therefore, passion for teaching, at least at the secondary level, is less likely to be seen as generic and more likely subject-specific. Research by Siskin (1994) into the culture of subject departments in secondary schools found that what mattered for the teachers in her study was “not simply that they teach, but what they teach” (p. 155, emphasis in original).

Neumann (2006) asserts that, in the context of scholarship in higher education, “passion illuminates the complexity of both teaching and research, showing that what resides at the heart of both is the learning of a particular subject” (p. 413, italics in original). Subject here refers not necessarily to a school subject or discipline but a subject of thought on which a conversation can be focused. In the classroom, the teacher makes the focus of conversation the ideas of mathematics or science, however, how they represent these ideas depends on the teachers beliefs about what the subject can offer the students. For Rose, mathematics offers training in logic and a potentially enjoyable endeavour. A passion for teaching is coloured by the teacher’s conceptualisation of the subject.

According to this view, pedagogy is influenced by a link between the way teachers see their students and the subject: “Teachers understand and value their subjects for what they offer students, and understand their students through the metaphors and assumptions of the subjects” (Siskin, 1994, p. 158). Consequently, pedagogical knowledge is tied to how the teacher understands the knowledge of the
subject. Conversely, the content knowledge of teachers is transformed in a way that meets the perceived learning needs of the students.

8.3. **Learning that brings unification or coherence to aspects of the world or the subject**

The unification and coherence of an aesthetic experience acknowledges that “it is not possible to divide in a vital experience the practical, emotional, and intellectual from one another” (Dewey, 1934/1980, p. 36). Experience is complete and results in deep meaning because the experience retains its value and wholeness, and this coherence can be used to guide future experiences. According to Girod et al. (2003, p. 578), an “aesthetic understanding depends on developing a similar coherence of parts, pieces, ideas, and concepts”. This is evident in the classroom when the learning of individual parts of a concept brings greater understanding of the entire concept.

The teachers in my study demonstrated this element of aesthetic understanding when they referred to how their backgrounds of experiences shaped their practice. In Chapter 5, Donna, Ian and Pauline particularly attributed a confidence in teaching their preferred subjects, or disciplines, to a history of positive experiences. Donna also talked about how a coherent understanding of the subject matter arising out of such experiences has implications for her lesson planning.

Donna explained that a stronger grounding in biological science due to personal experiences with the subject matter, the discipline, and the type of thinking required, was manifested as a more intuitive approach to teaching science than mathematics:

DONNA: I don’t have a big mathematics background, so I have to spend a bit of time thinking about what could be available and what I could do; whereas with a science background, I think of things just because I’m experienced in that area. So I suppose it might depend on how much mathematics you’ve done or what resources you’ve been exposed to, what you might know of... I do a lot more prep for a topic like physics than I would for chemistry or biology. I’m teaching a 9/10 combined class in biology, and I’m finding that, like I do my normal prep but I can just go off in class and say, I did this and I’ve got this example, and we’ve been having great class discussions and fun activities. I wouldn’t have the confidence doing that with a physics topic. So I might spend a lot more time researching it, I might check a few things with another teacher. But I wouldn’t have that flamboyance in a topic that, because I haven’t done physics at all, apart from bits and pieces of it. [FGD:91,96]

Physics is not my area, and I find that in topics that I am not as familiar with I go over the homework a bit more because that makes me feel like I am getting concepts home a bit more. Whereas topics I am comfortable with, I know how to teach, and I know what works, so I can better gauge whether they have got the concept. [S2AR:45]

Donna compared her teaching of biology to that of physics. Donna’s coherent and unified picture of biological science stemmed from her experiences of learning biology and working with these science concepts in the natural world. Physics,
however, was perhaps as foreign for her as any other subject that had not been encountered in any meaningful way. It was for this reason that her teaching of biology required less planning and research compared to her teaching of physics or mathematics.

8.3.1. Aesthetic, coherence, and the subject

In Donna’s reflection, there is a degree of understanding of the connections between biological ideas; knowledge of the content matter and the knowledge required to teach this knowledge is evident.

The knowledge that Donna refers to can be aligned with Shulman’s knowledge domains that he introduced in 1986 and 1987 to emphasise the domain-specificity of knowledge. Shulman distinguishes between subject matter knowledge, pedagogical content knowledge and pedagogical knowledge (see Section 2.2.2).

“Subject matter knowledge”, also called content knowledge, is the knowledge that teachers have about the content considered appropriate for teaching. Donna explained that such knowledge is related to the extent of her background in the subject. Having a limited background in physics has meant that she has less content knowledge, which results in her having to do more preparation for her lesson planning.

“Pedagogical content knowledge” (PCK) adds to this dimension of subject matter the knowledge required for teaching it to students, and includes the “ways of representing and formulating the subject that makes it comprehensible to others” (Shulman, 1986, p. 10). PCK refers to that teacher knowledge that transforms the subject matter in a way that is sensitive to the needs and requirements of the learners.

In Donna’s case, she recognises that her pedagogical content knowledge is limited by her deficient subject matter knowledge of physics and mathematics. In comparison, she attributes her ability to teach biology to her “background” of experiences, and claims that this allows her to more meaningfully transform subject matter knowledge using classroom strategies where her richer understanding of the subject narrative can be shared with students. At first blush it appears that knowledge of content, resources and strategies for teaching accounts for her greater confidence with the teaching of biological science. The “flamboyance” she refers to suggests something other than knowledge, such as an intuitive sense of how to use the science ideas and her experiences to draw students into thinking, talking and engaging with the ideas: “You probably can think of different ways to get it across to the kids” [FGD:104]. Ivie (1999) asserts that, indeed, intuition is essential for teachers as they read and respond to a class of students. For Donna, her feelings of “comfort” and confidence in her ability to bring the subject of biology to life for her students arise out of a unified assemblage of parts. Teachers’ identity and work, according to van
Manen (1982), is organically bound up in what they know about their subject so that teachers describe themselves as teachers according to what they know: “To know a particular subject means that I know something in this domain of human knowledge… To know something is to know what that something is in the way that it is and speaks to us” (p. 295). That which first appears cognitive takes on an intuitive nature, and this becomes part of what teachers do but may not know that they do or why they do it.

8.4. Perceived transformation of the person and the world

Donna’s description of her teaching above illustrates a sense of pride in what she knows and how she can share this with students in an engaging way. Beyond passion, she has also “developed a sense of self in which the pride of the craft [is] the key” (Palmer, 1998, p. 14). A person is transformed by what they have experienced and what they have come to know out of that experience. “Knowing changes the individual as well as the individual’s world” (Girod et al., 2003, p. 578). The transformative nature of aesthetic understanding can lead to identity formation and personal positioning. A person can say “I am the type of person that looks at the world in this way”. In the context of my study, this relates to how teachers position themselves as teachers of a subject, and how this positioning stems from their experiences of teaching, learning and doing mathematics and science. I describe two teachers here, Rose and Pauline, to demonstrate how they position themselves in relation to the subject based on their level of competence and confidence with teaching the subject.

Rose’s identity as pedagogue

Rose’s experiences and interests shape the way she sees herself. As introduced in Chapter 6, Rose stated a number of times that she describes herself as a teacher of students, not a teacher of the subject: “I see myself as a teacher first, not a mathematics teacher… I’d been looking after little kids from when I was this high. I just loved looking after kids” [S2AR:244,248]. She situates herself not necessarily outside of being a teacher of mathematics, but prefers to identify herself as someone who has strong beliefs about the centrality of the student in the teaching-learning interface. This was demonstrated also when, on viewing her video recorded lessons, she said that: “I looked for how the kids were working because that’s interesting. What I said and how I responded to the kids. To their needs. That’s what I look for” [S3AR:86].
Rose, therefore, has an aesthetic understanding that transformed her from being a teacher of mathematics to a person who is attentive to the needs of her students. As discussed in Section 7.1.1, this sense of care compels her to teach mathematics in a way that makes it less threatening for students:

ROSE: I want them to enjoy mathematics. Because mathematics is a threatening subject, it is so threatening because it is so sequential...[At the start of the year] there was hardly anyone that liked mathematics, some of them thought they were good at it, but hardly any of them liked it. You ask them now they have come right round because they enjoy it. [S2AR:62]

Because she understands the threatening nature of school mathematics, her sense of care for the students compels her to employ actions that transform the subject into one that supports her view of “mathematics-as-enjoyable” and makes learning more accessible and in the realm of possibility for her students.

Pauline’s identity crisis as she negotiates subject boundaries

In Section 7.3.1 Pauline spoke of a rich science background with interests and studies in physics, and many engaging and interesting experiences in relation to science. Pauline expressed both her passion for science and an appreciation for the purpose of science in her own and her students’ lives.

In comparison, limited expertise in mathematics teaching made it difficult for Pauline to be confident in her abilities. As a result, she identifies herself as a science teacher rather than a mathematics teacher, as evident in the following:

I am not really experienced enough or done enough PD to know better ways of doing it. A major part of my PD plan, especially for middle years, is doing more PD and finding better ways to teach stuff 'cause I don’t like the way I teach Mathematics at the moment. [S2AP:16]

I think I am a crap mathematics teacher. [S2AP:103]

It is funny. I feel more confident teaching science than I do mathematics, even though I have been teaching both for the same amount of time. [S2AP:54]

I have always felt Mathematics is kind of my fall-back method. Whereas if I was asked to describe myself I would describe myself as a Science teacher, first and foremost. [S2AP:54]

She attributes her stronger sense of herself in relation to science teaching than mathematics teaching partly to her limited background experience with mathematics: “I did mathematics to second year at Uni. There was nothing that I did in my teaching degree that prepared me for teaching mathematics. The only preparation that I had was my rounds” [S2AP:226]. She laments not knowing how to make learning more interesting for her students because of her limited intuitive sense of what will work in the classroom. She is less capable of finding resources and knowing what to look for, and she has a limited sense of how to be passionate about teaching the subject in a way that will profit student learning at the junior level. She enjoys teaching mathematics at the senior level because she enjoys toiling over
problems with the students, but she is unable to do this as much at the junior level. These limitations to her pedagogical content knowledge led her to the conclusion that she is less comfortable with the label of mathematics teacher than she is with that of science teacher. Therefore, the transforming of the person through experience is connected to her self-evaluation of her content knowledge and pedagogical content knowledge.

8.4.1. Aesthetic, identity, and the subject

A socio-cultural framing of identity describes it not as fixed, but as an ongoing process of becoming (Beijaard et al., 2004) and where context plays a crucial role (Beijaard et al., 2004; Connelly & Clandinin, 1999). The modern self, according to Giddens (1991), “is not something that is given…but something that has to be routinely created and sustained in the reflexive activities of the individual” (p. 52). From this perspective, the becoming of a subject teacher is a continuous process of identity construction that takes place as the teacher interacts with and reflects on their professional and personal experiences. Further, because identity is context-dependent a teacher may have multiple identities, “sub-identities” (Beijaard et al., 2004) that shift with the context. These sub-identities undergo continual formation and maintenance and may work in harmony with each other or conflict.

Evident in Pauline’s description are two sub-identities that contribute to her broader picture of herself. How she perceives of herself in relation to science differs from her perception of herself in relation to junior mathematics. Research into the interplay between the private and public in developing identity makes a distinction between role and identity (Beijaard, 1995). How a teacher conceives of their professional role is believed to constitute only part of their identity construction. Beijaard asserts that hope and courage, care and compassion, are associated with identity, not role. In the above example, Pauline appears to accept the role of mathematics and science teacher and the associated activities that are assumed as part of this role, but her identity arises out of her history of caring for and committing to science as an area of study.

Earlier, Donna recognised that her teaching of biology benefits from knowing what activities will work and when. Day (2004), however, points out that knowing what and how to teach is not limited to cognitive engagement. Good teachers, he asserts, tend not to describe themselves only in terms of technical competence, but also acknowledge that “teaching and learning is work that involves the emotions and intellect of self and student” (p. 64). This difference between a competence-based view and an aesthetic view of teaching was demonstrated by Pauline’s different appraisal of herself as a mathematics teacher and a science teacher. Her deficit image of herself in relation to mathematics, which she attributes to limited technical
competence, is based on limited knowledge of what and how to teach, and her hope lies in future professional development to provide useful strategies for teaching. By comparison, her appraisal of her competence and confidence in science was laden with meaningful experiences and stories from her history of engaging with the subject. Pauline exhibited a richer sense of herself in relation to her science teaching, one that is positive and based not solely on competence, but she also aligns herself with science teaching at an emotional level. Her knowledge of how and what to teach is “continuous with” her affective response, meaning that one cannot think of one without the other.

In Rose’s account of herself, she maintains a strong commitment to her students and what the subject can be for her students. Recent research into teachers’ professional identity identifies three categories that contribute to the self image of the teacher: the subject one teaches, the relationship with students, and the teacher’s role or role conception (Beijaard, 1995). A later study with his colleagues (Beijaard, Verloop, & Vermunt, 2000) found that experienced teachers often draw on a variety of influences to construct themselves as a combination of subject matter experts, pedagogical experts and didactical experts. Subject matter experts prioritise expertise in subject matter knowledge and skills. Didactical experts signal planning, execution, and evaluation of teaching and learning processes as the basis of their practice. Pedagogical experts prioritise the support of students’ social, emotional, and moral development. As discussed in Chapter 6, Rose described herself a teacher of students rather than a teacher of the subject. Rose’s commitments to her students suggest that she sees herself as a pedagogical expert, making the moral and ethical features of her role central in her teaching.

What role does the subject culture play in Rose’s identity? In Chapter 7, Rose showed a strong commitment to supporting her students to be successful learners. She described herself, demonstrated in her teaching, and was heralded by the other teachers, as a teacher who had a strong command over the subtleties of how the subject matter is connected across year levels, where students need most support, and how to provide this support. The subject and its content, therefore, provide the context within which she is able to pedagogically care for, and respond to, her students because the organisation of the subject matter makes this pedagogical imperative central for Rose. Her sense of herself in relation to the subject is steeped in how she understands what is required to be an effective mathematics teacher, and the extent to which she feels empowered by what she knows and by the people around her. Her aesthetic understanding of what it means to be a teacher of mathematics is, therefore, constituted by, and a product of, pedagogic interactions and discursive practices (Zembylas, 2005a) that have been affirming of her role as subject teacher expert. Although she does not personally identify with the label of
“mathematic teachers” on principle, the subject and her aesthetic understanding of it plays an enormous role in shaping how she sees herself.

8.5. Valuing the aesthetic in discussions about subject culture

The previous analysis and discussion have explored the idea that a teacher’s aesthetic understanding of and response to the subject determines: where their passions lie with respect to teaching the subject, to what extent they have a coherent and intuitive sense of what is required to teach the subject, and how the teacher is transformed by what they know as they develop an identity in relation to the subject. These discussions are valuable in understanding the relationship between subject culture and pedagogy because they highlight the aesthetic dimensions of teaching, and what is involved aesthetically for teachers as they negotiate subject boundaries. These two ideas are discussed below.

8.5.1. Appreciation for the aesthetic dimensions of teaching

A framework of aesthetic understanding helps to clarify and assign some level of importance to the role of the aesthetic dimension of teaching subject matter to students. A teacher who can be regarded as having an aesthetic understanding of the subject:

• is compelled by and passionate about the subject and students engaging with the subject;
• has a coherent, unified and intuitive sense of what the subject is about and how to bring it to life for students; and
• has been transformed by what they know and believe in a way that enables them to personally and professionally identify with the subject.

Being attentive to aesthetic understanding when evaluating teaching redirects the question from simply asking, “what does the teacher know and believe about the subject and what is required to teach it?” Instead, the question becomes, “how does what the teacher knows and believes affect their sense of who they are in relation to the subject, and how is this personal positioning reflected in the classroom?” The analysis has shown that a teacher with an appreciative aesthetic understanding of a subject sees themself, the subject matter, their teaching and their students in relation to the subject. Even Rose, who labelled herself as a teacher of students rather than a teacher of the subject, expressed her sense of care in the context of, and in response to, the nature of the subject and what was required for students to learn. The student is central to her conceptualisation of the subject. She was unable to describe what the subject is like without including stories about her interactions with students on a
personal level, and in relation to how the students learn in the subjects. By talking about how she interacts with students and the students’ learning needs, Rose gives clues to her values and aesthetic commitments to the subject. These values and commitments are viewed through the lens of what the subject offers her students as well as what it offers herself as learner, practitioner and teacher of the subject.

As discussed in Chapter 7, current science education reform emphasises the need to draw on and respond to student interests when selecting contexts for teaching science-related content. Pivotal in achieving this end is giving teachers appropriate space within the curriculum to inject their own interests, hobbies and expertise when constructing such contexts. Tytler (2007) provides examples of innovation occurring in schools where “teachers with serious interests [felt] that they were being given permission to import these into the classroom” (p. 57-58):

In one school a teacher with no previous history of innovation was encouraged by the SIS coordinator, who knew of his interest in winemaking, to initiate a Chemistry of wine making unit. The school is now producing award-winning wines. (p. 52)

These types of stories, he asserts, exemplify a re-imagined science education for Australia, where teachers’ interests are highlighted as important in the development of local content and approaches. In these situations, teachers are more likely to possess an aesthetic understanding that is deeply rooted in their experiences, and where the subject matter has personal meaning for them. Pedagogical practices can be enriched by a deep understanding of the associated content, which, provided the learning needs and interests of students are taken into account, provide a strong foundation for knowing what value it might have for students and how such contexts could be generative of new interests.

8.5.2. The aesthetic in the negotiation of subject boundaries

Examining teacher pedagogy from the perspective of aesthetic understanding provides insight into what is involved for teachers, aesthetically, as they move between subject cultures. Such insights are particularly pertinent at present when a shortage of suitably qualified mathematics and science teachers is resulting in a relatively high percentage of teachers teaching out-of-field, that is, teaching a subject for which they lack tertiary training, and arguably have limited experience, commitment and, aesthetic understanding. A survey involving 8.2% of teachers of junior science in Australia (Harris et al., 2005) showed that 16% of respondents lacked a minor in any university science discipline, while 8% had not studied any tertiary science. Similarly, a survey of mathematics teachers from 30% of Australian schools (Harris & Jensz, 2006) showed that 20% of teachers of junior mathematics had not studied mathematics beyond first year university, while 8% had no tertiary training in mathematics. Other reports in the media reflect similar or higher
proportions of teachers teaching outside their fields of expertise (Rodd, 2007; Topsfield, 2007). The figures are even more startling for teachers beginning their careers. Unfortunately, these teachers are more likely to be asked to teach out-of-field than their experienced colleagues (Ingersoll, 1998). In fact, a recent study of beginning teachers in Australia showed that 40.1% of teachers nationally and 57% in Victoria had taught subjects outside their qualifications (Rodd, 2007).

While it is acknowledged that tertiary training will not automatically result in effective teaching, the major concern both nationally and internationally is that without solid tertiary experience in the discipline, teachers lack content knowledge, and without studies in the teaching of a subject, teachers are not equipped with the variety of methods and teaching skills required to teach the subject effectively (Darling-Hammond, 2000; Education & Training Committee, 2006; Ingersoll, 1998; Thomas, 2000).

The data reported in this chapter also suggests, that a teacher teaching out-of-field, whether it be a science teacher teaching mathematics (in the case of Pauline) or a biologist teaching physics (in the case of Donna), potentially has limited aesthetic understanding of what the nature of the subject can offer their students. This has implications, especially when the history of engagement with the subject has been negative, restricted by poor traditional teaching practices, or limited. Reliance on traditional teaching approaches may result, as may a lack of “flamboyance” in the way the subject is presented, with a potential outcome of not demonstrating for students what it looks like to appreciate the subject. Also teachers teaching outside of their disciplines, such as a mathematics teacher teaching science, may bring with them a sense of what constitutes good teaching appropriate for one subject that may be inappropriate in another. A theoretical framework of aesthetic understanding, therefore, helps to identify the barriers, disconnections, and lack of appreciation that may prevent teachers who are not trained in the discipline from personally engaging with the subject, which, inevitably impacts negatively on the quality of teaching. The problem for the “untrained” mathematics or science teacher is not simply a lack of content knowledge. This framework of aesthetic understanding shows the importance of teachers being committed to the subject, being able to identify with it personally and professionally, and knowing how to bring the subject matter alive for students.

