Science and Mathematics Education Centre

Classroom Factors Affecting Student Scientific Literacy: Tales and Their Interpretation Using a Metaphoric Framework

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Dedication

To Fariba, my darling wife, without whose support I could not have begun, let alone finish, this thesis.

To Nadia, my adorable daughter, an unending source of fascination and delight as she grows.

To Dad and Mom, for always battling through and inspiring their children to do likewise.

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Abstract

The *scientific literacy* of four students in Year 8 was the main focus of one year of participant observer research. An interpretive research methodology was employed to generate tales about each student, in order to provide rich descriptions of the participation of these students in Science classes and in non-Science classes.

A major theme was the complementarity of epistemological referents for scientific literacy. Objectivism, personal constructivism and social constructivism were identified as major referents for scientific literacy, and therefore as underpinning factors for the diversity of definitions of scientific literacy. Some authors have called for these referents to complement one another. In this study, I used the conceptual tool of *metaphor* to facilitate the holding together, in dialectical tension, of these often competing ideas.

No a-priori notion of scientific literacy was adopted for the research, but an emergent theoretical framework for scientific literacy evolved. This metaphorical framework was shown to be a viable way of organising a diversity of literature-based definitions of scientific literacy. It was subsequently utilised to interpret the tales about the four students, and helped reveal significant themes.

Foremost amongst the emerging research themes was equity of access into scientific literacy. Ten major assertions from the research provide different considerations of the ways that students access, or are denied access to, scientific literacy. Finally, implications of the three-metaphor framework for research, and speculations about its place in informing classroom practice are presented.

Chapter One
Introduction

It is conceivable that the greatest curse of *scientific literacy* has been the variety and breadth of meanings attached to it. This, however, may be one of its greatest assets. Such a term, with multiple nuances, whilst never able to be a precise descriptor of a particular entity or characteristic, may provide an anchor point in the realm of science education for discussion amongst people with radically different views on science and the learning of it. (In this thesis, 'science' is used for the human endeavour and 'Science' is used for the school subject.)

It was, in no small part, because of the diversity of meaning of scientific literacy that three themes emerged from the research conducted at one high school. Each theme pertains to some recent major issue in the literature. The first theme is for different theoretical orientations to complement one another (Duit & Treagust, 1998), as objectivism, personal constructivism and social constructivism seem to be major underlying epistemologies that inform the diverse notions of scientific literacy (see Chapter Four). The second theme is metaphor's pervasiveness, prevalence and power to provide understanding (Lakoff & Johnson, 1999), characteristics that made metaphor suitable for its role as the frame of reference for this thesis, to enable the above epistemologies to be held in dialectical tension, especially in the context of scientific literacy (Willison, 1999). The third theme involves equity of access issues (Calabrese Barton & Osborne, 1998; Kyle, 1997) highlighted in this thesis through the development of four case studies in a specific local context, which began to address the issue of why scientific literacy rates are considered to be low (Devlin, 1998). This thesis is written in a mixed genres form (see Chapter Two).

The Research

The first reason for engaging in this research was the ongoing lack of agreement in the literature about what scientific literacy entails (DeBoer, 2000), promoting the need to develop a different approach to defining scientific literacy. Notable recent research by Lakoff and Johnson (1999) and Lakoff and Nunez (2000) into the origins of philosophy and mathematics, respectively, suggested that metaphor could play a significant role in conceptualising objectivism, personal constructivism and social constructivism, especially as referents (Tobin & Tippins, 1993) for scientific literacy. My previous research utilised two metaphors to interpret vignettes depicting students' active participation in science investigations, and made me ask, 'are there other metaphors that can provide us with more useful ways of construing scientific literacy?' (Willison, 1999, p.124). This thesis research explored the deeper use of metaphor as a frame of reference, and considered further specific metaphors for conceiving of scientific literacy. The fuzziness of scientific literacy required utilizing complementarity and metaphor as significant tools of thought.

The second reason for engaging in the research was that although scientific literacy had often been measured in quantitative studies, only a small amount of qualitative research had provided in-depth, contextualised portraits of student scientific literacy. Moreover, most of the qualitative studies had focused on specific interventions, and their evaluations (e.g., Bezzi, 1999; Hanrahan, 1999; Meichtry, 1992; Palincsar, Anderson & David, 1993). Therefore, this research attempted to provide a few, in-depth, contextualised portraits of students and their own forms of scientific literacy without the effects of any specific intervention.