8.6. Conclusion

This chapter has shown that teachers’ construction of the subject, their students, and teaching, is not simply cognitive but has an important aesthetic dimension. The analysis teases out what it can mean for a teacher to be compelled by and passionate about the subject and students engaging with the subject, to have a coherent and
unified sense of what the subject is about and how to bring it to life for students, and to be transformed by what they know and believe in a way that enables them to personally and professionally identify with the subject. The diversity evident amongst the teachers was not simply a result of differences in content or pedagogical knowledge, although the knowledge and skills base of teachers certainly is essential in teaching. However, the experience of having (or not having) the appropriate knowledge and skills base involved both cognitive and emotional dimensions. An implication of this is that teachers who teach outside of their subject area—their subject area typically being dependent on whether they are “mathematics- or science-trained”—may be lacking that aesthetic understanding.

Teachers construct their own view of what it means to teach the subject as they engage with the subject culture, and develop commitments and identities based on those experiences. The development of the teacher’s aesthetic understanding of mathematics and science teaching is subjectively determined, although it takes place within the context of the subject culture. This personal dimension to the relationship between subject culture and pedagogy implies that teacher actions are not simply scripted by the subject culture, but are more likely to be dependent on a teacher’s commitments and the ways in which they see themselves in relation to the subject. While institutional, cultural, and social expectations can be powerful in shaping a teacher’s practice, their own values and beliefs give meaning to teachers’ experiences of teaching the subject (Helms, 1998).

How then, does this subjective determination of teaching relate to the subject pedagogies and common basic assumptions underpinning practice I described in Chapter 6? In the following chapter I describe a model for representing the relationship between these basic assumptions that make the subject identifiably mathematics or science, and the mediating lenses that individual teachers bring to the subject.
Chapter 9. A model for understanding the relationship between subject culture and pedagogy

In the previous chapters I highlighted pedagogical practices and assumptions that were recognisably associated with mathematics or science teaching, while at the same time describing some of the diversity of practices that I saw in the classroom. The subject culture was seen to play a complex role in how teachers conceptualised the subject, and their personal responses to the subject. This complexity arises from the multi-faceted nature of subject culture.

In this chapter I propose a way of conceptualising the relationship between the subject culture, the individual, and their practice, that takes account of this complexity. I describe a model for representing both the relationship between the various traditions in a subject culture, and the relationships between subject culture and the individual teacher and their practice. I apply this model to the findings emerging from the themes in Chapters 6 and 7 in order to better understand how teachers constructed the subject culture, and how these constructions were reflected in their teaching. I then discuss how teachers’ experiences of subject culture come to bear on the process of “becoming” a teacher of a subject. This process of becoming, I argue, is aesthetic in nature.

9.1. Relationships between different traditions of subject culture

Subject culture refers to traditions of practices, beliefs, assumptions, expectations and knowledge that act as a guide to what it means to teach the subject. The findings of this thesis indicate that there are different “traditions” within a subject culture. Some traditions perpetuate practices that might be considered “outdated”; others challenge the current situation through innovation and new ways of thinking about teaching and learning; and others develop within a school as expectations for practices. Below I describe each of these traditions with reference to situations, beliefs or dynamics that I represented in Chapters 5 to 8. These subject traditions are referred to here as the Traditional, Reformist, and Local Subject Cultures.

The Traditional Subject Culture refers to traditions representing mainstream practices with roots in past practice, often referred to in research literature as “traditional” practices or instruction; see, for example Siorenta and Jimoyiannis’s (2008) description of “the traditional instruction of science” (p. 185). These
traditions are often conceived of by educators as “outdated” and considered inappropriate and in need of reform. Teachers often referred to traditional practices and beliefs when they reflected on what they did not do, or would like to change about their practice. Certain conditions and expectations serve to perpetuate these traditions by constraining teachers’ attempts to change. Such conditions might include:

- perpetuation of a curriculum that is based on canonical knowledge grounded in textbook traditions, populist views of knowledge and expertise, and supported by examination traditions. These can inhibit moves by a teacher to embrace a more humanistic approach to curriculum (see, for example, Aikenhead, 2006);
- insistence on a curriculum that adheres to a sequence as set out in the textbook can support the perception that activity-based and open teaching approaches are unnecessary or a distraction (see, for example, Boaler, 1998); and
- assumptions about the role of practical experiences in learning that take for granted an inherent link between the practical experience and theory can overshadow the need to engage students in the wonder of knowledge (see, for example, Lemke, 2002).

The Reformist Subject Culture refers to the emerging traditions that emanate from researchers, policy makers, and teacher educators who provide commentary on, and offer alternatives to, traditions deemed ineffective. In Chapter 6 I described a number of alternatives to traditions being perpetuated through the subject pedagogies. Emerging from the Reformist Subject Culture are, these alternatives demonstrate possibilities for rethinking, and moving forward from, basic assumptions that represent the current state. The degree to which these alternatives were implemented in the school depended on direction from the leadership team, the cohesion of the staff in their acceptance of the need for change, and whether teachers felt supported by the department, other teachers, their own knowledge, and access to resources to implement this change.

The different traditions are situated within the context of School Culture. School culture refers to the broader culture of schooling that is underpinned by certain beliefs about pedagogy and curriculum. For example, the Principles of Learning and Teaching (Department of Education & Training, 2002b) represent the ideal for pedagogy, such as making the subject meaningful and interesting, using assessment to inform teaching as well as for summative purposes, and developing meaningful and supportive learning environments. The Victorian Essential Learning Standards (Victorian Curriculum & Assessment Authority, 2007) represent the ideal for curriculum that emphasises disciplinary based knowledge and processes, interdisciplinary learning, and physical, personal and social learning. Together, these
strands aim to “equip students with capacities to ... prepare them for success in education, work and life” (p. 6). School culture tends to impose imperatives that subject teachers are then required to translate into their subject teaching, such as the imperative to make schooling relevant (see Chapter 7). Translation requires understanding the demands of the subject and knowing what shape those imperatives might take in the subject.

The **Local Subject Culture** refers to the particular set of goals, purposes, practices, assumptions and commitments associated with the teaching of a subject at a particular school. Talbert and McLaughlin (2002) assert that “while the cultures of teacher communities do not determine individuals’ beliefs or actions in the classroom, and thus do not directly impact on artisanship in teaching, they do set terms of teachers’ practice and opportunities for their success” (p. 330). The Local Subject Culture arises out of the diverse practices and beliefs that are held by the staff at a school. Helms (1998) accounts for this diversity in her analysis of the relationship between teachers’ understanding of subject matter and their identity formation as follows:

within professional communities, such as that of science teachers, there exists tremendous diversity in beliefs about the subject matter (e.g., religious, rational, aesthetic, creative), a sense of purpose, and a sense of what is worth doing. That is, while the teachers’ thoughts and actions were conditioned by the social and cultural context, their search for meaning... came from their sense of themselves as individuals in the larger world. (p. 831)

The notion of a diversity of practices across the Local Subject Culture supports Paechter’s (1991) conceptualisation of “subject subcultures,” recognising that every school is likely to have their own consensual view about the nature of the subject, the way it should be taught, the role of the teacher, and what might be expected of the students. My analysis involves teachers across two schools, therefore more than one subject subculture, what I have called Local Subject Culture, is represented in this research. Differences between the two schools were evident in the data, such as the greater emphasis on complex problem solving at School B than at School A due to the Head of the Mathematics Department being a strong proponent for the use of problem solving activities.

The Local, Reformist, and Traditional Subject Cultures represent “external” traditions within subject culture. They are external because they are perceived by the individual teacher. The teacher has some control over how the subject culture is perceived, and the extent to which they embrace cultural practices, beliefs and knowledge.

The **Constructed Subject Culture** is a version of subject culture that is personally selected, ordered and edited from teachers’ phenomenological encounters with the subject. A teacher may recognise that their version of the subject culture
reflects inappropriate traditional practices. For example, Pauline knew that her mathematics teaching lacked innovation, and as a result she was looking for alternative ways of conceptualising mathematics teaching from the Reformist Subject Culture through professional development. A teacher’s version of the subject culture may be in the process of change due to changes occurring in the Local Subject Culture, or hold strongly to certain ways of thinking about teaching so that the teacher resists change.

The basic assumptions from Chapter 6 represent what was commonly assumed as being central by these teachers. These assumptions represent the Constructed Subject Culture because they refer to teachers’ conceptualisation of what it means to teach the subject. They do not represent the external traditions within a subject culture, but rather commonalities in the teachers’ versions of the external traditions.

Relationships between the various traditions within a subject culture are depicted in Figure 9.1 as a “Subject Culture Triangle”. The Constructed Subject Culture sits centrally and is informed by the external traditions within subject culture that occur at the vertices of the triangle. The Subject Culture Triangle sits within the context of school culture.

This model represents the relationships between the various traditions. Subject culture is shown to be situated within and informed by the context of school culture. According to this model, school culture imperatives, like relevance, support, and engagement, are translated according to the demands of the subject cultures. The subject teacher must consider how the demands of the subject give shape and meaning to such generic teaching and learning imperatives.
A teacher experiences aspects of the different traditions. The Constructed Subject Culture is a reasonably malleable and fluid conceptualisation about what it means to teach the subject that takes into account the possibilities, constraints and affordances of the social milieu, particularly those imposed by the Local Subject Culture. This makes a teacher’s version of the subject culture context dependent. As a result, a teacher’s Constructed Subject Culture is likely to be different at two different schools.

The limitation of this model is that it takes no account of how the teacher’s experiences unrelated to subject culture act as filters for, or give shape and meaning to, the ideas that the teacher perceives from the external versions of subject culture. Helms (1998) referred to such meaning coming from teachers’ beliefs and purposes. Another layer is needed in the model to demonstrate the subjective determination of a teacher’s Constructed Subject Culture, and another to demonstrate how subject culture relates to pedagogy.

9.2. **Depicting the relationship between the individual and subject culture**

Evidence from the observations and interviews shows that the effect of the subject culture on pedagogy is mediated by teachers’ beliefs, knowledge and experiences. I refer to these aspects of the self as a “mediating personal lens”. The model in Figure 9.2 shows the relationship between the various school and subject cultures, the
mediating personal lens, and classroom practice. Central to the research question is how teachers’ experiences of the subject culture shape their practice. The mediating personal lens plays a pivotal role in this relationship. In the following section I explore how the inclusion of the mediating personal lens in this model takes account of the complex role of subject culture in providing the parameters for subject culture membership. Next I explore how the individualisation of these parameters by personal experiences and contextual forces leads to personal agency in constructing one’s own pedagogy. Both sections ask what is involved in becoming a subject teacher.

9.2.1. The mediating personal lens and the culture member

What role does the cultural setting play in the process of becoming a subject teacher? As shown in the Subject Culture Triangle (Figure 9.1), the Constructed Subject Culture is nested within the mediating personal lens and arises out of the teacher’s experiences with the external subject culture tradition. The mediating personal lens, therefore, acts as the “interpretive backdrop” to a teacher’s practice. Being a member of a culture requires exhibiting certain behaviours and beliefs that are consistent with those of the culture. Similarly, as a member of a subject culture, a teacher constructs a set of knowledge, beliefs, and assumptions that enables the teacher to function within that culture. These cultural understandings are situated within the Constructed Subject Culture. Two theories help to understand how the individual holds views that might be considered cultural.

One is cultural model theory (Quinn & Holland, 1987). This theory comes out of a cognitive anthropological tradition, which is concerned with the study of the
knowledge required by an individual to enable them to be a functioning member of a society (Goodenough, 1957). According to this view of culture as shared knowledge, the interest is moved from the customs, artefacts and oral traditions that define the culture, to what people “must know in order to act as they do, make the things they make, and interpret their experience in the distinctive way they do” (Quinn & Holland, 1987, p. 4). Consistent with this tradition, cultural models are presupposed taken-for-granted models of the world that are widely shared (although not necessarily to the exclusion of other, alternative models) by the members of a society and that play an enormous role in their understanding of that world and their behaviour in it. (p. 4)

These cultural models are inferred from what people say; however, the authors caution that, although cultural models relate to people’s behaviour in complex and powerful ways, they do not always naturally translate into practice. Cultural models, instead “frame experience, supplying interpretations of that experience and inferences about it, and goals for action” (p. 6).

The second is cultural script theory from the field of linguistics, which analyses culture-specific ways of speaking that “constitute a behavioural manifestation of a tacit system of ‘cultural rules’” (Wierzbicka, 1999, p. 241). Cultural scripts serve to reveal the cultural norms, attitudes and assumptions attributed by the culture to particular words. Goddard (2004) adopted this theory in his analysis of the Malay speech-act lexicon. These scripts, he states, are not intended as description of behaviour as such, but more as:

a depiction of shared assumptions about how people think about social interaction. Individuals may or may not follow the cultural guidelines; they may follow them in some situations but not in others; they may defy, subvert or play with them in various ways; but even those who reject or defy culturally endorsed modes of thinking and modes of action are nonetheless aware of them. It is in this sense that cultural scripts can be regarded as part of the interpretive backdrop of actual social interaction. (pp. 8-9)

Both of these theories contribute to my understanding of the relationship between subject culture and pedagogy. A theory of shared knowledge as widely shared cognitive models helps to explain how teachers come to understand the behaviours and ways of thinking that are associated with teaching a subject. In Figure 9.2 this knowledge is situated within the mediating personal lens, and in particular constitutes the Constructed Subject Culture. Similarly, a theory about shared assumptions among members as providing interpretive scripts for behaviour can be applied at the classroom level to represent basic assumptions that guide practice. The basic assumptions about curriculum content organisation and the role of practical activities (see Chapter 6), for example, represent common assumptions about what was central for these teachers.

Such theoretical approaches to the relationship between cultural practices and beliefs give some sensibility to ways of speaking that might “otherwise look like a
strange collection of idiosyncrasies” (Wierzbicka, 1999, p. 280). In the same way, certain teaching practices might appear idiosyncratic if not juxtaposed with common threads in the belief systems of teachers from within and across subject cultures. A level of analysis focusing on “idiosyncratic practices”, claims Clarke et al. (2007), can be more informing of teachers’ practice through the sharing of effective pedagogical practices that might not be apparent without such cultural analysis. Learning what it means to become a subject culture member requires coming to understand what might be acceptable ways of thinking about the content, how to teach it, and what learning might look like.

**9.2.2. The mediating personal lens and the individual teacher**

What role do the individual’s experiences play in the process of becoming a subject teacher? Figure 9.2 shows that the mediating personal lens is also composed of “other influences”, and “personal factors”. Other influences include experiences related to the discipline (such as tertiary training or employment), background in other subject areas, general pedagogical experiences and beliefs, and personal life experiences, such as being a parent and hobbies. Personal factors include individual teaching style, personality, commitments and personal preferences. The pedagogical response feedback arrow emphasises the iterative nature of teaching. Reflections on their experiences from the classroom interface form part of a teacher’s mediating personal lens.

The “Constructed Subject Culture” is nested in the mediating personal lens. Thus it is shown as part of this interpretive backdrop. The model accounts for the mediation of teachers’ experiences with the subject culture by the other influences and personal factors, as indicated by the blending of colours for the mediating personal lens and the Constructed Subject Culture. Through the mediating personal lens the teacher interprets their experiences of the external versions of subject culture.

The “pedagogical response” is shaped by the teacher’s conceptualisation of how to teach the subject as represented in the Constructed Subject Culture. Given that no two individuals have the same personal lens, the resultant pedagogical response will be individually determined. These individualised versions of the subject culture contribute to why we see a diversity of practices in schools. The Pedagogy of Support and Pedagogy of Engagement are examples of two pedagogical responses (see Chapter 6) that arose out of basic assumptions underpinning the teachers’ Constructed Subject Culture.

The arrow leading from the mediating lens to the pedagogical response suggests a direct relationship between teachers’ beliefs and their practice; however, research has shown that this is not necessarily the case. For example, Simmons et al.
(2008), in their study of beginning teachers, found that, for some teachers, student-centred beliefs that were developed during teacher training were inconsistent with teacher-centred approaches exhibited in their classroom practice. A number of factors impinge as teachers enact their conceptualisation of what it means to teach and learn a subject. Constraints and affordances in the school, such as timetabling, the nature of the class, availability of resources, and openness to alternative curriculum models or teaching approaches, influence the way teachers’ beliefs and assumptions can be enacted in the classroom. These aspects are accounted for in this model by the relationship between school culture and Local Subject Culture, both of which impact on the Constructed Subject Culture, and, therefore, practice. The teachers at School B demonstrated how the Local Subject Culture can impact on practice by making innovative approaches central to the mathematics program. A different scenario might be that a teacher is aware of alternative possibilities for action, but is unable to enact them because of constraints within the Local Subject Culture.

9.3. Subject culture framing possibilities for action

The various traditions within subject culture, therefore, define possibilities for action. While the basic assumptions act as parameters or guidelines for how a teacher functions, these assumptions are always subject to individual interpretation. How a teacher moves forward from these assumptions by embracing new and innovative practices depends on both individual and contextual forces. In the next two sections I draw from Chapters 6 and 7 to explore how teachers’ experiences of the subject culture frame possibilities for teacher and school development, and the translation of school culture imperatives into their subject teaching.

9.3.1. The role of subject cultures in teacher and school change

While teachers agreed about the basic assumptions and the subject pedagogies, they exhibited different styles, approaches, and fundamental beliefs about what was needed for students to learn. The subject pedagogies, therefore, provide only a starting point. The three traditions within the subject culture came to bear on teachers as they personalised their version of the subject culture and responded to it through their teaching, both as individual teachers and as cultural members.

The Reformist Subject Culture plays an important role in vitalising classroom practice; however, only some of the research findings and directions are adopted and inform policy, curriculum, professional development and teacher education. Well informed research and commentary that are sensitive and responsive to the needs of teachers within the settings that they are in are more likely to have an effect on Local Subject Cultures.
Given that there is constant interplay between individuals who are diverse in their beliefs and experiences within a school, it would make sense to think about subject culture, particularly the Local Subject Culture, as being continually rewritten. Within a school environment, less experienced teachers with beliefs and experiences newly developed in light of new theories about teaching and learning encountered through their teacher education (Reformist Subject Culture) work alongside, and interact with, practised teachers who have more experiences to inform pedagogical decisions and practice, but who may also have commitments to more traditional aspects of the subject culture. While drastic changes in the Local Subject Culture are unlikely under these circumstances, the diversity of experiences, knowledge, commitments, beliefs and energy shifts slightly when the mix of staff changes.

For the new teacher, becoming a member of a subject culture means understanding what it means to teach the subject in that school, within the imposed constraints, and knowing the possibilities. A teacher may choose to fit in with established traditions, or feel enabled to push the status quo. A teacher can contribute to a cultural shift if they are recognised and accepted as a change agent, as was seen with the head of mathematics at School B. A teacher might bring into their subject teaching assumptions, knowledge and beliefs that originate from other subject areas, either successfully or unsuccessfully.

How a Local Subject Culture at a single school changes will depend on how the teaching body as a whole, often with guidance of the head of the subject department, embraces ideas emerging from the Reformist Subject Culture. Also, knowing the expertise and lack thereof within the teaching team plays an important role in how a department head can move his or her staff forward. A major difference in the Local Subject Cultures was the degree to which there was a comprehensive, cohesive, and widely understood vision amongst the teachers under the direction of the head of department. At School B, the head of mathematics gave clear direction in incorporating complex problem solving activities, group work and metacognitive thinking. The ideals of the Reformist Subject Culture were evident. At School A, there appeared to be a push by the head of science to combat student disengagement through an activity-oriented program. Hands-on activities to exemplify and make concrete the science theory were typical. Other purposes associated with practical work promoted by the Reformist Subject Culture, such as reasoning, authentic science experiences, and science-society links were less represented through the practical experiences. This suggested that, although there was a clear vision, it had a narrow focus.

Without strong leadership, it can be difficult for teachers to understand the Local Subject Culture. However, a lack of leadership might also afford agency to individual teachers to move forward in their own way. Huberman (1993) argued that
a strong school community can undermine a teacher’s independent artisanship by limiting professional judgement and forcing time to be spent participating in mandated teacher collaboration. According to Huberman’s artisan model of teaching, teachers work independently in a given context to accumulate “a requisite knowledge base and skill repertoire” (Huberman, 1993, p. 22). His argument is that teachers work, learn and derive professional satisfaction alone and “from interactions with pupils rather then peers” (p. 23).

However, teachers who act in isolation to create change are likely to confront obstacles. For example, in attempting to revitalise the mathematics syllabus with hands-on activities, Rose struggled to obtain the complete support of the middle school mathematics teaching staff. While this case of resistance is not extreme, it is not uncommon for teachers who attempt to create change without the support of their peers to get “burned out”. Talbert and McLaughlin (2002) found that innovative teachers became disenfranchised and demoralised in “weak” teaching communities due to a lack of support from their peers and the school structures. Their research showed that in such situations a tradition of privacy governed teacher interactions and limited “opportunities for collaboration on course design and learning through feedback and knowledge sharing” (p. 331). They claim that the culture of teacher communities “set terms of teachers’ practice and opportunities for their success” (Talbert & McLaughlin, 2002, p. 330). Learning opportunities in the workplace and a capacity to sustain innovative classroom practice, they claim, are determined by the professional community in which the teacher is situated.

The individual teacher thus plays an important role in moving themselves and their school forward from the basic assumptions that might be representative of traditional practice. How a teacher moves forward will depend on how they approach their own professional development and embrace ideas from the Reformist Subject Culture, their personal experiences and beliefs, their willingness to embrace change through reflection on their own practice, and how they see themselves, and their students, in relation to the subject.

9.3.2. Subject culture, school culture imperatives, and the individual teacher

The culture of school imposes certain imperatives for teaching, such as engagement, support and relevance, which teachers must translate into their subject teaching. As the teachers responded to the school imperative of relevance they saw this as opposed to the Traditional Subject Culture. The tradition that teachers were moving away from was de-contextualised science and mathematics content. They talked about the need to make links between students’ life experiences and the content that was covered in science and mathematics.
Links were seen to be made more easily in science than mathematics because of the phenomenological nature of the school science content. The teachers, however, understood that these links needed to be made explicit as part of the science instruction program. Teachers’ stories about where science ideas can be evident in students’ lives, and about the human role in the advancement of science ideas, were seen as necessary for humanising potentially irrelevant content. The teachers did not refer to the Reformist Subject Culture ideas when talking about the use of stories in science, but some did refer to their experiences of the science discipline as stories they can bring to life in the classroom. These discipline-based stories, and stories about science in daily life, formed part of the interpretive backdrop of the teachers, and were essential in giving the teacher a sense of confidence in their attempts to align the subject with their students’ lives and interests.

In mathematics, linking content to students’ lives and interests was considered, to some extent, inherent in the utilitarian purposes of mathematics. As was the case with science, the teachers understood the need to use familiar contexts to demonstrate how the abstract mathematical concepts and processes could be used or recognised in students’ lives. Humanising the subject took place mostly through presenting a utilitarian view of mathematics. This view appeared to be understood by the teachers as a directive of the Reformist Subject Culture that must then be interpreted at the school level within the school syllabus. Stories of the discipline represented mathematics in use, such as in designing a bridge, but these were limited. Most of the stories came from teachers’ use of mathematics in daily life, and were limited to certain types of mathematics, such as statistics and decimals. As with science, the interpretive backdrop of the teacher played an important role in how the teacher was able to make the subject relevant.

Responding to this imperative of relating the subject to students’ lives is particularly dependent on teachers knowing the stories, and the breadth and nature of their experiences of the various traditions. The teacher’s pedagogical response can also be shaped by the Local Subject Culture. The provision of structures to support curriculum development that takes learning into the realms of students’ lives or responds to students’ interests, for example, requires space, resources, and a loosened hold on traditional curricula structures focused on canonical content and the textbook.

All of these experiences contribute to a teacher’s Constructed Subject Culture, as do the teacher’s “other experiences” and “personal factors” (see Figure 9.2). Other experiences, for example, may include work experiences and training that a teacher can draw on to tell stories about what it means to be or think like a scientist or mathematician. Background in other subject areas may assist with forging productive links with the knowledge and skills from these other subject areas,
thereby situating the subject within the student’s broader school experience. General pedagogical experiences and beliefs developed as a learner might prompt a teacher to reject their own experiences of a disconnected subject matter and ensure vigorous attention to relevance and connectedness between the content and the lives of their students. Personal life experiences, such as a teacher’s hobbies provide examples of how the subject knowledge, processes and skills of the subject can impact on one’s personal and daily life. A teacher’s commitments and personal preferences ultimately determine where their passions lie.

A teacher’s orientation to relevance, therefore, depends on what the teacher knows, believes and values about the subject and what the subject can mean for their students and themselves. This is ultimately a personal response. Hipkin’s (2006) investigation of science teachers’ approaches to the teaching of the nature of science found that teachers tended to replace formal accounts of the way science knowledge is generated with more impassioned accounts based on the practices and objects of their own scientific inquiries. She found that teachers’ narratives revealed passion for their personal learning, as well as an ethical concern for their students’ learning to care for the natural world and for science as a means of investigating the natural world. In the context of my research, this emphasises an aesthetic dimension to the way teachers approached their interpretation of cultural beliefs and practices, and therefore, teaching of a subject.

9.4. The subject-specificity of subject teaching

The model in Figure 9.2 highlights the importance of thinking about pedagogy in a subject-specific way. In Chapter 1 I raised the issue of the debate about generic versus subject-specific approaches to pedagogy. In support for the latter, Stodolsky and Grossman (1995) claim that the content provides the context for the secondary teacher, not just in terms of the subject matter to be taught, but in the ways teachers think about learning, assessment, and their roles as teachers (see also Grossman & Stodolsky, 1995; Siskin, 1994; Stodolsky, 1988). Chapter 7 has shown that, for these teachers, the content as context placed demands on their interpretation and response to a “generic” imperative to make schooling relevant. Teachers’ beliefs about the value of the subject were bound up in the perceived potential purposes that the content could have for students and themselves. Their response to this generic “relevance” imperative was, therefore, subject-specific because of the subject matter context, but also because their teaching was based on their historical interactions with the subject.

My research has shown that, at a fundamental level, a teacher’s pedagogy is informed by subject matter and passion. A teacher’s multiple identities arise out of
the interaction between their perceptions of themselves as subject-specialist and pedagogue. Their identity, therefore, is deeply seated in the subject that they teach. Rose indicated that she thought of herself as a teacher of students rather than a subject specialist (see Chapter 8); however, her dealings with students were bound up in her awareness of the learning needs of her students that were specific to that subject. Although the welfare of her students was foremost in her mind, the subject-specificity of her pedagogical purpose lies in her awareness of the reasons for these approaches, and what aspects of mathematics she values and expects to expose for her students to respond to (see Ball et al., 2005). It is, therefore, not possible to think of teacher identity, particularly at the secondary level, in a non-subject related way.

Subject-specific descriptions of pedagogy take into account a subject-specific awareness of content that informs pedagogical decisions. Teaching strategies are described in terms of when to use them and the degree to which they are deemed useful (Ball et al., 2005). Where pedagogical frameworks (such as PoLT) or educational policy are described in generic terms, the focus shifts from the knowledge structures, skills, processes and stories of the subject to more general issues, such as student learning, developing relationships and personal development. Also, the teacher’s identity shifts from subject-specialist to pedagogue. While these shifts in themselves are not necessarily negative outcomes for teachers with strong aesthetic understanding and content appreciation, for teachers who do not have those passions and positive background experiences to inform their teaching, the aesthetic of the subject can be lost.

Generic-based professional learning opportunities cater for only part of the teacher’s professional needs. Research has shown that teachers in rural or regional settings can feel disenfranchised by professional learning programs that cater for the needs of the whole school at the expense of subject-related needs (Tytler, Malcolm, Symington, Kirkwood, & Darby, 2008). Other research shows that the subject matters in regard to teacher support. Subject-specific mentors have been shown to be more effective in US science teacher induction programs due to the specific support they can give in the areas of instruction, running practical activities, and planning, as well as support to incorporate “science as inquiry” and the “nature of science” into their teaching (Luft, 2008). Grossman et al. (2004) further highlight the importance of providing external sources of subject-matter expertise when supporting reform efforts. They assert that the extent, and availability, of subject-specific instructional leadership has an effect on the degree to which teachers incorporate reform ideals into their practice: “how teachers and administrators respond to and implement subject-specific policies will vary considerably, depending largely on their own knowledge of and beliefs about the subject in question” (p. 12).
The specificity of subject teaching is based on the content, but the teacher’s aesthetic understanding of teaching the subject is based on more than their content knowledge. Sullivan (2003) recognises the importance of this aesthetic dimension of teachers’ mathematical knowledge, asserting that:

this knowledge is not just about the formal processes that have traditionally formed the basis of mathematics curriculums in school and universities but the capacity to adapt to new ways of thinking, the curiosity to explore new tools, the orientation to identify and describe patterns and commonalities, the desire to examine global and local issues from a mathematical perspective, and the passion to communicate a mathematical analysis and world view. (p. 3)

How a teacher translates descriptions of pedagogy, embraces professional learning opportunities, and interprets and implements curriculum structure depends on their experiences of the subject, and their subject-specific beliefs about teaching and learning.

Crossing the boundaries between subjects can be seen as a cultural border crossing (Aikenhead, 2001; Aikenhead & Jegede, 1999) in the same way as it is for students. Negotiating this boundary can be difficult for the out-of-field teacher who has limited background and aesthetic understanding of teaching the subject. Unfortunately, for some of these out-of-field teachers, there is limited access to people who might be seen as culture brokers (Stanley & Brickhouse, 2001) who play an important role in assisting them with their border crossing. The head of department and other subject teachers may assume this role, but some teachers receive little support, particularly in small schools in rural and remote locations where there are no other teachers to participate in subject-specific professional dialogue or where professional development is not readily available or only deals with generic teaching and learning issues (see Tytler, Malcolm et al., 2008). My research has shown that the out-of-field teacher relied on support and guidance from other teachers in the school, but also sought subject-specific professional development in teaching approaches suitable for engaging junior mathematics students.

9.5. The role of the aesthetic in subject teaching

In Chapter 8 I concluded that the teachers had a stronger sense of themselves in relation to a subject for which they had an aesthetic understanding. Such understanding determined where their passions lie with respect to teaching the subject and the discipline, to what extent they have a coherent and intuitive sense of what is required to teach the subject, and how the teacher is transformed by what they know as they develop an identity in relation to the subject.

Despite the centrality of the aesthetic to how teachers respond to the subject, the aesthetic dimension of teaching is under-represented in discourses around
teaching and teacher and school change. Bredeson (2002), for example, states in relation to professional development that “the idea that there is an aesthetic component in professional development seems tenuous given the lack of evidence in the literature and in everyday discourse in education” (p. 667).

My research provides strong evidence that teachers’ affective responses are inextricably linked to their knowledge of subject matter and what is required to support student learning. As understanding of how to teach the subject grows, so does confidence in one’s abilities. This understanding is based on the experiences, feelings, knowledge, qualities and beliefs that emanate from the personal factors and other influences. Such understandings become aesthetic when the knowledge of what and how to teach is linked to a teacher’s passions and interests, and they begin to identify themselves as somebody who knows how to teach, and is interested in, the subject and students engaging with the subject. A teacher’s Constructed Subject Culture is, therefore, inextricably linked to their aesthetic understanding of what it means to teach the subject. The mediating personal lens incorporates the many components that determine the aesthetic understanding that a teacher has in relation to their teaching of the subject.

My research has also shown that teachers develop a sense of self in relation to the subject through their experiences with the various traditions within the subject culture. Simmons et al. (2008) suggest that the “self lies at the centre of teachers’ interpretations, explanations, and understanding expressed through their beliefs and classroom actions” (p. 948). As teachers adapt to different educational environments, they construct their knowledge and beliefs “from the perspectives of self-in-relation-to-social context” (p. 948). Expectations placed on teachers by the school context, such as the local School Culture and Local Subject Culture, require teachers to adapt to different educational environments. Simmons et al. explains that “how the environment in which one functions, especially with regard to the expectations of others, contributes to teachers modifying their actions and eventually their beliefs” (p. 932).

Having an aesthetic understanding of the subject is important for embracing change emerging from the Reformist Subject Culture, or change occurring within the Local Subject Culture. But it may also lead to teacher resistance to change. Disruptions to the expectations of teachers can be imposed by either the Reformist Subject Culture, for example through a redefining of effective pedagogy as part of a school change program like IMYMS or curriculum reform through VELS, or the Local Subject Culture, for example through moving away from a process-oriented approach towards a problem based approach in mathematics.

The more experienced teachers in this research were happy to embrace change in mathematics approaches because they were confident in themselves as
competent teachers. Their commitment to engaging students in deeper learning was congruent with the imperatives behind the new directions within the Local Subject Cultures. Such changes, however, could potentially render a teacher’s basic assumptions inadequate because they are inconsistent with the new expectations. Introducing new practices that require shifts in their pedagogical beliefs can unbalance a teacher’s confidence and competence. Experiences with emerging traditions from the Reformist Subject Culture can make a teacher question their beliefs.

For example, a teacher’s experiences of the Traditional Subject Culture may have a strong shaping effect on their choice of pedagogical approaches and how they deal with students. If the teacher participates in a Local Subject Culture that perpetuates these traditions, they will feel confident and competent in meeting these expectations. Facing imposed change, a once confident teacher, who felt that they had an aesthetic understanding of what it means to teach the subject, is forced to reconsider whether their passions and commitments are relevant and useful, whether their understandings of what and how to teach are still coherent, and therefore, whether they can perceive of themselves in the same way in relation to the subject. Imposing school change can cause real identity issues that impact on teachers’ confidence and competence. The same issue arises for teachers who are assigned subjects for which they have limited background or experience. Teachers teaching out-of-field face the same disequilibrium as their knowledge and skills suitable for one subject area are set aside, or at least require substantial translation to fit the new subject.

Professional development practices that take into account the aesthetic dimension of teaching are essential if real change in beliefs and practice is to be achieved. For example, Bredeson (2002) uses a framework from architecture to describe professional development that attends to the function, structure and beauty of professional development programs. Function refers to constructing the design, delivery and intended outcomes of professional development to meet the needs and interests of the clients, while structure refers to concrete and visible dimensions of the professional development experiences that support and enhance professional practice. Beauty was more difficult for Bredeson to define. He states that “beauty comes from the artistic arrangement and use of materials and systems to create learning spaces that engage teachers and administrators in growth opportunities that meet their needs and change them as people and professionals” (p. 667). He refers to the “artful designs for learning” (p. 667), the “hoped for result” in terms of the interactions between teachers, provision of spaces and processes to reflect on practice, and capacity building that leads to substantial change in practice. Ultimately, he states that “beauty in professional development may be expressed in
enhanced motivation, positive emotions, and renewed feelings of empowerment” (p. 667).

In light of my research, and in keeping with a Deweyan perspective on aesthetics, these affective elements are entwined with the cognitive experience. The result of such an experience is not just empowerment, but also transformation of one’s identity. The transformative nature of gaining knowledge is a consequence of an affective response. In his analysis of McWilliam’s pedagogy of desire, Zembylas (2007) uses a Deleuzo-Guattarian perspective on productive desire. Here, desire is seen as

an “immanent principle” of creativity and movement [that] enables a new view on affect that does not assume simple feelings but immanent becomings (Deleuze & Guatteri, 1994). In this manner affect in education may be redefined as a landscape of becoming in which forces, surfaces and flows of teachers/students are caught up in a desiring ontology and consequently, a pedagogy of desire is explored as a transformative practice. (p. 332)

When we view teachers as passionate beings we unleash the possibility for them to embrace innovation, and to be desirous in their dealings with students so that they seduce students into caring about the subject. Teacher preparation, professional development and teacher development are dealing with not only issues of content and pedagogy, but also issues of identity, passion, and seduction. On this basis, it is fair to conclude that the process of becoming a teacher of a subject is essentially aesthetic in nature because it is fundamentally about transformative experience.

9.6. Conclusion

In this chapter I have argued that the mediating personal lens is an essential element in the relationship between subject culture and pedagogy. The teacher is both a member of a culture and an individual teacher, building practice within the parameters set by a dynamic and multi-faceted subject culture.

The model of the relationship between subject culture and pedagogy helps to explain relationships between individual and cultural practices by foregrounding those common views that make the subject identifiable. It also helps to explain how an individual’s personality, experiences and beliefs shape and mediate their experiences of the subject culture so that their teaching practice is subjectively determined, resulting in a diversity of teaching and learning practices within the subject culture.

The model explains how a teacher’s interpretation of the basic assumptions can be tangential or in opposition to the Local Subject Culture, and, therefore, can be considered outside the expectations held by other culture members. The model supports the idea that the individual teacher is the site of cultural construction through which the external subject culture is transformed into pedagogical action. It
also supports Paechter’s (1991) idea that different schools can be described as having different subject traditions—what I have called Local Subject Cultures—which result from the diversity of interpretations of the basic assumptions. What is considered important by members of the mathematics subject department at one school may differ from that of another school. The model helps to understand why effecting teacher change requires working at both the Local Subject Culture and individual level.

Finally, the model helps to demonstrate how a teacher’s classroom practice is “impromptu” to varying degrees. The performance of teachers who are less aware of the expectations and assumptions that have come to characterise practice at that location appears more impromptu. With experience, their performance is less impromptu as they learn to align themselves with the systems of knowledge, beliefs and practices that are promoted or tend to be predominant within the subject culture.
Chapter 10. Cultural and individual differences: Conclusions and implications

Both the cultural and individual dimensions of teaching are central to the research question of the relationships between teachers’ experiences of mathematics and science subject cultures and their pedagogy. The data have provided new insights into how a teacher experiences the subject culture demands of mathematics and science, and how these demands are personalised into a teacher’s pedagogy. I arrived at these insights by looking closely at teachers’ reflections on their practice. I analysed teachers’ experiences of mathematics and science subject cultures by highlighting commonalities and juxtapositions across the interviews and classroom observations. Significant differences were found in what teachers considered to be at the core of their subject teaching in mathematics and science.

Differences that made the subject identifiably mathematics or science could be characterised as cultural in nature. In mathematics, supporting students to move through sequentially organised curriculum content, and the importance placed on mathematics in the school curriculum, led to a Pedagogy of Support. In science, the more topic based curriculum, and an imperative to foster student interest in science, led to a Pedagogy of Engagement. A school culture imperative to link the subject matter to students’ lives was translated differently in mathematics and science. In this respect, the individual teacher can be seen as a member of a culture who holds agreed upon basic assumptions about what is central to teaching the subject.

Individual differences between teachers resulted in a diversity of practices across and within the two schools. In Chapter 5, I introduced the individual pedagogies of the teachers through brief case studies that highlighted differences in the way they taught, their subject preferences, and their experiences with the subject or discipline through learning, teaching, playing and working. In Chapter 6, I showed that how schools and individual teachers embraced alternative ways of thinking about teaching and learning influenced how they moved forward from basic cultural assumptions. Teachers related practical work to theory differently. The two schools approached open-ended problem solving differently, resulting in different degrees of latitude for teachers to move away from traditional teaching modes. In Chapters 7 and 8 I demonstrated how the teachers made pedagogical decisions based on their beliefs, experiences, knowledge, and preferences in relation to the subject, and teaching and learning generally. The translation of an imperative arising from the school culture, such as the need for relevance, is a product of both the nature of the
subject, and an individual’s personal knowledge of, and perspective on, the nature of the subject matter and purposes associated with the subject. Whether or not teachers had stories to tell that related the subject matter to students’ lives influenced their approach to making the subject relevant. The extent to which teachers had an aesthetic understanding of the subject was bound up in how they saw themselves in relation to the subject as a result of what they knew, had experienced and were committed to. Teachers’ understanding of content and pedagogy, their passions and their identity, were shown to be integral to the way they positioned themselves in relation to the subject, and in shaping their confidence and competence.

The logic of the thesis has been to respond to the main research question through the three subquestions, and weave elements of the subquestions into each chapter. In this chapter I pull together eleven key conclusions that emerge from Chapters 6 to 9, and relate these to the three subquestions:

Subquestion 1. What pedagogies are characteristic of the subject cultures of mathematics and science?
Subquestion 2. What experiences of the subject cultures of mathematics and science become evident through teachers’ reflections on their practice?
Subquestion 3. How do teachers’ experiences of the subject cultures shape their pedagogy?

The chapter concludes with implications for the research and methodological reflections.

10.1. Responding to the research questions

Eleven conclusions draw together the key ideas that have emerged from the analysis in Chapters 6 to 9. Elements of the research subquestions are represented in each conclusion to varying degrees.