The third (emergent) reason addressed equity issues, suggested by calls for 'scientific literacy for all', which highlight the need to consider marginalised students' scientific literacy. Calabrese Barton and Osborne (1998) asked:

- How can historically marginalised students become involved in science?
- How can we shape practice and curriculum to address the needs of diverse learners? (p.340).

Of the four students studied, three could be considered to be marginalised in one way or another, that is, to be struggling to access aspects of scientific literacy. Therefore, this research provides a deeper understanding of equity of access issues, including the types of forces that may marginalise students inside and out of the Science classroom. This understanding served as a basis for suggestions about how to more fully involve these students in Science, and how classroom practice may be shaped to facilitate increased access.

Research Question

The above reasons of inconsistency (of what scientific literacy means), incompleteness (of in-depth portraits of student scientific literacy) and inequity (of access to scientific literacy) were the focus of a single interpretive research question: *What are the effects of learning tasks set in Science and non-science subjects on students' scientific literacy?*

As a participant observer, I addressed this question by focussing on four students, Tara, Darrien, Shelly and Jimmy, in their Science classes. Occasionally I also followed them into the classes of other subjects. My purpose was to conduct a fine-detailed study of student scientific literacy. Several questions sprung to mind. What would scientific literacy entail in the context of their particular school? How similar and how different would be the scientific literacy possessed by each student? What access is provided by learning tasks into scientific literacy? My perspectives of the experiences of the four students are represented in this thesis in the form of two tales (Van Maanen, 1988), each composed of three vignettes.

To make sense of these tales, I needed to develop an appropriate interpretive framework. Kyle (1997, p. 770) stated that 'the current goals of access to knowledge and equity afford educators the opportunity to shift the *active participation* [italics added] toward the learner and the process of learning'. Therefore, even though many definitions of scientific literacy have focussed on the entity itself, I utilised a three-metaphor framework that focuses on the active participation of students in the enterprise of scientific literacy.

What I found as a participant observer, informed by the literature and attempting to make sense of student experiences, was that, whilst the range of conceptions must be broad to encapsulate scientific literacy, a perception of what it entails needs not be ethereal. Utilisation of a metaphorical framework to delineate the breadth of types of participation of students engaged in different facets of scientific literacy provided a deepened understanding of what the concept is and could be.

Not surprisingly, perhaps, I found that different students responded in different ways to the same learning tasks. However, it was the breadth of responses amongst a small number of students that was impressive. It was from this range of responses that the issue of *equitable access* to scientific literacy became readily visible, particularly in terms of the question: 'if students respond very differently to the 'same' Science learning activities, in what ways can Science teachers provide activities that will facilitate all students increasing their scientific literacy?'.

Moreover, I had considered that factors affecting access to becoming scientifically literate may not necessarily be restricted to the context of Science classrooms. Therefore, for the purpose of providing a deeper understanding of what scientific literacy may entail for each student, I set one of the three vignettes which make up each tale in non-Science classrooms. Participant observation in English, Maths, Social Studies and Italian classrooms provided further insight into the four students' development of scientific literacy. No doubt, numerous factors influencing scientific literacy prevail outside the boundary of the schoolyard, but this issue falls outside the scope of this study.

Addressing the reasons for conducting the research, and considering the resulting themes, may contribute to understanding of scientific literacy by educational researchers and teachers, and especially to the enrichment of students and their scientific literacy.

Research Context

The research site was Righschool; a senior high school with a population of around 500 students and 40 teaching staff. It is located in an outer suburb of a Western Australian city in an area of low socio-economic status. It has expansive grounds with 25-year-old buildings inconveniently arranged around the site. When the school was built, two Science laboratories were located at one corner of the school grounds, and, when expansion of the school population prompted the building of three more, these later additions were located at the furthest possible distance from the original ones.

At the beginning of 1994, my third year as a Science teacher, I was sent to Righschool by the State Education Department. I arrived at the school as a full-time teacher and began to conduct action research on scientific literacy with my Year 8 Science class in the third term of the same year. In Western Australia, Year 8 (twelve-year-olds turning thirteen) is the year of transition from the five-day-a-week interaction with a single teacher trained in general pedagogy, to numerous four-hour-per-week encounters with teachers often most educated in the content of their subject area. At about the same time as I commenced action research, some students went on strike, waving a placard with large writing that simply stated 'WE HAVE RIGHS TOO!' Thus 'Righschool' received its name for this research. I continued complexified action research (Sumara & Davis, 1997) for the next three-and-a-half years (Willison, 1996; 1999) until a change in research methodology seemed necessary for generating greater detail in understanding student scientific literacy. Consequently, I engaged in the participant observer research presented in this thesis as a way to generate this detail.