The first subquestion focused on the particular pedagogies that are characteristic of the subject cultures of mathematics and science. Discussions relating to this subquestion explored the pedagogical demands associated with teaching each subject. Conclusions related to the first three themes in Chapters 6 and 7 compare pedagogies employed in the two subjects, and how the nature of content and cultural expectations shaped these pedagogies. Conclusions 1 to 5 below focus on the pedagogies that were characterised in the subject cultures, but refer also to teachers’ experiences of the subject culture to draw conclusions about what was central to their teaching of the subject.

The second subquestion related to teachers experiencing the subject culture of mathematics and science. The teachers’ experiences of subject cultures were the
basis for their reflections in this research. When teachers commented on their practice, or talked about their personal experiences of learning, teaching and using science and mathematics, they exposed something of their experiences of the different subject traditions. All of the themes were used to reconstruct some of these experiences. Conclusions 6 to 9 relate to the different subject traditions that teachers experienced or referred to in our discussions. They also show how these experiences shape their pedagogy.

The third subquestion drew the first two together by looking at how teachers’ experiences of the subject cultures shape their pedagogy. I proposed two models to encapsulate the ways that teachers experience subject culture, the effect of the individuality of the teacher in selecting, shaping and giving meaning to those experiences, and then how teachers respond pedagogically to their experiences. Conclusions 10 and 11 relate to these models, and the central role that the aesthetic dimension of teaching plays in the relationship between subject culture and pedagogy.

The eleven conclusions are as follows.

**Conclusion 1. Curriculum content organisation placed subject-specific demands on teaching and learning.**

Teachers believed that the organisation of curriculum content was more highly structured in mathematics than in science. The nature of organisation gave rise to teaching imperatives and learning demands that were subject-specific.

In mathematics, the teachers believed that the curriculum content is organised as a carefully structured sequence of concepts, skills and processes, moving to greater degrees of abstraction and complexity. Teachers showed concern that students’ poor skill development can result in insecure foundational understandings, posing a threat to future success. As a result, students can feel threatened by the learning demands of school mathematics. The imperative for the mathematics teachers is to support students in developing firm foundations to allow them to move successfully to the next level of complexity and abstraction. Teachers’ assumptions about the relative stability of the mathematics curriculum content were based on what they believed to be a general acceptance of the steps that students should take as they move to greater degrees of complexity. The imperative to ensure student success comes from the importance given to mathematics for school, university and life.

In science, the teachers believed that the curriculum content is organised in topics that are relatively discrete, but there is some sequencing of ideas within the disciplines of science. Topics tend to be iterative and ideas often overlap with those covered in earlier topics. Missing science content at the junior level was assumed to
have limited bearing on students’ future success with science learning. Students’ willingness to engage with future learning experiences, however, was seen to depend on coherent and suitably targeted content. The imperative for the science teacher is to add more pieces to the puzzle for students so that they develop a coherent picture of the knowledge and skills of science, and move on to more encompassing concepts. Teachers’ assumptions about the relative changeability of science curriculum content reflect an acceptance that there is no single trajectory through the subject matter required for students to achieve success in their learning.

**Conclusion 2. Teachers were more committed to representing the subject matter through practical, hands-on activities in science than in mathematics.**

Whether a teacher incorporates activity-based experiences in mathematics and science is not simply a matter of having a variety of activities at hand, but requires an awareness of the purpose and nature of the types of activities appropriate for the subject. It also requires a particular epistemological stance, underpinned by a web of beliefs, knowledge and experiences that provides a rationale for incorporating activity-based experiences.

In science, teachers showed a firmer commitment to students experiencing natural phenomena because the subject traditions demand it. The teachers relied on such experiences to engage students at an aesthetic and motivational level, as well as at a deeper conceptual level.

In mathematics, while teachers considered practical experiences to be beneficial for learning, they were also resistant to some degree due to practical issues that arose as a result of their experience of a traditional commitment within the subject culture to a skills and process based, tightly structured curriculum.

**Conclusion 3. A Pedagogy of Support in mathematics and a Pedagogy of Engagement in science characterise what teachers perceived as being central to the subject cultures of mathematics and science.**

The themes of curriculum content organisation and practical activity, represented in Conclusions 1 and 2 above, highlighted important differences in what was perceived by these teachers as central to the subject cultures of mathematics and science. Cultural expectations were experienced by teachers as basic assumptions about what is regarded as suitable for teaching and learning. Teachers’ pedagogical responses are shaped by these assumptions. I described these responses as distinct “subject pedagogies” (see Ball & Lacey, 1980). Two subject pedagogies arose out of the first two themes: a “Pedagogy of Support” in mathematics and a “Pedagogy of Engagement” in science.
A Pedagogy of Support in mathematics acknowledges that it is fundamentally important that students are given the best opportunity to achieve ongoing success in the subject; therefore, support for learning dominated the teachers’ approach to teaching. This need for support was seen to arise from the nature of the sequentially and tightly organised curriculum content which places demands for mastery on students. While engaging students through activity-based pedagogies was valued, cultural traditions and expectations constrained teachers through a curriculum that was believed to be more efficiently taught through pedagogies that focus on the mastery of skills and processes.

A Pedagogy of Engagement in science acknowledges that representing the compelling nature of objects and relating these to science ideas dictates a teacher’s pedagogical moves. Appropriate infrastructure and availability of resources are accepted as the norm. Teachers relied on practical work to draw students into the subject, to promote interest in science ideas, and to make students’ science experiences both meaningful and understandable.

**Conclusion 4.** Teachers’ commitment to linking the subject to students’ lives was expressed through four pedagogical approaches, which were emphasised and interpreted in different ways in mathematics and science.

All teachers believed it was important to relate the content matter to students’ lives; however, they seemed to approach this issue of relevance differently, both in practice and in their stated beliefs about what it means to teach effectively. Four types of pedagogical approaches were found to be representative of how the teachers recognised what and how the content needed to be made meaningful and relevant. These were labelled as Categories of Meaning Making. While each category had elements in common, teachers emphasised and interpreted their usefulness differently in mathematics and science, emphasising fundamental differences in the purpose and value of the subject matter. The four categories are summarised below.

*Illustrations of relevance* were references to familiar things that connected students’ lives with the subject matter. They were the most prominent and recognisable attempts to relate the subject matter to students’ lives that emerged from the interviews and during classroom observations. They generally involved the applications of concepts, skills or processes that put the subject matter into a familiar framework. They were seen to occur across mathematics and science as examples that gave shape, meaning, relevance and a sense of what is sensible to explanations given in class. In science they were examples of scientific phenomena that students recognised, while in mathematics, they referred to recognisable patterns and ways of thinking in the natural and social world. Examples generally emanated more easily from students’ personal experiences in science than in mathematics.
Explorations of contexts were built around students’ interests, or were generative of new interests. The exploration of a context can be built around a web of events and experiences. The story is the context within which the concepts are applied. Connections are made between the subject matter and ideas or phenomena that are already understood by the student or that hold intrigue. The result is a coherent and deeper understanding of the subject matter. In science, they provided a vehicle for connecting real life to science concepts, and required students to select, connect and sequence the ideas. In mathematics, they were contexts for problem solving or understanding patterns in society, and required students to select the mathematical skills and processes appropriate for solving the problem. They generally arose out of students’ questions more often in science than in mathematics.

Humanising stories of historical and contemporary “heroes” were used to demonstrate how science and mathematics ideas are generated out of human exploration, intrigue and need. They provide insight into teachers’ understanding of how the historical and biographical nature of the disciplines, and disciplinary knowledge as a way of thinking about and understanding the world, could enter their classrooms. In science, they were exemplars of the way knowledge is constructed out of human discovery and intrigue, and they allowed students to identify with the human context of scientific research. These stories were absent in teachers’ commentaries about their mathematics teaching, possibly as a result of school mathematics content being necessarily simpler than the mathematics applied in “real” problems, and potentially too far removed from the students’ experience of mathematics.

Representations of the human response were teachers’ representations of the human endeavour of using, practising and being passionate about disciplinary ways of knowing and practices. The nature of mathematics and science are represented in their many facets, especially their role in society and what it means to be human. In science, these are explicit and implicit messages about what it means to be interested in and interact with scientific ways of knowing and phenomena, and, in mathematics, the intriguing nature of solving a problem, and the usefulness of being able to work with mathematics.

Some elements of these illustrations, contexts, humanising stories and representations were common across mathematics and science. In all categories, connections were made between the subject and students’ lives, they were used to engage students in their learning, and they were included by teachers to support the learning process. Other characteristics of the categories illustrate differences between mathematics and science. They differed in the image of the subject that they presented, their form in relation to the subject matter, from where and how they arose.
during a lesson, and how students used and responded to them in their conceptual learning.

**Conclusion 5. Translating the imperative of relevance required teachers to be aware of and appreciate subject-specific demands relating to purposes and pedagogy.**

Teachers were aware that a discourse of relevance as part of the school culture played an important role in making the curriculum accessible and meaningful for students. Teachers needed to understand how to relate the content to students’ lives in meaningful and appropriate ways. The demands of content, the perceived role that the content could play in students’ lives, and teachers’ experiences of the subject, contributed to how teachers conceptualised relevance for that subject, and therefore, how they made the subject relevant for their students. There were three findings that emerged from this theme.

Firstly, the variety of ways in which these teachers connected the subject matter to real life illustrates the various meanings that relevance can have. Expecting teachers to make the curriculum relevant is not unproblematic because the meaning of relevance is not collectively understood, nor is it the same for mathematics and science. For teachers moving between mathematics and science teaching, especially when moving into a subject for which they have limited appreciation or experience, understanding how the subject can be made relevant for their students, and themselves, is of prime importance. Translation of this rhetoric into classrooms depends on teachers being aware of, and having an appreciation for:

- how the subject matter can be connected with students’ lives, such as through the use of “stories” of relevance;
- the nature of this connection in terms of what the stories say about mathematics and science; and
- the aims that are reflected in the connections that they draw, such as relevance to students’ interests and future careers, to citizenry preparation, to understanding the world around them, and to disciplinary practices.

Secondly, there were subject related differences as to what could be made relevant. According to these teachers, making school science relevant means emphasising science as:

- a way of explaining natural phenomena and familiar objects that are aligned with student interests;
- a body of knowledge used to explain the complexity of these phenomena in students’ lifeworlds;
- a human construction that developed out of a need to understand the natural world; and
• a worthwhile pursuit that can capture one’s imagination.

Making school mathematics relevant involves focusing on mathematics as:
• a tool, or system of thinking, that fulfils a recognisable need in everyday life and work;
• a tool for solving interesting problems or making sense of data; and
• an intellectual pursuit that is functional and holds intrigue, challenge.

The development of mathematical ideas over time was not mentioned; however, Dioxiadis (2003) asserts that mathematics can also be portrayed as a history of ideas. The absence of historical stories in mathematics demonstrates a silence and a lack of appreciation for the historical development of mathematical ideas, and how this can inform the learning process. Emphasising this historical development has the potential to depict mathematics as a search for ideas, and not just a utilitarian subject that is only relevant through its direct application to students’ current or future lives.

Thirdly, teachers’ beliefs about effective teaching, their disciplinary background, and personal commitments were salient factors in shaping how they related the subject to students’ lives. Therefore, “having stories to tell” is not simply a cognitive issue, but requires a personal response from the teacher. It is likely that evaluative judgements about what might be of interest in the subject shape the teacher’s pedagogical choices; judgements arising from what the teacher knows and values, judgements which are aesthetic in nature.

Conclusion 6. Teachers operate with a “Constructed Subject Culture” that represents a personal perspective of an external subject culture that has traditional, reformist and local variants.

Subject culture refers to traditions of practices, beliefs, assumptions, expectations and knowledge that act as a guide to what it means to teach the subject. The findings indicated that there are different traditions within a subject culture. In examining teachers’ experiences of subject culture it was useful to differentiate between the Traditional Subject Culture, Reformist Subject Culture and Local Subject Culture (see Chapter 9). I have called these “external” subject culture traditions because they are external to the individual and are thus perceived and experienced. Each tradition offers different messages about what it means to teach the subject, and they place different demands on teachers. A teacher’s “Constructed Subject Culture” arises out of their experiences of the subject traditions (see Figure 9.1).

Conceptualising subject culture in this way complexifies the way we think about the many influences that shape a teacher’s construction of teaching the subject. Conclusions 7 to 9 highlight how the multi-layered construction of subject culture
informs the way we describe, think about, and support teaching of the subject and teacher and school change.

**Conclusion 7. Teachers draw from, and are influenced by, different aspects of the subject cultures when constructing their pedagogy.**

The subject pedagogies (represented in Conclusion 3) and the basic assumptions underpinning them represent only a starting point for teachers. As discussed in Chapter 6 and 9, how teachers personalise these and make decisions about how to represent them in their teaching depends on the teacher’s opportunities to engage with and select from the various traditions within the subject culture. The Reformist Subject Culture can inform new and innovative ideas. The Local Subject Culture can set the parameters for what is possible within the constraints of the location so that teachers can be supported or inhibited in their attempts to embrace change. The Traditional Subject Culture provides a benchmark of what teachers may want to move away from as they reflect on what they want to change about their practice.

**Conclusion 8. Teacher pedagogy is influenced by an interaction between school culture imperatives and Local Subject Culture.**

The culture of school imposes certain imperatives for teachers that they must translate into their subject teaching. All teachers accepted an imperative to relate the content to students’ lives (see Chapter 7). In responding to this imperative, teachers viewed a tradition of using a de-contextualised curriculum as being out-dated and part of the Traditional Subject Culture. At the school subject department level, the Local Subject Culture plays an important role as it sets the parameters for the extent to which student choice and interests are seriously integrated into the enacted curriculum.

**Conclusion 9. Teachers’ experiences of subject culture is linked in important ways with their aesthetic understanding of what it means to teach a subject.**

A teacher’s Constructed Subject Culture is inextricably linked to their aesthetic understanding of what it means to teach the subject. As knowledge of how to teach the subject grows, so does confidence. Such understandings become aesthetic when the knowledge of how to teach is associated with their interests and passions, and when they begin to identify themselves as somebody who knows how to teach the subject and fosters interests in both the subject and students engaging with the subject.

**Conclusion 10. The effect of the subject culture on pedagogy is mediated by a personal lens of beliefs, knowledge and experience.**
Figure 9.2 from Chapter 9 situated the teacher between subject culture and the pedagogical response. The model takes account of how the complex nature of subject culture (see Conclusion 6) sets the parameters for membership of a subject culture. The Constructed Subject Culture arises for an individual teacher out of their experiences of the external traditions of subject culture. Learning what it means to be a subject teacher involves understanding culturally accepted ways of thinking about teaching and learning.

No two teachers, however, experience subject culture in the same way, nor do they have identical Constructed Subject Cultures. Teachers’ encounters with the subject culture are personally selected, ordered and edited. This personal version of subject culture is informed by a teacher’s assumptions, beliefs, and knowledge associated with subject teaching, as well as other influences (such as tertiary training or employment, background in other subject areas, general pedagogical experiences and beliefs, and personal life experiences) and personal factors (such as individual teaching style, personality, commitments and personal preferences).

The model depicts the relationships between subject culture and pedagogy as being mediated by a teacher’s interpretive backdrop, called here a mediating personal lens. The teacher’s pedagogical response is informed by their conceptualisation of what and how to teach. The diversity of practices evident within the classroom arises from the individuality of the mediating personal lens.

Therefore, while the subject frames possibilities for action, the individual teacher is essentially autonomous in how they respond pedagogically. A teacher’s sense of agency depends on how well they understand the subject, including their knowledge of the subject matter, pedagogical practices, learning-related issues, and how to access and use resources. Also influential is the degree of latitude that a school and subject department allow a teacher to express their own ideals and beliefs.

Conclusion 11. Becoming a subject teacher is essentially aesthetic in nature.

The process of becoming a subject teacher is aesthetic in nature in two ways. The notion of “becoming” refers to developing an identity based on a confidence that the qualities of one’s teaching and the nature of one’s assumptions about teaching are appropriate and suited to being a teacher of the subject.

The notion of “becoming” also refers to a sense of attraction. The teacher is attracted to what the subject has to offer them and their students. Students become attracted to the subject through their teacher as the teacher displays a passion for what is being taught.

The aesthetic dimension of teaching is fundamental to the way we think of the subject teacher. Teaching varies across subjects because the subject matter differs. But the teacher’s aesthetic understanding of what it means to be a subject
teacher is based on more than content knowledge. The aesthetic dimension of teaching is fundamental to how teachers develop an appreciation for the subject they teach, respond to the pressures of change, align themselves with the subject culture, and negotiate subject boundaries when teaching out-of-field.

10.2. Implications and future research

The significance of this research lies in its contribution to understanding the interacting demands associated with subject teaching for individual teachers and schools. Findings relating to the subject demands associated with negotiating subject boundaries have implications for supporting teachers who are teaching “out-of-field”. Teachers’ experiences of the demands associated with translating school culture imperatives into their subject teaching raise questions about the usefulness of generic descriptions of pedagogy. The findings also imply that teacher and school change processes can be informed by better understanding of subject and individual pedagogies. These implications, along with suggestions for future research, are discussed below in three sections.

10.2.1. Issues faced by teachers teaching out-of-field

This research has shown that problems can arise for teachers as they negotiate subject boundaries. Two of these problems are discussed below as implications of this research. Suggestions for future research are also discussed.

1. Problems with lacking aesthetic understanding:

My research found that problems arose for teachers when they lacked an aesthetic understanding of the subject; problems such as feelings of incompetence, frustration with not being able to translate approaches that worked well in one subject into another, and difficulties in elaborating on subject matter to enrich students’ learning experiences. A theoretical framework of aesthetic understanding helps to identify the barriers, disconnections, and lack of appreciation that may prevent teachers from personally engaging with the subject. This inevitably impacts negatively on the quality of teaching.

The problem specifically for the “untrained” mathematics or science teacher is not simply a lack of content knowledge. This research emphasises the importance of teachers being committed to the subject, being able to identify with it, and knowing how to bring the subject matter alive for students. Efforts to improve mathematics and science teaching should be premised on the understanding that an aesthetic appreciation for mathematics and science is a critically important adjunct to developing conceptual and pedagogical knowledge.
2. **Problems with not understanding subject traditions:**

Teachers teaching a number of different subjects are expected to understand pedagogical traditions in each subject, including basic assumptions that underpin these traditions and expectations. Out-of-field teachers may be less aware of the demands imposed by the subject culture, and may be ill-equipped to appropriately filter, or respond to the subject pedagogies, such as the “Pedagogy of Support” and the “Pedagogy of Engagement” presented here.

In addition, being aware of the demands of the subject can enhance a teacher’s ability to seek appropriate alternative practices. This is significant for a number of reasons. First, subject pedagogies within the school have the potential to shape the practice of a novice or out-of-field teacher, particularly if those traditions and practices are deeply rooted in the school subject culture. Teachers who are flexible and embrace innovation and change are more likely to be successful in countering prevailing subject pedagogies that perpetuate traditional and ineffective teaching practices. Second, knowing what works and what does not, and an appreciation for how the subject both affords and limits change is required before a teacher can contribute meaningfully to conversations about curriculum development and innovation.

3. **Future research into experiences leading to confidence for out-of-field teachers:**

The data shows that having a background in a discipline is likely to equip teachers with the disciplinary knowledge to draw on in their teaching and an appreciation and enthusiasm for the subject that can be transmitted to students, qualities that are often used to define effective teachers (Darby, 2005) and potentially lacking for teachers teaching out-of-field (Ingvarson, Beavis, Bishop, Peck, & Elsworth, 2004). Other research shows that, while a teacher’s practice is dependent on the experiences that the teacher has had with the subject or discipline, these experiences are not necessarily related to exposure at university level. For example, other factors, such as career trajectory (Siskin, 1994) and professional development (Tytler, Smith, Grover, & Brown, 1999), have been found to be cogent in determining how teachers approach teaching and learning. These research outcomes highlight the importance of paying attention to teachers’ experiences of the subject they are teaching. Evident also is an assumption that teachers can be inducted into the culture of a subject through their experiences, and that, with further training, teachers can improve their competence and confidence in teaching a subject in which they have previously had limited background. Further research is needed that problematizes the assumption
that disciplinary training automatically and alone leads to effective teaching. Such research could explore those experiences that teachers teaching out-of-field believe are instrumental in developing confidence and competence in their teaching.

10.2.2. Contributing to the debate about generic and subject-specific pedagogical description

This research has shown that teachers’ pedagogy arises out of their interactions with their students within the context of the subject. Each subject imposes its own demands on these pedagogical encounters. The following implication and suggestion for future research emphasise the need to ensure that the shaping effect of the subject on pedagogy is attended to through subject-specific exemplars of teaching and learning.

4. **Subject-specific descriptions of pedagogy are more useful and informing of subject teaching:**

In the face of the recent move towards generic pedagogical descriptions, it is important for teachers, educators and policy makers to understand how the subject plays a role in determining pedagogy. Often these links are made during teacher education. While descriptions of generic skills, knowledge and attitudes associated with teaching are important and have the potential to provide a strong foundation for all teachers, my research implies that translating these from subject to subject is not necessarily straightforward. Initiatives to improve teaching at the secondary level in particular should be informed by an understanding that any pedagogical skill needs to be translated in the process of subject teaching. Consequently, professional support programs, such as mentoring or coaching, are likely to be more beneficial if subject matter specialists are used or provide substantial input.

5. **Future research on successful translation of generic pedagogy:**

Further research is needed to develop rich descriptions of those knowledge, skills and attitudes that teachers bring into their out-of-field teaching from their in-field subjects, particularly in terms of how the demands of the subject come to bear on their translation for teaching in the out-of-field subject.

10.2.3. Cultural and individual differences informing the change process

My description of the relationship between subject culture and pedagogy suggests that, in terms of teacher change, the Constructed Subject Culture is the locus of change, but the external subject cultures set the parameters for change. The following
implication emphasises the need to consider both cultural and individual pedagogies when considering change.

6. Describing subject and individual pedagogies to inform teacher and school change:

Pedagogical descriptions that represent both the subject pedagogies and individual pedagogies inform teacher and school change in a number of ways. First, diversity of practices amongst staff in a school act as a pool of perspectives, experiences, and possibilities from which innovation can emerge. Second, evaluating cultural practices that staff have in common, and assumptions underpinning these, has the potential to highlight strengths and weaknesses, and connections and disconnections, associated with the prevailing subject pedagogies. Research has shown that a cohesive subject department is more likely to produce positive student outcomes than a subject department that is disparate in terms of goals and beliefs about what is effective teaching and learning. Understanding the local school science and mathematics cultures is the first step in knowing where change is needed, and how to effect school-wide change.

10.3. Methodological Reflections

Comparative studies of subjects have highlighted various points of differences and similarities between school subjects and their cultures. Many of the ideas in the themes in this thesis have been researched and documented, mostly individually and in response to other research questions. For example: Stodolsky with Grossman (Grossman & Stodolsky, 1995; Stodolsky, 1988, 1993) reported on how the nature and organisation of the subject matter in mathematics and English influenced teachers’ conceptions of their work; through the TIMSS project, researchers (Hollingsworth et al., 2003; Lokan et al., 2006; Stigler et al., 1999) conducted comprehensive analyses of the instructional methods used in the teaching of mathematics and science; a growing body of literature is examining the importance of narratives in science learning (for example, Boström, 2006; Milne, 1998) and in mathematics learning (for example, Burton, 1996; Doxiadis, 2003); while there is an increasing body of research into learning as an aesthetic experience using a pragmatist paradigm (for example, Girod et al., 2003; Wickman, 2006).

No studies, however, have brought together these various themes in the type of cultural analysis represented in this thesis. The result is an analysis of teachers’ personal responses to the subjects they teach that takes into account the shaping of pedagogical practice by both personal and cultural influences.

Having only a small number of participants enabled me to focus at a deep level on the processes and meanings under consideration. The strength of an inquiry
employing co-construction of meaning between the researcher and the participants lies in the depth, richness and authenticity of the data. Given my attention to only six teachers, the extent to which these interpretations “can be applied to a new situation must be based on a judicious comparison between two contexts” (Hanrahan, 1998, p.750). In order to provide a basis for comparability, further research into the influence of subject culture of teachers’ pedagogies is likely to be needed in a variety of other contexts, such as other science and mathematics classrooms, schools with different middle school structures to deal with the influence of departmental and school structure and organisation, different socio-economic contexts, teachers and students of varied cultural backgrounds, with teachers of different orientations to teaching and learning, and by a researcher with a different theoretical and experiential background. My research has provided a framework within which such research might proceed.

Researching the classroom through qualitative methods requires the researcher to capture something of the lives, knowledge and belief systems of the participants. I needed to make decisions about what was relevant for observing, recording, analysis and reporting. Even though every effort was made to feed the developing analysis and interpretations into my discussions with teachers, in reality it was my role as researcher to determine the final analysis and the development of the final thesis. I was challenged by Schultz’s (2001) assertion that if participatory research is about improving the participants’ lives, then we need to extend our understanding of “participation” “to include a multitude of voices and perspectives” (p. 23) (students, teachers, schools, educationalists, and so on) and re-invent relationships by forming “a collaborative team and co-construct a representation of their perspectives without co-opting and silencing them and without pretending that we are giving over or even equally sharing the research projects with them” (p. 23). Having worked with these teachers over a period of 18 months, even in the context of a state funded school improvement project, the participating teachers were reticent to give up their time, unless it directly gave them feedback on their teaching. Other than giving teachers this opportunity to watch and reflect on their practice, I felt powerless to offer critique to inform their teaching, or opportunities for working collaboratively with them.

**Final messages**

In this thesis I have provided evidence that teachers have subject commitments, passions, and a diverse range of expertise, views about teaching and learning, and pedagogical approaches. In setting out to examine the relationships between subject culture and classroom practice, I found that the “inner” teacher is at the core of this
relationship. How the teacher sees themselves in relation to the subject they are teaching is inextricably linked to their historical interactions with the subject culture. Feelings of competence and confidence are fostered as one develops an aesthetic understanding of what it means to know and teach the subject.

Description of what it means to teach a subject, therefore, cannot be approached at a generic level but must attend to the knowledge that makes a teacher competent in their teaching, as well as what it means to have an aesthetic understanding of the subject. Preparing teachers to teach a subject or supporting teachers to teach out-of-field becomes a process of not only building their knowledge of content and pedagogy and assisting them in developing pedagogical content knowledge. Nor is it simply enculturating them into the ways, traditions, beliefs and practices associated with the subject. But it is also be a process of “becoming” where teachers increasingly see themselves in relation to subject matter and its teaching.
Marg asks a student to explain his answer to $7^{8/2}$. (16 minutes)

Marg explained after the lesson that she felt students did not really “get it”.

- Students are encouraged to study for tomorrow’s test. (1 minute)

**Note.** S1 = Data Sequence 1; M1 = Lesson code (Marg); VIDEO = video recorded lesson.


References


Boaler, J. (1997b). When even the winners are the losers: Evaluating the experience of "top set" students. *Journal of Curriculum Studies, 29*(2), 165-182.


Stacey, K. (2003). The need to increase attention to mathematical reasoning. In H. Hollingsworth, J. Lokan & B. McCrae (Eds.), Teaching mathematics in Australia:
Results from the TIMSS 1999 Video Study (pp. 119-122). Camberwell, Vic.: Australian Council of Educational Research.


Appendices
Appendix 1. Observation Protocol

- Ask groups and individuals for permission to observe and/or video record them for some time – if any objections move to the next group.
- Record observations on the Observation Template
- Diagram of room layout – movement of people, describe areas of the room, artefacts in the room
- Context notes – context of this lesson, for example, where in the unit, what happened in previous lesson/s, events preceding/following lesson such as camps/special events/visitors/school-related incidences
- Recording observation:
  - Speech acts, body movements, body postures
  - Low inference vocabulary
  - Record time frequently
  - [OC] Observer Comments noted – speculations of meaning, questions to follow up in the interviews, potential lines of inquiry, key events
- Make specific reference to (prompt included at the base of the Observation Proforma):
  - Organisation and development of students, concepts, the lesson, curriculum
  - Subject culture: artefacts, ways of behaving, specific routines, language
  - Interactions (dialogue, activity) between teacher/student, student/student, teacher/content, student/content.
- Potential focus during a lesson:
  - Student focus – individual students for short time, for example, 5 minutes
  - Overall focus – take in individual agendas (students, teacher, researcher); mood, movement
  - Teacher focus – who/where teacher directs their attention, interaction between teacher and students
  - Group focus – friendship groups, working groups
Appendix 2. Observation Template

Three types of pages were used:
1. Front page with details of the class and rubric for recording notes
2. Notes page only
3. Blank page for boardwork or diagrams.
Appendix 3. Interview Protocol VSR Trial

1. Watch the video.

2. As you watch the video provide a running commentary of your intentions and reasons for actions that may or may not exemplify the way you operate in maths and science.

3. More specifically, break the lesson up into phases and reflect on:
   a. What are your intentions for this lesson? Were these intentions actualised?
   b. How does your role and that of your students change throughout the lesson?
   c. What is the purpose and role of support materials (and people?)
   d. How are concepts/ideas contributed, constructed and used by the students and the teachers?
   e. Thinking about what you know about maths/science and what children need to learn: What is evident in this lesson that manifests what you know? (e.g. needs of the students in keeping them engaged with the ideas and activities)

4. In what ways may the “subject culture” of maths or science at your school be evident in this lesson? For example, does there tend to be a certain way of operating, teaching, learning, organising, planning or assessing that distinguishes maths from science?

5. What is common across your maths and science teaching? What do you ensure is in the classroom environment? How is this evident in these lessons?

6. What do you perceive as your role as a maths teacher as compared to a science teacher?

7. What affords (enables) and constrains (gets in the way of) what you consider to be effective teaching in maths and science?

8. Other areas for comparison that may emerge: artefacts/equipment, board work, group work, questioning, planning, interactions with the students, assessment, student engagement

9. How indicative of your practice was this lesson?
## Appendix 4. Sample observation

<table>
<thead>
<tr>
<th>Observation Code</th>
<th>SKOM1KB1</th>
<th>Teacher: KB</th>
<th>Date: 15-3-05</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teacher code</td>
<td>KB</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>15-3-05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Period/Time</td>
<td>9 - 9:55</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Room</td>
<td>M7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Videoted</td>
<td>taped</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comments</td>
<td>first lesson with this group</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### CONTEXT

![Diagram of classroom layout]

### ROOM LAYOUT

- Maths room's walls have artefacts e.g. st work, photos of people doing maths (containers with maths equipment, posters)
- Other rooms near the room have blank, cupboard and shelves.

<table>
<thead>
<tr>
<th>Time</th>
<th>Notes</th>
<th>Observer comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.02</td>
<td>T makes pupil continue to sit at front</td>
<td></td>
</tr>
<tr>
<td>9.07</td>
<td>T reads reading notices. Sit more quietly, but some quiet chatter.</td>
<td></td>
</tr>
</tbody>
</table>
| 9.11  | 'Let's try a move on' T goes to front desk, gets some paper, writes on board clean
|       | T writes activities for lesson on board, reexplain as she writes them (obj's of lesson clear to sit)
|       | T reads puzzle. Puts main pt on board.                                |
|       | T reads puzzle. Puts main pt on board.                                |
|       | T reads puzzle. Puts main pt on board.                                |
|       | T reads puzzle. Puts main pt on board.                                |
|       | Some boys yell out. 7 13. T asks for more possibilities, 19 25.      |
|       | All from boys.                                                      |
|       | T asks for 'a method we can use'                                     |
|       | So n has more than one ans.                                          |
|       | T says has more puzzle.                                              |
|       | Do 2 things: work out how many                                      |
|       | T describes the pattern.                                             |

* is this common?  
In twos I left over  
In threes I left over  
How many might there be?
<table>
<thead>
<tr>
<th>Time</th>
<th>Notes</th>
<th>Observer Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>9:38</td>
<td>T puts notes on board. Helen: In 25 In 45 In 65 T restates. T directs it to continue. It says they are finished.</td>
<td>Why is math often perceived to be a boring subject? Facilitated?</td>
</tr>
<tr>
<td></td>
<td>席: louder, some getting distracted 69-76 players with push buttons 5 put hand up 30 not appropriate. T detects a misprint. Goes to catch teacher to tell her there is a misprint, can't work, should say I over.</td>
<td>Difficult in teacher-teacher relationship with numbers, fast, evident in kids.</td>
</tr>
<tr>
<td>9:45</td>
<td>'Everybody to class, I get some more answers.' How many - any numbers here? T trying to elicit answers from wid jtt, draws girls in, some ask what pattern (eg, goes up by twenty)</td>
<td>35, 59, 71.</td>
</tr>
<tr>
<td></td>
<td>girl suggests 11, 35, 61 for John. Some disagreement from other kid, 'it might be right, but that's not what we got', 'it goes 11.' T asks for pattern. Some boys yell out - all odd, start with odd number, multiples.</td>
<td></td>
</tr>
<tr>
<td>10:00</td>
<td>T tries to get pattern for each problem. Other pattern identified by a student - all patterns are even. 'Oh your was Ti response.' T asks kid to try and work out where the number comes from. T picks up on 'multiples' as a word they might use to use in their answer. T: is there a way of determining where the starting # comes from? (only finished table, setting an extra challenge)</td>
<td>How do you control for frustration, yet provide challenge for those that need it?</td>
</tr>
<tr>
<td>9:54</td>
<td>T at 3. T explaining challenge of looking to see where the number comes from (is it in the clues?)</td>
<td></td>
</tr>
<tr>
<td>9:55</td>
<td>Can I ask you to round - T collecting sheets.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Observer Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I sat still only when I talking. A st collects sheets. Set sits at chat easily while I sort them out at front desk. I got it to be quiet. Next lesson video. This is about multiples then they work. May do another activity next lesson.</td>
</tr>
<tr>
<td>Time</td>
</tr>
<tr>
<td>-------</td>
</tr>
<tr>
<td>9.18</td>
</tr>
<tr>
<td>9.20</td>
</tr>
<tr>
<td>9.24</td>
</tr>
<tr>
<td>9.31</td>
</tr>
<tr>
<td>9.34</td>
</tr>
</tbody>
</table>
Appendix 5. Interview Protocol S2 VSR and Reflective Interview

Science Teaching

Video-stimulated recall instructions and reflective questions

Watch the video. As you watch the video, please think about the following questions.

During the interview you will be asked to provide a running commentary of your intentions and reasons for actions that may or may not exemplify the way you generally operate in science.

1. Break the lesson up into phases and reflect on:
   a. Your intentions for this lesson and for each phase? Were these intentions actualised?
   b. How does your role and that of your students change throughout the lesson?
   c. What is the purpose and role of support materials (and people?)
   d. How are concepts/ideas contributed, discussed and used by yourself and the students? Who does the thinking and acting at each stage?
   e. Thinking about what you know and believe about science and what children need to learn: What is evident in this lesson that demonstrates this? (e.g. What do you believe students need to keep them engaged with the ideas and activities?)

2. In what ways may the “subject culture” of science at your school be evident in this lesson? For example, do there tend to be certain ways of operating, teaching, learning, organising, planning or assessing that are usual? Are there any that are different for teaching science at different levels and for different topics?

3. What is common across your science teaching? What do you ensure is in the classroom environment? How is this evident in these lessons?

4. What do you perceive as your role as a science teacher?

5. What in the past and at present influences the way you teach science?

6. To what extent does this lesson illustrate your usual practice?

7. Other areas for comparison that may emerge: artefacts/equipment, board work, group work, questioning, planning, interactions with the students, assessment, student engagement

8. How does teaching science compare to teaching maths?
Mathematics Teaching

Video-stimulated recall instructions and reflective questions

Watch the video. As you watch the video, please think about the following questions.

During the interview you will be asked to provide a running commentary of your intentions and reasons for actions that may or may not exemplify the way you generally operate in mathematics.

1. Break the lesson up into phases and reflect on:
   a. Your intentions for this lesson and for each phase? Were these intentions actualised?
   b. How does your role and that of your students change throughout the lesson?
   c. What is the purpose and role of support materials (and people?)
   d. How are concepts/ideas contributed, discussed and used by yourself and the students? Who does the thinking and acting at each stage?
   e. Thinking about what you know and believe about mathematics and what children need to learn: What is evident in this lesson that demonstrates this? (e.g. What do you believe students need to keep them engaged with the ideas and activities?)

2. In what ways may the “subject culture” of mathematics at your school be evident in this lesson? For example, do there tend to be certain ways of operating, teaching, learning, organising, planning or assessing that are usual? Are there any that are different for teaching mathematics at different levels and for different topics?

3. What is common across your mathematics teaching? What do you ensure is in the classroom environment? How is this evident in these lessons?

4. What do you perceive as your role as a mathematics teacher?

5. What in the past and at present influences the way you teach mathematics?

6. To what extent does this lesson illustrate your usual practice?

7. Other areas for comparison that may emerge: artefacts/equipment, board work, group work, questioning, planning, interactions with the students, assessment, student engagement

8. How does teaching mathematics compare to teaching science?
Mathematics and Science Teaching

Video-stimulated recall instructions and reflective questions

Watch the video. As you watch the video, please think about the following questions.

During the interview you will be asked to provide a running commentary of your intentions and reasons for actions that may or may not exemplify the way you generally operate in mathematics and science.

1. Break the lesson up into phases and reflect on:
   a. Your intentions for this lesson and for each phase? Were these intentions actualised?
   b. How does your role and that of your students change throughout the lesson?
   c. What is the purpose and role of support materials (and people?)
   d. How are concepts/ideas contributed, discussed and used by yourself and the students? Who does the thinking and acting at each stage?
   e. Thinking about what you know and believe about mathematics and science and what children need to learn: What is evident in this lesson that demonstrates this? (e.g. What do you believe students need to keep them engaged with the ideas and activities?)

2. In what ways may the “subject culture” of mathematics or science at your school be evident in this lesson? For example, do there tend to be certain ways of operating, teaching, learning, organising, planning or assessing that are usual? Are there any that are different for mathematics compared to science?

3. What is common across your mathematics and science teaching? What do you ensure is in the classroom environment? How is this evident in these lessons?

4. What do you perceive as your role as a mathematics teacher as compared to a science teacher?

5. What in the past and at present influences the way you teach mathematics and science?

6. To what extent does this lesson illustrate your usual practice?

7. Other areas for comparison that may emerge: artefacts/equipment, board work, group work, questioning, planning, interactions with the students, assessment, student engagement
Appendix 6. Focus Group Discussion statements

STATEMENT 1
Maths and science place different demands on teachers and students. For example, a student absent from maths for an extended period of time is at a greater disadvantage than a student absent from science for an equal amount of time.

Is this necessarily the case? Are there parts of learning and teaching in maths and in science for which this is not really true?

STATEMENT 2
a. There are some practices that are translated readily from maths to science and vice versa.
b. There are some practices in science that really should be used more often in maths, and vice versa.
c. There are some practices that cannot be translated because the subjects are very different.

What are your views on this?

STATEMENT 3
The influences on teachers' treatment of content in their teaching, and their attitude to the subject, are in the following order:
1. school, personal and work experiences in relation to subject interests;
2. their undergraduate degree experience;
3. conversations and interaction with other teachers;
4. experiences of teaching the subject;
5. curriculum documents and direction by the subject department; and
6. professional development.

To what extent is this true for you?
Appendix 7. Focus Group Discussion example of feedback for Simon

<table>
<thead>
<tr>
<th>Discussion Statement</th>
<th>Excerpts from Interview transcript</th>
<th>Thoughts from Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>STATEMENT 1</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| Maths and science place different demands on teachers and students. For example, a student absent from maths for an extended period of time is at a greater *disadvantage* than a student absent from science for an equal amount of time. | [221] B: Yes, I just want them to be not be one of those people who has no idea about numbers later on in life, even if they do do high maths or they do low maths, I hate with my teaching to get them to have no understanding of it: ‘geez, what's he talking about length by width’ stuff like that. I want to be able to get kids jobs.  
[239] B: … if I was teaching Yr.7 kids I would them to know enough to in Yr.8 they have got those concepts in their head ready to go and to build for on next year and build on those for the next year and follow that process the whole way through.  
[304] B: In Maths … if they're struggling with a bit of work that means they are struggling with, that could be the whole concept, like Jacinta for example with algebra she can only do backtracking and she still struggles with backtracking. Whereas in Science if they are doing anything ... ‘why are these rocks like this’ you explain it, and then normally they just go ‘oh’, ‘I see’, you get that ‘oh’. Where in Maths its like 'but I still don't get why you are doing it’. I had a girl, Jacinta, she got really angry with herself ‘I just don't know what to do, what's this algebra bit’ and I was showing her the fractions and why its over a fraction and what the fraction is and she still didn't get on to that, so I had to teach fractions again. It's like revisiting a lot of work for one thing. Where mathematics is characterised by an “ordered progression from place to place through a sequence of steps” and different levels, science is characterised by a progression through disciplinary routes (Sis1 1994). | |
| Is this necessarily the case? Are there parts of learning and teaching in maths and in science for which this is not really true? | | |
What are your views on this?