Thesis Layout

Section One details the research methodology, deals with the frame of reference for this thesis, and specifies a working definition for scientific literacy utilising a metaphorical framework. Section Two is concerned with the vignettes that represent students in classrooms, and their interpretations utilising the metaphoric framework. Section Three summarises findings, compares them to other research and draws out implications.

Section One

Section One is comprised of Chapters Two, Three and Four, and is concerned with the methodology and theoretical frameworks of the research. Chapter Two deals with the methodology and representation of the research. The participant observer research utilised an emergent interpretive research methodology (Erickson, 1986), and was conducted according to the manner of Palonsky's (1975) *participant as observer*. Vignettes of salient lessons were employed as the strategy to depict data generated, and were written utilising a *confessional* genre, and occasionally a *dramatic* genre (Van Maanen, 1995). Epistemological considerations are discussed in Chapter Three, which presents a perspective on the need for the referents of objectivism, personal constructivism and social constructivism to complement one another. This is contrasted with a conflict view that utilises 'competing theories'. I propose that relating the three referents in a *complementary* manner is educationally most helpful, and thus there is a need to facilitate the conceptualisation of learning from the vantage point of several different referents. Metaphor is defined and suggested as the frame of reference to achieve this, and its role in language, thought and science is specified. Therefore, in Chapter Four, I use metaphor as a basis for a *framework for scientific literacy*. This consists of three metaphors: *student-as-recruit*, *student-as-judge* and *students-as-scientists*. The first two metaphors are in the singular, as they emphasise processes at work in individual learners. The third metaphor is in a plural form, as its emphasis is on social processes. The three metaphors function together to encapsulate the variety of conceptions of scientific literacy found in the literature (see Chapter Three). The framework's viability was considered in terms of its utility for organizing a variety of definitions of scientific literacy found in the literature, and was the means used to interpret the data presented in Section Two.

Section Two

Section Two presents the two tales, and their interpretations using the three-metaphor framework. Chapters Five, Six and Seven each contain a single vignette, and together these form Tale One, featuring Shelly and Jimmy. Each vignette is followed by an interpretation using the three-metaphor framework to make sense of the scientific literacy of the two students. Chapter Five portrays Shelly and Jimmy engaged in a 'closed' science experiment (see Chapter Two), and finds, in interpretation, that the two students not only approached the learning task in very different ways, but took out of it very different scientific literacy experiences. Chapter Six depicts both students attending English, Italian and Mathematics classes. Both students make artistic contributions to the English lesson, Shelly's in a salient cartoon, and Jimmy's in utilising visual literacy. These contributions and their context help make further sense of the emerging nature of each student's scientific literacy. This enriched understanding is further assisted by examining Jimmy's and Shelly's participation in Italian: Jimmy is depicted as showing a strong dependency on the text book for success in an Italian word-game, whilst Shelly displays disinterest in gaining anything but a bare pass. Finally, in Mathematics, both students are shown, individually and reluctantly, occupied in building a tower made of toothpicks, an activity arranged by their teacher to supposedly develop group-work.

Similar isolating factors re-emerge in Chapter Seven, where Jimmy and Shelly are portrayed as being required by their teacher to work individually in Science. In this final vignette of Tale One, Shelly diligently works on an open-ended experiment (see Chapter Two), whilst Jimmy refuses to take part. Together, the three chapters suggest that Shelly, who has a strong written literacy, was provided ready access into rich scientific literacy experiences. This is in contrast to Jimmy, whose predominately visual literacy was often unrecognised and unrewarded, and therefore became a barrier to enjoying successful scientific literacy experiences.

Tale Two, similarly composed of three vignettes, is found in Chapters Eight, Nine and Ten. Chapter Eight depicts Tara and Darrien involved in an experiment that is, at first glance, more open than closed. Tara becomes disenchanted, whilst Darrien is uninvolved with the task. The three-metaphor framework provides helpful insight into Tara's frustration, yet the lack of involvement by Darrien remains difficult to understand. It is the way that Darrien is depicted in Chapter Nine that helps us make more sense of his scientific literacy. In this chapter, his involvement in English and Social Studies provides a stark contrast to his lack of motivation in Science, whilst his actions in Mathematics parallel those of Science. For Tara, English provides a safe forum for creativity, whereas her creativity in Science seems only to promote trouble. Chapter Ten provides the concluding vignette of Tale Two. This presents insight into Tara's unique way of construing phenomena in class, which ends, it seems, in something worse than frustration. Darrien's continuing minimal involvement raises questions about the explanatory power of the three-metaphor framework.