STATEMENT 2

a. There are some practices that are translated readily from maths to science and vice versa.
b. There are some practices in science that really should be used more often in maths, and vice versa.
c. There are some practices that cannot be translated because the subjects are very different.

[18] B: ... But that's our real main focus in Science at the moment, trying to make things fun.

[56] B: I just think any Maths knowledge you can pass on is a good thing, whereas in Science if you take knowledge from another year level or you have already taught it to them ... that teachers that are set in their ways know that they will get the kids up to this step and then if I can introduce this concept, they might do some theory and we might do this prac and we might do the consolidating of that and introduce another theory. They are very meticulous. Whereas in Maths they have already done you go 'oh, you already know this', then why don't you try this harder concept. Whereas in Science if they already know acids and bases they can't really go that much further into acids and bases.

[72] B: I think they are both very logical ... but Mathematics generally you follow a formula or a state of mind, whereas Science, probably the best Scientists have had a theory or a formula and then collected a bit and added another chemical to see what happens ... whereas that's what science is for me, you have got a bit more ownership and you've got a bit more freedom where like, they've got a formula that they have to work to to create something ... But Science is, you can reflect on it a little bit more ... where Maths is if I taught it like, 'just do what ever, just half that times it by 4, see what happens', I think if a kid did that they might get lost and go 'Why am I doing this again' ... where Science they'll see the reaction and go, 'oh, its because I did this, or I should have stirred it before.'

[74] B: ... they can see what they have done and then the outcome. Whereas Maths is write it down, it's right or wrong, it's black or white ... where Science is 'geez it worked for two seconds and then died away' ... in Maths you'd get every kid to do the same, you might advance one or two, but ... [76] B: [in science] maybe trying something a little bit different than the person next to you ... whereas in Maths you have everyone doing the same, it just that little bit harder or that step extra.

[200] B: ... In Science I am a little bit more on edge because I know I have got gas taps around here and if a kid bumps this chemical on somewhere ... In Maths I have got the boundaries of the room, but kids know that I wont stand for anything, but they have got a bit more freedom where like, they've got a formula that they have to work to to create something ... But Science is, you can reflect on it a little bit more ... where Maths is if I taught it like, 'just do what ever, just half that times it by 4, see what happens', I think if a kid did that they might get lost and go 'Why am I doing this again' ... where Science they'll see the reaction and go, 'oh, its because I did this, or I should have stirred it before.'

[211] B: ... [For maths] I suppose you can do [stories] in all of them, if you doing graphs you can talk about the weather in Australia goes like this , it is not linear graph, petrol prices sometimes go in a linear function... you try and bring it in as much as possible, but most kids can't do that ... Where kids aren't switched on enough mathematically thinking to go 'oh is that sort of like when i gave you $6 for basketball and you gave me 50c back'... where Science is more, 'geez that's like cooking' or 'that's like what Dad does out in the back shed' or that sort of stuff ... Maths is all around them, but they don't realise it ... whereas science, Dad might go 'that's science son' and they would go 'I'll remember that' that sort of stuff or weird science on TV and just stuff like that.

[261] B: Science, kids have the attention span of 5 or 10 minutes on one concept ... friction is this, you couldn't talk about friction for 20 mins, whereas Maths you could talk about why you do it and how you do it, a few examples and that is probably 20 mins ... whereas in Science you need about 5 or 6 different concepts to get through in one lesson ... I just think the emphasis is on a lot more teaching of new concepts in Science or revisiting.

Maths and science share the following attitudes:
• desiring knowledge (as a way of knowing and understanding);
• being sceptical (recognizing when to question "self-evident truths");
• relying on data (explaining natural occurrences by collecting and ordering information, testing ideas, respecting the facts that are revealed);
• accepting ambiguity (recognise that data are rarely clear and compelling, appreciate new questions and problems that arise);
• being willing to modify explanation (seeing new possibilities in the data); cooperating in answering questions and solving problems (working together to pool ideas, explanation and solutions);
• respecting reason (valuing patterns of thought that lead from data to conclusions, and constructing theories);
• being honest (viewing information objectively without bias).

"Habits of mind or dispositions specific to current curricular, instructional, and assessment goals for both mathematics and science include curiosity, creativity, inventiveness, leadership, organization, persistence, resourcefulness, risk taking, self-confidence, self-direction, self-reflection and thoughtfulness" (Berlin and White, 1995, p.27).

Science and maths teaching methods and strategies that overlap and are supportive of one another requires environments that include: "a broad range of content, give time for inquiry-based learning, stimulate and support discourse, furnish opportunities to use laboratory instruments and other tools, provide appropriate and ongoing use of technology, encourage alternative assessment procedures, and maximise opportunities for successful experiences" (Berlin and White, 1995, p.28).

"Because mathematical knowledge is about relationships between things, it is inherently an abstract discipline. This abstractness makes it applicable to a wide variety of situations, but presents particular challenges to teachers and learners" (Board of Studies, 2000, p.5)

"Science knowledge is characterised by a complexity of application of concepts to the real world, and to classroom activities" (Tytler et al., 1999, p.211).
**STATEMENT 3**

The influences on teachers' treatment of content in their teaching, and their attitude to the subject, are in the following order:

1. school, personal and work experiences in relation to subject interests;
2. their undergraduate degree experience;
3. conversations and interaction with other teachers;
4. experiences of teaching the subject;
5. curriculum documents and direction by the subject department; and
6. professional development.

**To what extent is this true for you?**

<table>
<thead>
<tr>
<th>B:</th>
<th>I hated those periods and I always used to get into trouble because I'd be like, this is boring, and I would be the trouble maker in the class ... and I figure if I cut that down ... and I see kids that remind me of me when I was that age and they do the same things that I would have done if I was doing a boring lesson.</th>
</tr>
</thead>
<tbody>
<tr>
<td>B:</td>
<td>The aims and method normally, materials I would say you can copy the materials down... I tried to do that with Yr.9 last year and Paul was saying 'we haven't done this' and me being the new teacher I thought 'oh...' And then I thought, 'geez am I doing this wrong, should I be doing it', but I thought, its my class, I might as well give it a go. If I've done something wrong I'm sure I will be told.</td>
</tr>
<tr>
<td>B:</td>
<td>We don't have that many meetings, but when we do have them they are pretty full on. They might only go for an hour, but its not like the ones where you just sit there, we are always writing a syllabus or writing a unit or doing something important.</td>
</tr>
<tr>
<td>B:</td>
<td>Yes, like I am a lot weaker in my Science as a teacher than in my maths, like I was pretty good at Maths, so I plan a lot more for Science than for Maths...</td>
</tr>
</tbody>
</table>

A teacher's identity and work, according to van Manen, (1982), is closely associated with what teachers know about their subject so that teachers describe themselves as teachers according to what they know: “to know a particular subject means that I know something in this domain of human knowledge... To know something is to know what that something is in the way that it is and speaks to us” (van Manen, 1982, p.295).

According to Siskin (1994) what matters for teachers is “not simply that they teach, but what they teach” ( p.155). Siskin found that teachers revealed their disciplinary background through the teacher’s choice of words, how they structure an argument and their goals for teaching and learning.

Mathematical qualifications and initial training are not strongly correlated to highly effective teaching practices (Askew, 1999). Other factors, such as beliefs and understandings underpinning teaching (Askew, 1999) and career trajectory (Siskin, 1994) have been found to be cogent in determining how teachers approach teaching and learning.
Appendix 8. Annotated lesson for Lesson P8 “Language of Algebra”

VIDEO STUDY 2005

Thanks for coming on board for another year. This semester I am interested in the topics you were teaching for the filming. This will involve two parts:

PART A. Unit Discussion
A discussion between you and I where I invite you to bring along the unit plans, texts, brains, etc that you drew on to teach the units for both classes. I would like to get a sense of how the lessons videoed and observed sat within the context of the whole unit. Before the meeting it would be good if you could think about:

a. The main ‘things’ that you like to bring out, encourage, foster or develop throughout your teaching of this unit.
b. Any influences on your teaching of the unit.
c. Your personal response to the unit.

PART B. Video Reflection and Discussion
After this, I will give you the video of your two lessons for private viewing at home, then an interview about the video will follow.

The lessons I videoed related to:

<table>
<thead>
<tr>
<th>Year 7 science</th>
<th>Light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 7 maths</td>
<td>Algebra</td>
</tr>
</tbody>
</table>

VIDEO STUDY 2005

PART B

1. Please think about the main ‘things’ you raised in the first interview about the units.
2. Watch the video and identify any parts of the lessons that you feel were important in encouraging, fostering or developing any of these main ‘things’. They may:
   - be single moments, segments or whole parts of the lesson; and
   - involve you, the students, or interactions that occur within or outside the classroom.
3. Please note the times on the video (bottom right hand corner of the screen) so we can fast forward to these points during the following “Video Discussion”. I have provided sheets that may assist in organising your thoughts.
4. The 1 hour Video Discussion will involve going through each of these things that you identify as important to get a sense of how the lesson and these ‘things’ fit into the unit.
<table>
<thead>
<tr>
<th>Time</th>
<th>Event</th>
</tr>
</thead>
</table>
| 9.12-9.28 | • Intro to new topic.  
• Open text books, going to start a new topic, the language of algebra.  
• T writes heading on board “Language of algebra”, draws angle.  
• T explains fundamental purpose of algebra.  
• T puts a word problem on the board. How would we write this in words?  
• We already know why we use numerals instead of word.  
• T instructs students to write a word equation using mathematical terms.  
• T asks students to put a secret number into the equation and work out what the answer is. |
| 9.28-30 | • T asks students to take down some notes on some key words: pronumerals, number in front of brackets. |
| 9.30-48 | • T hands out worksheet for practising changing word problems into the language of algebra.  
• Students work on worksheet. Ask T questions. |
| 9.48-56 | • T goes through worksheet with students, gives the answers by constructing each part. |
| 9.56-10.00 | • Students continue with worksheet.  
• T sends around a check list for work they will be doing during the algebra unit.  
Students expected to glue it into their books. |
| 10.00-10.08 | • T gets ready to go through answers for back of the sheet. Distracted by a student and tends to his question.  
• T moves to board and takes class through the back of the sheet. |
| 10.08-10.15 | • Students continue working through worksheet. |
Appendix 9. Initial coding framework

These codes include the initial and emergent codes. Only Pauline’s interview was coded.

<table>
<thead>
<tr>
<th>Intensions</th>
<th>Statements about the teachers’ intentions for the lesson</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-ref</td>
<td>Post reflections on the lesson, prompted by video</td>
</tr>
<tr>
<td>Student response</td>
<td>Teacher’s representation of how students responded during the student/teacher interaction</td>
</tr>
<tr>
<td>Classroom culture (CC)</td>
<td>“Normal” types of interactions, actions, responses, rules, norms, expectations, values exhibited in the classroom. May be generic or subject-specific. “I normally have…”</td>
</tr>
<tr>
<td>Instructional pedagogy (IP)</td>
<td>“Normal” teacher actions, activities focusing on teaching the subject</td>
</tr>
<tr>
<td>Impressions/Knowledge of learners (KL)</td>
<td>Teachers’ knowledge, feelings, inferences, beliefs about learners, e.g. how learners respond to or think about science/the activities/concepts. Also generic knowledge.</td>
</tr>
<tr>
<td>Representation of the Science/Maths Discipline (RS/RM)</td>
<td>How the teacher represents the culture of the discipline, heroes, the way science/maths works, values, experiences. Culture</td>
</tr>
<tr>
<td>Representations of school versions of Science/Maths (RSS/RSM)</td>
<td>How the teacher represents the culture of school science/maths. Purposes, values, expectations. Representation is through direct statements (explicit) about how to act, this is why; or indirect statements (implicit).</td>
</tr>
<tr>
<td>Representation of scientific concepts/topics (CON)</td>
<td>How teacher talks about the concepts, apparent levels of understanding</td>
</tr>
<tr>
<td>Development of the teachers (DEVELOP)</td>
<td>Socialisation, background experiences</td>
</tr>
</tbody>
</table>
## Appendix 10. Sequence 2 themes, assertions and elements

<table>
<thead>
<tr>
<th>Theme</th>
<th>Assertion</th>
<th>Elements</th>
</tr>
</thead>
</table>
| **Learning culture**       | Students respond differently in maths than in science. In science students have a shorter attention span so need to have a greater number of activities.                                                           | • Student response to learning  
• Planning                                                                                                                   |
| **Enculturation**          | A teacher’s experiences with and interests in maths and science influences how they teach and identify themselves.                                                                                         | • History with subject  
• Influence of interest and personal commitment  
• Identity and positioning within the social setting of the school/subject Discourses  
• Personal orientation |
| **Curriculum**             | The nature of the maths and science curriculum are essentially different and demand different ways of teaching                                                                                        | • Sequential  
• Utility of syllabus  
• Conceptual/theory and skills/processes  
• Teacher response  
• Demands of the subject |
| **Purposes**               | In both maths and science teaching, making connections to students’ lives is a fundamental purpose. Students make connections to real life easier in science because science is more observable than maths. | • Goals of teaching  
• Ways of knowing  
• Nature of student learning                                                                                                  |
| **Discipline versus school versions** | School science and maths are essentially different from maths and science outside of school.                                                                                                       | • School                                                                                      |
| **Student response to curriculum** | A student absent from maths for an extended period of time is at a greater disadvantage than a student absent from science for an equal amount of time.                                       | • Nature of curriculum organisation  
• Struggling/student difficulties  
• Purposes and importance of the subject and what the subject offers                                                                 |
| **Pedagogical knowledge**  | There are some elements of classroom teaching that cross subject boundaries. However, these ‘generic’ elements may look different depending on the subject due to:  
• the nature of the learners;  
• the teacher's interests and expertise; and  
• demands of the subject.                                                                 | • Generic pedagogical elements  
• Subject-specific pedagogical elements  
• Learning culture  
• Teacher interests/commitments |
Appendix 11. Final Coding framework

1. Subject

<table>
<thead>
<tr>
<th>Subject</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maths</td>
<td>1.1 Ideas relating to maths only, discipline or subject, nature of mathematics</td>
</tr>
<tr>
<td>Science</td>
<td>1.2 Ideas relating to science only, discipline or subject, nature of science</td>
</tr>
<tr>
<td>Maths v Sci</td>
<td>1.3 Ideas relating to science and maths, discipline or subject</td>
</tr>
</tbody>
</table>

2. Views about mathematics and science teaching and learning

Many of the ideas from teachers emerged as they compared mathematics against science.

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest</td>
<td>2.1 Nature of teachers’ personal interest in maths and science, experiences as a learner, user, doer and teacher, confidence/ability/knowledge.</td>
</tr>
<tr>
<td>Curriculum</td>
<td>2.2 Nature of the curriculum, organisation</td>
</tr>
<tr>
<td>Subject matter</td>
<td>2.3 Nature of the subject matter, theory, process. Making connections between ideas; teacher content knowledge</td>
</tr>
<tr>
<td>Progression</td>
<td>2.4 Nature of progression, implications for how students progress through the curriculum</td>
</tr>
<tr>
<td>Learning</td>
<td>2.5 Nature of student learning, how students understand ideas, how they work with ideas, nature of student response to learning the subject. Needs for learning. Interaction for learning, e.g. social classroom. Relationship between teacher and students.</td>
</tr>
<tr>
<td>Discipline</td>
<td>2.6 Nature of the disciplines, what maths/science is like and carried out by mathematicians, scientists, presence in ‘real’ lives, epistemological underpinnings and values</td>
</tr>
<tr>
<td>Value</td>
<td>2.7 Value of the subject, nature of its importance</td>
</tr>
<tr>
<td>Support</td>
<td>2.8 Nature of student assistance/support, areas where they struggle</td>
</tr>
<tr>
<td>Reasoning</td>
<td>2.9 Pedagogical reasoning, purposes of pedagogical moves, strategies, resources, planning, assessment</td>
</tr>
<tr>
<td>Resources</td>
<td>2.10 Resources used for teaching or planning</td>
</tr>
<tr>
<td>Planning</td>
<td>2.11 Reasoning for planning, procedures for planning</td>
</tr>
<tr>
<td>Assessment</td>
<td>2.12 Thoughts about assessment, examples</td>
</tr>
<tr>
<td>Lesson structure</td>
<td>2.13 Reasoning for lesson structure</td>
</tr>
<tr>
<td>Strategies</td>
<td>2.14 Different teaching and learning strategies</td>
</tr>
<tr>
<td>Correction, right wrong</td>
<td>2.15 Having to get the right answer, needing to correct work</td>
</tr>
<tr>
<td>Working out</td>
<td>2.16 Need to show working out</td>
</tr>
<tr>
<td>Extending</td>
<td>2.17 Notion of extending students</td>
</tr>
<tr>
<td>Language</td>
<td>2.18 Focus on language and vocabulary</td>
</tr>
<tr>
<td>Activity</td>
<td>2.19 The uses and nature of activity</td>
</tr>
<tr>
<td>Prac–theory</td>
<td>2.20 Nature of prac/theory divide</td>
</tr>
<tr>
<td>Role</td>
<td>2.21 Beliefs about role of teacher</td>
</tr>
</tbody>
</table>

3. Influence of the subject culture/discourses

<table>
<thead>
<tr>
<th>Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Out there</td>
<td>3.1 Nature of the bigger picture, ‘they’ and ‘out there’ – predominant discourse and those that act on and determine this discourse</td>
</tr>
<tr>
<td>Tradition</td>
<td>3.2 Tradition, and the pressures this applies to teachers through socialisation for the teachers, expectations by teachers, students and parents based on their experience of traditional approaches to teaching and learning, expectations of</td>
</tr>
</tbody>
</table>
requirements for teaching the subjects

| KLA | 3.3 Subject department at each school, KLA, where the ideas of a few experienced or at least passionate teachers influences the emphasis at the school, e.g. problem solving in maths, attention to activities, activity directed science programs |
| Socialisation | 3.4 Socialisation and career trajectory of teachers, experiences with the subject, discipline and education; continued experiences |
| Teachers | 3.5 Teaching community |
| Constraints | 3.6 Constraints imposed on teachers by the nature of school, the subject or other influence |
| Strategies | 3.7 Particular strategies that are well accepted in the subject |
| School | 3.8 Nature of school, schooling. Management issues. Issues that are non-subject-specific, generic |
| Students | 3.9 Nature and expectations of students |

### 4. Contexts for comparing maths and science using these themes:

| Stories | 4.1 Story telling – a teaching strategy giving insight into the nature of the subject matter. Relevance, humanising the subject matter, making connections between concepts and students’ lives. (2.3, 2.5, 2.7, 2.6/2.14) |
| Progression | 4.2 Student progression – teachers' views about students. ((2.4, 2.5/2.8, 2.2, 2.3, 2.9) |
| Thinking | 4.3 Thinking – how teacher provides opportunities for students to engage with the ideas and act and think mathematically and scientifically. Questioning, intrigue. (2.5/2.3, 2.9, 2.14, 2.6) |
| Discourses | 4.4 Discourses – discourses of the subject culture that influence the teachers. (2.5, 3.4, 3.2/3.5, 3.8/2.10/2.3/2.9) |
| Passion | 4.5 Passion – relationship between the personal and the public as an aesthetic overlay shaping pedagogy/subject culture interface. Passionate about the subject and teaching and the students (2.1, 2.5, 2.3/3.4, 2.21) |

### 5. Bio

Personal details of the teacher, including socialisation, snippets from personal lives, ideas that could be used to build a case study, preferences in subject, teaching strategy, subject matter, personal orientation.

| Simon | 5.1 |
| Rose | 5.2 |
| Donna | 5.3 |
| Pauline | 5.4 |
| Ian | 5.5 |
| James | 5.6 |

### 6. Research effect

Comments relating to how the research has affected the teachers, classroom activities, response during researchers’ presence.
## Appendix 12. Matrix of theme codes against all codes

<table>
<thead>
<tr>
<th>subject</th>
<th>Discourses Theme</th>
<th>Passion Theme</th>
<th>Progression Theme</th>
<th>Stories Theme</th>
<th>Thinking Theme</th>
<th>total in themes</th>
<th>total in+out themes</th>
</tr>
</thead>
<tbody>
<tr>
<td>maths</td>
<td>24</td>
<td>9</td>
<td>11</td>
<td>17</td>
<td>25</td>
<td>86</td>
<td>123</td>
</tr>
<tr>
<td>nature of maths</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>5</td>
<td>8</td>
<td>27</td>
<td>27</td>
</tr>
<tr>
<td>science</td>
<td>12</td>
<td>21</td>
<td>4</td>
<td>17</td>
<td>23</td>
<td>77</td>
<td>111</td>
</tr>
<tr>
<td>nature of science</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>3</td>
<td>7</td>
<td>22</td>
<td>23</td>
</tr>
<tr>
<td>maths v sci</td>
<td>11</td>
<td>6</td>
<td>9</td>
<td>12</td>
<td>18</td>
<td>56</td>
<td>60</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>views about maths and sci</th>
<th>Discourses Theme</th>
<th>Passion Theme</th>
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## Appendix 13. Rose’s Lesson Summaries

| S1 | Year 8 MATHEMATICS  
Lesson R1: Algebra problem solving activity  
• Rose uses “Garden Beds” MATHS300 problem for the whole lesson as a teacher-led activity. Paper squares are used to represent pavers and shrubs that are laid on the floor so that any line or grouping of shrubs is surrounded by pavers. Different combinations are discussed.  
• Together, students and Rose develop a mathematical model from the concrete representations. She refers to algebra as a way of writing the model.  
Filler lesson for students not attending school camp |
|---|---|
| S2 | Year 8 MATHEMATICS  
Lesson R2: Percentages and fractions VIDEO  
• Continue calculating percentages and changing fractions into percentages. Rose introduces different problems on the board, including: What % of girls and boys are in this class? How many more girls are needed to make it 50%? 10% of 1km? 13m as a % of a km?. In each case students are invited to provide an answer and explain how they did it. Rose goes through each step and sometimes repeats a step for students who do not understand. (15 minutes)  
• Students work through textbook problems for the remainder of the lesson while Rose gives assistance. (30 minutes)  
Lesson R3: Revision of percentages and fractions  
• Rose writes revision problems on the board and students work through them. Rose responds to students' questions either privately or publicly. (48 minutes) |
| S3 | Year 8 MATHEMATICS  
Lesson R6: Circumference of a circle  
• The formula for finding the circumference of a circle is revised briefly. (2 minutes)  
• Students individually answer two problems from the board and other textbook exercises while Rose assists students having difficulties. (40 minutes)  
• Rose answers the board problems publicly. (2 minutes)  
• Students continue with textbook problems. (15 minutes)  
Lesson R7: Area of a triangle and parallelogram VIDEO  
• Rose revises the formula for the area of a triangle and explains that the triangle is half a rectangle. Rose introduces the term perpendicular as two edges that form a right angle by using examples in the classroom, for example, the wall is perpendicular to the floor. (4 minutes)  
• Students then work on different tasks. Students are at different stages because some students were absent from last lesson: (46 minutes)  
• Some students work on problems from the board and textbook exercises. These students have already completed the following activity.  
• The other students cut out an equilateral triangle and trace around it in their books, |
| S4 | Year 9 MATHEMATICS  
Lesson R4: Median, mean and mode VIDEO  
• Rose introduces median, mode and mean through a series of public-private-public sequences where Rose discusses with students the terms and the mathematical procedures involved (public), followed by students privately solving equations from the board (private), then public correction (public).  
• The different sequences deal with the following procedures: finding mean from lists of numbers; working out the missing number from a series of numbers with a given mean; and finding median from a series of numbers.  
Lesson R5: Consolidating mean, median and mode  
• Rose revises how to find the median and mean for a series of numbers.  
• Rose begins by publicly working through some median and mean problems with student assistance.  
• Students are then assigned problems from the board.  
• The process for finding the mode is revised with examples from the board. The main idea that a series of numbers have zero, one or two modes is introduced.  
• Students complete problems from the board then exercises from the textbook. |
| S5 | Year 9 MATHEMATICS  
Lesson R8: Trigonometry  
• Students work through textbook exercises for the most of the lesson. Rose roams and privately probes students’ understanding and responds to student questions. During this time Rose instructs the whole class occasionally, such as impressing the need for correction and that the “hard ones” are done on the board. (48 minutes)  
• The last part of the lesson is spent on non-mathematical matters. (17 minutes)  
Lesson R9: Algebra introduction VIDEO  
• A quiz on algebraic terms and concepts is used to introduce the new unit, algebra (10 minutes).  
• Rose lectures on algebraic terms (sum, difference, product and quotient), writing notes on the board that students record in their books. (3 minutes)  
• A series of equations are written on the board, such as 3a + 4b + 5a = ? and 4ab + 2a + 4b + 5ab = ?. Rose asks students to simplify them publicly and a few individual students provide their solution and a brief explanation. Rose talks about the letters as apples and bananas that cannot be added, but “you can mix them together when multiplying them”, to which one student said “You get a fruit salad”. (13 minutes) |
| Draw the perpendicular to the base on the paper triangle, cut it in half and paste the halves in their books as a rectangle. |
| Rose then asks students what a parallelogram is. She asks them to make a paper parallelogram and draw around the shape in their books. Students draw in the perpendicular to the base at one end and cut along the line to make a square end. The larger part is stuck in their books below the traced shape and the small triangle is glued to the diagonal end to make a rectangle. Rose then asks students for the formula of a parallelogram, and one student says it is base times altitude. (6 minutes) |
| Students work through textbook exercises, during which time Rose either deals with student difficulties privately at desks or publicly on the board, or discusses test results with individuals. (43 minutes) |

*Note. ST = Data Sequence 1; RT = Lesson Code (Rose); VIDEO = video recorded lesson.*
### S1 Year 8 SCIENCE

**Lesson D1: Human skeleton**  
- Ideas on skeletons from previous lessons are reviewed with teacher generated questions and student volunteered responses. (3 minutes)  
- Students privately record notes from an OHP on bone types and structure. (7 minutes)  
- Public discussion around questions about the body. Donna provides detailed information related to the body, including her experiences. (5 minutes)  
- Donna introduces the prac by taking students through the textbook description, emphasising the observations to be made, where information can be located to assist in answering questions, and directions for the prac write-up. (7 minutes)  
- In groups, students collect and examine bones of different shape and size, and cut in trans- and cross-section. (20 minutes)  
- Students are assigned homework to prepare for discussing observations next lesson. (2 minutes)

**Lesson D8: Energy transformations**  
- Donna revises previous ideas about energy in different situations, such as the amount of heat energy given out when burning food and heating water. She introduces forms of...
“scientific method.” She hands out a worksheet that she explains will “cement” that a bit. Donna goes through the worksheet and sets the work requirements. (13 minutes)

- Students work through the worksheet and Donna roams and gives assistance when asked. (12 minutes)
- Some answers are publicly discussed, while others are assigned for homework. Another worksheet is introduced on reading measuring scales. (19 minutes)
- Students work on the second worksheet while Donna provides assistance when asked. (16 minutes)

**Lesson D7: Physical and chemical changes**

- Introductory lesson. Donna begins the lesson with a discussion to find out students’ ideas of the meanings of “chemistry” and “reaction.” (6 minutes)
- Donna reads a section from the textbook publicly to introduce chemical and physical changes. She gives everyday examples and asks students for suggestions of reactions. Donna explains differences between chemical and physical changes with definitions and examples, such as a story to illustrate a chemical reaction that is non-reversible: cannot get back a burnt love letter. (7 minutes)
- Donna writes notes about chemistry and reactions on the board that students copy. Donna also writes on the board the appropriate textbook pages for the prac, and the results table. Donna reads through these to explain the terms (for example, precipitate) and emphasises what students should look for in the prac by referring to the textbook description. (12 minutes)
- Students collect safety gear then move to separate benches. Donna oversees distribution of equipment at the front. Students work through the various experiments. Packup. (20 minutes)
- Students return to seats and read the textbook while waiting for all to be seated. The lesson finishes with a class discussion and recording of observations on the board. (6 minutes)

- Students begin completing questions and a table of different forms of energy, and writing about energy changes from the textbook. (26 minutes)
- Donna explains the different energy types. She probes students for examples and the type of energy in different situations, eg. rubber bands, story of her neighbour with solar powered lights. Donna explains the energy transformation experiments. She explains the arrangement of the experiments around the room and where they are found in the textbook, expectations for student behaviour and safety. (18 minutes)
- Students begin prac. Donna roams and manages students, pointing out the main observations and energy transformations. (17 minutes)
- Students sit. Donna explains the energy transformations in the solar powered car. (2 minutes)

**Lesson D9: Classification I**

- Donna introduces a new topic, classification. She elicits students’ understanding of the term then asks students to classify animals from a list on the board (8 minutes)
- Students work individually to group the animals firstly into two groups, and then split each group into two groups. (6 minutes)
- Donna discusses publicly how different students grouped the animals. She points out the major principles of grouping and what happens when we group. A second activity is introduced where students group different types of lollies. (5 minutes)
- In pairs, students receive a cup of lollies, which they pour out and begin grouping. Donna roams and discusses the task with students privately. (25 minutes)
- Students are asked to share their thinking publicly (5 minutes)

**Lesson D10: Classification II**

- Review of previous ideas and homework related to classification, keys, groups. Introduction to new activity focuses on how keys can make groups smaller and individual, discussing also why keys might be useful. (9 minutes)
- Students privately complete a section of the worksheet and textbook that reinforces the process of grouping according to features of an organism. (14 minutes)
- Answers to the worksheet are publicly discussed. Donna emphasises the limitations of keys, the importance of using broad categories, and she uses the term “species”. She introduces the next activity: using keys to group animals in the room. She models how to use the textbook key by referring to features of the classroom pet lizard. (14 minutes)
- Students move around the room looking at various live and dead specimens. Donna talks with individuals and groups about features and instructions (16 minutes)
- Class discussion of what was noticed when observing and grouping animals. (2 minutes)

Note. S1 = Data Sequence 1; D1 = Lesson (Donna); VIDEO = video recorded lesson.

**Appendix 15. Pauline’s Lesson Summaries**

| S1 | Year 8 SCIENCE |
**Lesson P1: Circulatory system theory**
- Student observations from a heart dissection in the previous lesson are used to develop a diagram of a heart on the board. During this discussion, Pauline explains the relationship between heart and blood, relationships between air, respiratory system and circulatory system, and how the wastes are removed from the body. (10 minutes)
- Students work through questions from the textbook, during which time Pauline attends to student questions. She also discusses informally preferences for assessable tasks for the unit. (30 minutes)
- Answers are discussed publicly (3 minutes).

**Lesson P2: Static electricity practical**
- Pauline introduces the new topic of static electricity
- Students complete a series of experiments investigating static electricity. They investigate the effects of: objects and people in contact with a van de Graaff; charging balloons when placed near hair, walls, foil and other balloons; and a charged rod when placed near water. (45 minutes)

**Lesson P3: Static electricity theory**
- Pauline asks students to share their observations from the previous experiments. Student thinking is prompted with questions such as "What was the most fun?", "What did you see?", "What was special about the balloons?" "What happened when…?" Student observations are listed on the board, and Pauline sometimes paraphrases student responses to introduce the scientific language, such as repel and attract. (6 minutes)
- Pauline builds theory from explanations in a number of steps (22 minutes):
  - She tells the story of Benjamin Franklin’s discovery of static electricity, explaining the charge that he experienced as lightning was experienced by these students in the experiments.
  - She relates charge to magnets: “If this repelled and they work like magnets, what must this mean?”
  - She builds up three rules based on student observations.
  - She introduces atomic theory with a diagram to explain how objects become negatively or positively charged.
  - She discusses with the class how lightning is generated, relating lightning to charge from the van de Graaff.
- Students then work on questions assigned from the textbook. Pauline roams and contributes examples of static electricity to individuals, groups or publicly. (10 minutes)

**Lesson P4: Two-dimensional shapes**
- Pauline arrived early to draw diagrams of 2-dimensional shapes on the board.
- Pauline introduces each of the two-dimensional shapes to the students by name and their characteristics. (5 minutes)
- Students are assigned exercises from the textbook. Pauline assists students with queries privately, and publicly answers questions a number of times during the lesson. (35 minutes)

**Lesson P5: Three-dimensional shapes**
- Pauline recapcs prefixes used to describe two-dimensional and three-dimensional shapes. She distinguishes between polygons and polyhedra as two- and three-dimensional. She introduces the regular and irregular polygons with some shapes drawn on the board that students are challenged to name. During this discussion, she checks student understanding by asking questions such as "Why is this shape regular?" “Are there any prisms?” (10 minutes)
- Students are assigned textbook exercises. While students answer these, Pauline roams and talks with students. Graph paper is distributed for some questions. A row of six boys work on an alternative task from the textbook, an investigation into constructing paper three-dimensional shapes. (27 minutes)

**Lesson P6: Bones and nutrition theory**
- Pauline discusses activities from the previous experiment where students dissected chicken wings, focusing on whether students observed marrow, spongy bone and ligaments. Pauline hands out a worksheet, which forms the basis for further discussion on nutritional requirements of bones (8 minutes).
- Students complete the worksheet while Pauline roams and responds to student queries. (13 minutes)
- Answers are discussed publicly and Pauline emphasises the main points. A second worksheet is distributed in readiness for next lesson (15 minutes)

**Lesson P7: Reflection**
- The lesson is shortened for preparation for parent/teacher interviews.

**Lesson P8: Language of algebra**
- Pauline recaps prefixes used to describe two-dimensional and three-dimensional shapes. She distinguishes between polygons and polyhedra as two- and three-dimensional. She introduces the regular and irregular polygons with some shapes drawn on the board that students are challenged to name. During this discussion, she checks student understanding by asking questions such as "Why is this shape regular?" “Are there any prisms?” (10 minutes)
- Students are assigned textbook exercises. While students answer these, Pauline roams and talks with students. Graph paper is distributed for some questions. A row of six boys work on an alternative task from the textbook, an investigation into constructing paper three-dimensional shapes. (27 minutes)

**Year 8 MATHEMATICS**
- The new topic is introduced by drawing an angle on the board where the value of the angle is represented as a. This diagram is used to raise the question “When do we use algebra in real life?” Pauline then discusses the fundamental purpose of algebra and how to use the language of algebra to convert word problems into algebraic form. Pauline writes a series of equations and problems on the board to demonstrate how to use algebra. Students are invited to assign any number to x and work out the problems. Pronumerals and the process for expanding brackets are introduced. (18 minutes)
- Pauline hands out a worksheet for practising changing word problems into algebraic form, which students work through steadily. Pauline tends to student questions privately. Some students are asked to help their peers. (18 minutes)
- Pauline publicly discusses some of the solutions by constructing each part of the equation.
The new topic of “Seeing and Hearing” is introduced by stating the various activities and prac that students will be involved in. Pauline gives instructions for today’s prac on mirrors. Students begin writing the prac from the textbook. (10 minutes)

Students move to the front of the class for a demonstration of lightboxes, how to produce parallel lines, and how to distinguish between convex and concave mirrors. (5 minutes)

Students collect materials and work through the experiment in groups around the room. Pauline writes notes on the board about different types of lenses, then circles the room checking on set up, responding to students’ observations and questions, and publicly reminding students to draw diagrams. Students are then prompted to pack up. (24 minutes)

Students sit down and begin writing up prac, which is expected to be completed for homework. (6 minutes)

(8 minutes)

Students continue with worksheet (18 minutes)

More questions are publicly discussed, then students continue working till the end of class (9 minutes)

Note. S1 = Data Sequence 1; P1 = Lesson Code (Pauline); VIDEO = video recorded lesson.
Appendix 16. Simon’s Lesson Summaries

S1 Year 7 MATHEMATICS

Lesson S1: Data representation

- Students had completed a reflexes prac in the previous lesson. Simon collated the results in a data table on the board. A student calculated the class averages and this was recorded. (5 minutes)
- Students spend the rest of the class drawing graphs. (45 minutes)

Teachers are encouraged to integrate mathematics and science. Emphasis here is on presenting data mathematically.

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S2 Year 7 SCIENCE

Lesson S2: Different forces

- Simon directs a brainstorm of the types of forces. Student examples are written on the board: friction, pull/push, air resistance, gravity, non-contact, contact forces. Students read today’s experiments from the textbook then write their own aim. (Experiments include: pushing force with blowing ping pong balls with straws; gravitational force with dropping objects; electrostatic force with attracting paper with a charged pen; surface tension force with bubbles; and magnetic force with two magnets:). (2 minutes)
- Students complete the task and Simon roams. (4 minutes)
- Simon explains the gravitational force experiment and asks students to write a prediction of whether a piece of paper or the coin will land first and why. Students write an inference as to why the coin landed first. (6 minutes)
- Students pick up paper with an electrostatically charged pen at their desks. Students write down what force is acting and what happens when the charged pen is placed near to and far from the paper. Simon roams. (5 minutes)
- Simon leads a class discussion about whether the attraction worked over a distance, and compares the effect of different types of pens. Simon introduces the activity for magnetic force. Students are to find out what happens when like and unlike poles are joined. (2 minutes)
- Students complete the activity while Simon roams asking students about their “discoveries.” (4 minutes)
- Students share their discoveries publicly, eg. they push against each other when two blue ends are put together. Simon explains that this is a “magnetic push force” that results from two opposite poles repelling each other. (2 minutes)
- Students use the iron filings with their magnets. Simon explains publicly that the iron filings were attracted to the magnet because of the magnetic field, and that any type of metal is going to be attracted. Students are expected to write about the forces. Simon talks with a student about how in Year 9 the students will use a “vendergraf” during a static electricity unit. (10 minutes)
- Simon asks students to get into pairs for the push force activity next lesson. (5 minutes)

Lesson S3: Friction VIDEO

- Simon summarises previous work and activities by directing students to the textbook. Simon explains today’s focus is on pushing force and asks students to read the activity from the textbook and begin answering questions. The activity is a game. (2 minutes)
- While students work, Simon organises the game as a knock-out competition and

Lesson S4: Generating algebraic equations I VIDEO

- Simon summarises previous work on algebraic equations by writing four equations on the board. He uses these four equations to develop four rules, one exemplified per equation. Students then privately solve the four equations. While they work, students are asked to create two equations similar to those on the board on a slip of paper and submit them to Simon. (7 minutes)
- Students continue with the board equations. Simon hands out paper and students write and solve their equations. (3 minutes)
- Simon solves the board equations publicly with students, asking students for the answer then prompting them to explain what they did to answer them. (2 minutes)
- Students continue writing equations while Simon roams and assists students. Simon then collects equations. (5 minutes)
- Simon explains that these questions are like a mini test. He begins writing selected questions on the board for students to complete. Simon instructs students to think through the steps if they are harder. He congratulates each student as he writes their equation on the board. Sixteen equations are written up, and students write them all down and complete now or for homework. Simon roams and provides assistance when asked. (13 minutes)

Lesson S5: Generating algebraic equations II

- Students continue with the students’ questions generated in the previous lesson. Simon writes more questions on the board beginning with the seventeenth. Simon privately explains to students absent last lesson how each student wrote two “sums” and that they are now working out “what x is worth.” Simon puts a few questions at a time on the board then roams and tends to student problems. (6 minutes)
- Interruption by a visitor completing a survey. (3 minutes)
- Simon announces that because students seem tired and not concentrating that they will work out the problems on the board. He chooses an equation takes students through the steps for solving it. He asks students for the various steps, targeting particular students, eg. “Which number is furthest away from the x value?” “How do we get rid of that?”. “So we do the opposite function on both sides.” (3 minutes)
- Simon asks students to do the next question to be ready to answer in a couple of minutes. Simon impresses the need to write the working out because he wants to know how students are thinking through these. Simon roams and looks at students’ work. (2 minutes)
organises the draw. Simon explains the method, playing field, and establishes the rules. The students are to blow a table tennis ball through goals at the ends of their tables. Two teams compete, and each team consists of a pair of students. (5 minutes)

- Students begin setting up tables, then begin the competition. Simon yells instructions and watches different games. After the first round, Simon fills in the draw and students set up for the second round. The third round is the grand final, where all students gather to watch. Students then pack up and return to their seats. (19 minutes)
- A brief discussion (1 minute) of what students learned about friction follows. Students are instructed to answer three questions related to the activity from textbook. Students do this quickly. (3 minutes)
- A student reads publicly about friction and friction opposing motion in the textbook. Simon adds some ideas between paragraphs, such as how to increase and reduce the amount of friction of tyres. The students read the next experiment and to write their own aim, then complete two sentences beginning with "Friction is...". (10 minutes)

**Lesson S6: Everyday reactions**

- A student reads aloud a section in the textbook about physical and chemical changes. Students write an explanation of physical and chemical reactions and give examples. (6 minutes)
- Simon introduces two further tasks while students are working: writing examples of physical and chemical changes; and beginning a prac write-up. Simon roams while students work. (14 minutes)
- Simon publicly explains equipment, safety and procedure. (3 minutes)
- Students complete reaction of sodium bicarbonate and vinegar and watch the cork pop. Simon talks privately with student groups about gas production. There is much movement and excitement. Students clean up and sit. (16 minutes)
- Simon writes questions on the board for students to answer privately, instructing students that he wants to see students’ ideas of what is happening when he collects their workbooks. Students begin working on the questions immediately. (6 minutes)
- Simon directs students to the next prac in the textbook, observing reactions. He explains the materials and chemicals, stressing safety issues. Students write the aim, equipment and safety sections from the textbook. (5 minutes)
- Students do this. Simon then explains the various chemicals and procedures and how the chemicals will be distributed. (11 minutes)
- Students move to collect materials, and Simon reminds students of procedures and important safety tips, stopping students to get their attention. Students then carry out the reactions of magnesium and copper sulphate, and hydrochloric acid and hydroxide. Simon rushes students to finish and pack up. (9 minutes)

**Lesson S7: Reactants and products**

- Simon explains the day’s activities, then a student reads aloud a section in the textbook about “reactants and products” while Simon writes notes on the board. (4 minutes)
- Simon explains the text: what reactants are and some common examples. While students are working, Simon assigns the following tasks: (12 minutes)
  - write what they had for breakfast showing the reactants and products, for example, milk+cocopops⇌cocopops breakfast;

**Year 9 MATHEMATICS**

**Lesson S8: Algebra revision**

- The problem is solved publicly, with students giving the steps as directed by Simon. (2 minutes)
- Students privately answer the next question, and Simon impresses the need to do the opposite operation to both sides. (2 minutes)
- Public working out. Simon decides to give them a more difficult question. (2 minutes)
- Students work privately. (3 minutes)
- Public working out. Simon asks the questions to prompt each step. Simon then asks students to rule up a page and draw up a series of different sized tables. (5 minutes)
- Simon draws the tables with numbers in them on the board. Much time is spent on drawing up six boxes to specific dimensions. He then calls out numbers for each box and then asks individuals to read out the numbers to check they are correct. He then assigns an equation to each box and the bell goes. (26 minutes)
• complete sentence stems from board – “A reactant is…” , “A product is…” ;
• write a section from the textbook into workbook; then
• rule up a table from the board for hydrogen, oxygen and carbon dioxide (chemical symbols, what does the gas look like, features of the gas, use in everyday life).
• Simon roams and provides assistance where needed. He introduces the next task of completing the table from the textbook, followed by making a start on writing out today’s experiment from the textbook: aim, materials, read method, and draw simple diagrams of the apparatus. (15 minutes)
• Simon asks a student to publicly demonstrate the hydrogen “pop test” of hydrochloric acid and magnesium. Students are to do this experiment multiple times. (4 minutes)
• When finished writing the experiment, students move to gather safety equipment, materials and do the experiment. Simon yells instructions and assists groups of students. Students gradually finish and are seated to finish writing the experiment. (27 minutes)

Note. SI = Data Sequence 1; SI = Lesson code (Simon); VIDEO = video recorded lesson.
## Appendix 17. James’ Lesson Summaries

<table>
<thead>
<tr>
<th>S1</th>
<th>Year 7 MATHEMATICS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson J1: Number puzzles</td>
<td></td>
</tr>
<tr>
<td>• James reviews previous work with tile patterns and the use of the “number machine.” He explains the number machine again and attempts to differentiate between number and process (or rule). Eg. A student states that the process for the box is “X 3 + 1” (5 minutes)</td>
<td></td>
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<tr>
<td>• James hands out a worksheet and students work through this as James provides assistance when prompted.</td>
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<table>
<thead>
<tr>
<th>S2</th>
<th>Year 7 SCIENCE</th>
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<tbody>
<tr>
<td>Lesson J2: Making limewater</td>
<td></td>
</tr>
<tr>
<td>• James explains the experiment, to use limewater and see how long it takes to change colour when blowing through a straw. (2 minutes)</td>
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</tr>
<tr>
<td>• James demonstrates how the limewater changes colour when blown. (1 minute)</td>
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<tr>
<td>• A large group of students return and James explains the process again while students are seated. He mentions that the change of colour is due to a gas. A worksheet is handed out for the activity. (7 minutes)</td>
<td></td>
</tr>
<tr>
<td>• Students collect equipment and do activity while James roams. Students pack up and record findings on handout. (14 minutes)</td>
<td></td>
</tr>
<tr>
<td>• Some answers are shared publicly. (5 minutes)</td>
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</tr>
<tr>
<td><strong>Was to be video recorded. Much wasted time due to students without consent leaving then returning because only seven students remained and video recording was abandoned. Excessive management problems.</strong></td>
<td></td>
</tr>
</tbody>
</table>

| Lesson J3: Electric circuits VIDEO |
| • James introduces the experiment for today, electric circuits and how it will be discussed afterwards. He reviews the previous analogy of bucket and hose for electric circuits. He then sets the task: using the real thing (he shows the components) students are asked to connect the components to make the light globe work. James encourages students to try different arrangements and draw three in their workbooks, then introduce a second switch and see what happens. He warns that student will have different answers depending on where they put their switches. An imaginative approach is encouraged. (7 minutes) |
| • Students collect equipment and begin setting up circuits. James roams and interacts with groups. Students pack up. (40 minutes) |
| • A brief class discussion about what was needed for the circuit to work. James mentioned Thomas Edison as the inventor of the lightbulb and how he tested different materials. James instructs students to ensure student diagrams are completed then explains tasks for next lesson. (5 minutes) |

<table>
<thead>
<tr>
<th>S1</th>
<th>Year 10 SCIENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lesson J4: Genetics, ethics and debating genetically modified foods</td>
<td></td>
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<tr>
<td>• Students continue working in groups on their part of a debate about genetically modified food and other topics relating to the ethics of genetics. Students were expected to be ready for the debate today. (10 minutes)</td>
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<tr>
<td>• Some students read their responses. James reiterates the main arguments (5 minutes)</td>
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<tr>
<td>• Students continue working on debate responses. (20 minutes)</td>
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</tbody>
</table>

| Lesson J5: Genetics revision VIDEO |
| • James introduces revision sheet by reading aloud and asking for student answers for some questions. Other questions are left for students to complete themselves. (12 minutes) |
| • James explains the importance of studying before a test. (2 minutes) |
| • Students work through the questions while James walks around answering student queries. (31 minutes) |

**Note.** S1 = Data Sequence 1; J1 = Lesson Code (James); VIDEO = video recorded lesson.
Appendix 18. Ian’s Lesson Summaries

S1 Year 7 SCIENCE

Lesson I1: Separating mixtures by evaporation
- Ian introduces today’s activity by holding up a can of coke, saying that sugar can be separated from drinks. (6 minutes)
- Ian leads a class discussion on how to separate a solution. He uses a diagram on the board of an evaporating dish. (5 minutes)
- Students write down the boardwork as Ian introduces the equipment and method. Students are to evaporate some Coke and measure the quantity of remaining sugar. Ian demonstrates the use of an electronic balance to weigh the solution and sugar. Ian explains what observations need to be taken and where to collect equipment and safety gear. (14 minutes)
- Students collect equipment and conduct experiment. Ian interacts with groups of students. (20 minutes)

Lesson I2: Designing a fair test for separating mixtures - trialling the process
- Ian introduces the activity for today by reminding students of their previous experience of “simple filtering.” He hands out a sheet entitled “The best material for making a filter paper.” He asks students to think about the pracs they have already completed when designing their own experiment. A student reads the sheet and Ian discusses one of the main points – how to conduct a fair test. Students are asked to talk in pairs about how they would set up a fair test. Before they begin planning Ian directs a discussion about designing fair tests based around use of equipment and materials, quantities, measurements and time. (11 minutes)
- In groups, students begin designing and writing experiment in their workbooks. Ian roams then sits at the front of the class dealing with individual students on non-science related matters. (5 minutes)
- Ian leads a discussion about what an aim is and asks for some student examples. (4 minutes)
- Students continue working while Ian remains seated at the front. (3 minutes)

Lesson I3: Designing a fair test for separating mixtures - planning
- Ian explains that students will do their experiment, but that he wants to talk about it first. He reiterates what is meant by a fair test by asking students what it means in terms of quantities of mixture, using equipment to measure, whether the timing should be considered. Ian explains that students will test three papers for how well they filter a charcoal and water mixture. He gives the instructions briefly suggesting that they may make some mistakes before they get it right. (12 minutes)
- Students move to begin the experiment in groups. Ian assists students in collecting equipment and materials. Students conduct the experiment then pack up. (27 minutes)
- Ian reprimands students for poor work practices, such as solids being trapped in sinks. He then leads a brief discussion about what did and did not work, and what these results might mean. (1 minute)

Lesson I4: Designing a fair test for separating mixtures - repeating the process

S2 Year 7 SCIENCE

Lesson I2: Designing a fair test for separating mixtures - planning
- Ian introduces today’s activity by holding up a can of coke, saying that sugar can be separated from drinks. (6 minutes)
- Ian leads a class discussion on how to separate a solution. He uses a diagram on the board of an evaporating dish. (5 minutes)
- Students write down the boardwork as Ian introduces the equipment and method. Students are to evaporate some Coke and measure the quantity of remaining sugar. Ian demonstrates the use of an electronic balance to weigh the solution and sugar. Ian explains what observations need to be taken and where to collect equipment and safety gear. (14 minutes)
- Students collect equipment and conduct experiment. Ian interacts with groups of students. (20 minutes)

Lesson I5: Multiples problem solving – Line Up
- Ian uses the RIME lesson plan “Line up”. He introduces today’s tasks, then sets the first problem as a puzzle: “Ann lines up her toy soldiers, when in twos there is one left over, when in threes there is one left over. How many might there be?” Ian asks for possible solutions. Some boys call out four alternative answers (7, 13, 19, 25). Ian asks for “a method we can use”, but no discussion occurs. He then introduces more puzzles on a worksheet and asks students to work out how many and to describe the pattern. (7 minutes)
- Students work through the worksheets in groups. Ian roams and checks understanding of the task, encouraging students to write down some numbers that work and then to look for a pattern. Ian directs the class often restating the task (“the question asks for numbers of soldiers, not solutions, there may be many or none”). (9 minutes)
- Ian writes the names of the different problems on the board, then asks for solutions from different students for the problem called “Ann” saying “We are not saying these are all of the solutions.” (3 minutes)
- Ian roams and speaks with students. Contact with table groups involves engaging with individual students, just looking, answering student questions or asking questions to direct students to particular patterns. (11 minutes)
- Public sharing of solutions leading to patterns involves Ian asking for student answers. Some student-student talk occurs as students dispute the solutions or patterns found by other students: “It might be right but that’s not what we got”. Ian asks for patterns and some boys say that they are all odd, start with odd numbers, they are multiples, and all patterns are even. (5 minutes)
- Ian asks students to try and work out where the number comes from and write it down, and to use the word “multiples” in the answer. Ian keeps moving around the tables and challenges groups to think of where the starting number comes from. (2 minutes)
- Students are encouraged to finish and hand in their sheets, and he restates that “It’s all about multiples obviously”. (1 minute)

Lesson I6: Multiples problem solving reflection and consolidation
- Ian provides opportunity for students to reflect on the multiples problem from the previous lesson. Students are asked to write on the back of the “Line Up” sheet how they found a solution to one of the problems and to use the word “multiples” in their
IAN REMINDS STUDENTS OF THE PREVIOUS LESSON ON FILTERING AND FAIR TESTING AND EXPLAINS THEY WILL REPEAT THE PROCEDURE. HE INSTRUCTS STUDENTS OF THE MATERIALS TO BE USED, YELLOW CHALK AND WATER MIXTURE, THE VARIOUS FILTER MATERIALS, AND THE IMPORTANCE OF NOT CLOGGING UP THE SINKS. (5 MINUTES)

STUDENTS CONDUCT THE EXPERIMENT. IAN ROAMS AND SUPPORTS STUDENTS’ EQUIPMENT NEEDS AND DISCUSS VARIOUS IDEAS WITH STUDENT GROUPS AND INDIVIDUALS PRIVATELY, SUCH AS EXAMPLES OF FILTERS IN EVERYDAY LIFE. STUDENTS PACK UP. (34 MINUTES)

STUDENTS WORKED PRIVATELY ON A SERIES OF QUESTIONS FROM THE BOARD ABOUT HOW THE EXPERIMENT COULD BE IMPROVED. (5 MINUTES)

IAN PROMOTES CLASS DISCUSSION ABOUT THE OUTCOMES. (3 MINUTES)

Lesson 17: Multiples and Indices Problem Solving

THE LESSON IS BASED AROUND A RIME PROBLEM SOLVING ACTIVITY “ODDS AND EVENS.” IAN HANDS OUT THE SHEET AND EXPLAINS THAT FOR EVERY NUMBER BETWEEN 1 AND 32 STUDENTS ARE TO USE TWO RULES UNTIL THEY REACH THE NUMBER “1.” THE RULES ARE AN ODD NUMBER MUST BE Multiplied by 3 and 1 added (X3+1) AND EVEN NUMBERS MUST BE DIVIDED BY TWO (÷2). STUDENTS ARE TO DETERMINE THE LENGTH OF A CHAIN, THAT IS, THE NUMBER OF PROCESSES THEY HAVE TO GO THROUGH TO GET TO 1. (5 MINUTES)

STUDENTS WORK THROUGH THE SHEET WHILE IAN ROAMS AND ENGAGES WITH STUDENTS FOR VARIOUS REASONS, SUCH AS, CLARIFYING THAT “1” HAS NO STEPS BECAUSE IT IS ALREADY AT “1”, ENSURES THAT STUDENTS HAVE CALCULATORS, RESPONDING TO STUDENT QUERIES. (35 MINUTES)

IAN STOPS THE CLASS TO PUBLICLY EXPLAIN “COMMON MULTIPLES” ON THE BOARD WHEN PROMPTED BY A STUDENT. HE USES THE MULTIPLES OF 6 AND 8 AS AN EXAMPLE. (2 MINUTES)

STUDENTS CONTINUE WORKING (5 MINUTES)

IAN PUBLICLY DISTINGUISHES MULTIPLES FROM FACTORS, AND ASKS THE STUDENTS TO GIVE THE FACTORS FOR 15 AND 60. HE CHALLENGES STUDENTS TO FIND ALL OF THE FACTORS FOR A NUMBER WITH MANY FACTORS. (6 MINUTES)

Note. S1 = Data Sequence 1; I1 = Lesson Code (Ian); VIDEO = video recorded lesson.
### Appendix 19. Marg’s Lesson Summaries

<table>
<thead>
<tr>
<th>Year 8 MATHEMATICS</th>
<th>Lesson M1: Directed number with protons and anti-protons</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\times$</td>
<td>This is a continuing lesson for a worksheet on protons and anti-protons. Marg begins the lesson by revising some of the previous problems, doing some on the board. (10 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Students continue with the worksheet. Some students use counters. (40 minutes)</td>
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### Year 7A MATHEMATICS

<table>
<thead>
<tr>
<th>Lesson M2: Investigating number</th>
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</thead>
<tbody>
<tr>
<td>$\times$</td>
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<td>$\div$</td>
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<td>$\div$</td>
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<table>
<thead>
<tr>
<th>Lesson M3: Investigating powers of seven</th>
<th>VIDEO</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\times$</td>
<td>Marg reviewed the use of the power buttons on the scientific calculator. She takes students through a number of examples, for example, 7 to the power of 3, 5, 9, then 22. Marg showed how to write these with expanded notation ($7^3 = 7 \times 7 \times 7$), and tested student understanding of the base numeral and index number. (8 minutes)</td>
</tr>
<tr>
<td>$\div$</td>
<td>Marg hands out a worksheet and explains that students will be working out the unit digit for $7^{1999}$. Students begin by trying this on the calculator. In table groups, students are asked to solve the problem by using various strategies. (5 minutes)</td>
</tr>
<tr>
<td>$\div$</td>
<td>Students talk in groups to solve the problem. (5 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Students’ strategies are publicly discussed. They included: writing it out by hand; breaking up the 1999 so you can do it and add it up; adding up 7 to the powers of 9, 99, 999; (1999x5)+(2X1999)=7X1999. Marg draws attention to the poster “Guide to problem solving” hanging up in the room, referring to “use easier numbers”, and “look for a pattern”. Students are not sure where to go next so Marg asks them to do the answers for $7^{1-10}$ as indicated on the worksheet. Marg records answers on the board and asks students to look for patterns for the last digit. (20 minutes)</td>
</tr>
<tr>
<td>$\div$</td>
<td>Some students cannot see the patterns. Marg uses the thinking of one student to show how to work out the pattern of the unit digit. She asks “Which number in the cycle will it be? How many cycles fit into these numbers?” (that is, 7, 49, 343, 2401, 16807, 117,649 – cycle being 7, 9, 3, 1). Marg sees students are having problems and explains it another way: remainder from 1999 ÷ 4 is the number in the cycle (3 remaining, therefore, the third term is 8) and the remainder of 1999 ÷ 2 is the other term in the cycle (3 being odd so the answer is 7). (10 minutes)</td>
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<table>
<thead>
<tr>
<th>Year 7B MATHEMATICS</th>
<th>Lesson M4: Revision of two-dimensional shapes</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\times$</td>
<td>As some students have never done a test before, Marg explains how to do revision. She organises students into groups and assigns roles within the groups. Students are to use cards with questions and she explains the process of the collection and use. (10 minutes)</td>
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<tr>
<td>$\div$</td>
<td>One student from each group (“team leader”) collects a card from the front and the groups begin working. Marg places other revision questions from the textbook on the board. Marg roams and assists students where needed. As groups finish the 16 questions they begin the textbook questions. (21 minutes)</td>
</tr>
<tr>
<td>$\div$</td>
<td>Marg publicly answers the 16 questions. She chooses a group to answer the multiple choice questions. During this time Marg names the types of shape, for example, equilateral, scalene, parallelogram, obtuse angled triangle, polygon, octagon, pentagon. (9 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Marg talks about the test tomorrow: the type of questions and how it is structured, the importance of showing their working, and the need to bring a protractor and ruler. Marg was not aware of my attendance prior to this lesson.</td>
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<table>
<thead>
<tr>
<th>Lesson M5: Algebra OSCAR machine</th>
<th>VIDEO</th>
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<tr>
<td>$\times$</td>
<td>Marg introduces the new topic of algebra. Students are asked to write the heading “algebra rules” and draw the diagram of the OSCAR machine, “the number crunching machine” and two tables. (10 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Marg explains that they will start looking at the real algebra rules later but will start with the number crunching machine called OSCAR. She explains that it performs different operations on numbers. “When you put a number in OSCAR it does something to it and spits out a new number” and it works the same way as the algebra rules. Marg demonstrates with the pairs of numbers 1-13, and 7-49. She asks what can he be doing? She uses student responses increasingly. (7 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Marg puts six algebra rules on an OHP. The class continues working through some examples bearing in mind the rules. Tables of numbers are used to work out a rule suitable for each number. Three tables are done publicly as well as some developed by the individual students. (10 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Another student generated table is used as a challenge for Marg to work out. This time she explains how she was looking for patterns to help her work it out. She explains the terms multiplier and add-on. (10 minutes)</td>
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<tr>
<td>$\div$</td>
<td>Marg generates three more tables and asks students to work out the multiplier and add-on then write it as a rule. The rule is $\Delta x 8 – 5$. She takes the students through her strategy. (14 minutes)</td>
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