Section Three

Section Three draws together all the research findings, considers relevant literature, and contemplates the implications of the research. In Chapter Eleven major assertions are formulated and discussed in the light of theory and research findings from the literature. In Chapter Twelve, possibilities are presented for future research on, and for facilitating the development of, student scientific literacy. Arguments are presented for the necessity of the operation of all three metaphors in the classroom, based on the desirable complementarity of objectivism, personal constructivism and social constructivism, in order to facilitate access by a greater proportion of students to a more fully developed scientific literacy.

Significance of The Thesis

This thesis makes an original contribution to science education research in a number of ways. First, it specifies a way in which metaphor may be utilised as a frame of reference to allow educators to hold objectivism, personal constructivism, and social constructivism in dialectical tension. Second, it develops a metaphoric framework that embraces diverse conceptions of scientific literacy, and is potentially useful for understanding scientific literacy in Science classrooms. Third, the analysis of the vignettes about four very different students suggests that there is a broad scientific literacy spectrum, with a range of factors that facilitate and inhibit scientific literacy development in schools. Fourth, the participant observer research adds to a small body of literature providing a detailed picture of the scientific literacy of students in the transition year from primary school to high school. Finally, the consideration of effects of subjects other than Science on scientific literacy is a major inclusion, as it is surprisingly neglected in the literature on high school scientific literacy.

Section One
Research Methodology and Theoretical Framework

Section One deals with the nature of the research reported in this thesis. The starting point is specifying the methodology in Chapter Two, providing the rationale for the research. This chapter deals with the way in which the research took shape, including an emergent theoretical framework, and with the representation and legitimation of the research.

Chapter Three deals with metaphor as a conceptual tool. It begins by considering calls in the literature for divergent viewpoints, such as objectivism, personal constructivism and social constructivism, to complement one another, because each has impacted on notions of what scientific literacy entails. Metaphor is identified as a frame of reference that can provide a language for dialogue to allow opposing notions to be held in dialectical tension.

Chapter Four develops a metaphoric framework for scientific literacy that is intended to embrace a diverse range of notions entailed by the concept. The framework is utilised to arrange the scientific literacy literature, thereby demonstrating its theoretical viability prior to using it to interpret the dramatic tales constructed from the research in Section Two.

Chapter Two
Participant Observer Methodology

'The fact is that regardless of all our efforts, by any reasonable measure we [the United States of America] remain predominantly a nation of scientific illiterates' (Shamos, 1996, p.44). Typically, an objectivist referent has been used to define scientific literacy and measure it in statistically significant ways, using data gathered from a large number of people (e.g., Bowyer & Linn, 1978; Cannon & Jinks, 1992; Dulski, Dulski & Raven, 1995; Mitman, et al, 1987; Zuzovsky, 1997). Reports of these kinds of studies tend to agree that about five percent of the population of the United States of America is scientifically literate (Devlin, 1998; Miller, 1988). Results of the Third International Mathematics and Science study suggest that the rate of scientific literacy in Australia is higher than that of the USA (Western Teacher, 1998), as measured using an objectivist referent, yet is still relatively low. This leaves a large percentage of the Australian school population as 'scientifically illiterate', and demands a more in-depth look at *why* only a minority reach a minimum standard of literacy, and what factors help the small minority attain this status.

This question cannot be answered satisfactorily by quantitative methods alone. More explanatory power is necessary, in keeping with interpretive research methodologies (Erickson, 1986; 1998). This present research addresses the lack of empirical interpretive research on scientific literacy. The descriptive power of confessional and dramatic vignettes (see later this chapter) and the interpretive power of the three-metaphor framework (see Chapter Four), enabled the development of a fine-detailed understanding of the scientific literacy of four students.

I have positioned this chapter on methodology prior to the account (in Chapter Three) of the theoretical framework for the research. The purpose is to provide the reader with a strong sense of the emergent nature of the theory which, for coherence, is presented neatly in Chapters Three and Four, yet which actually arose in a recursive and messy fashion. Particularly, it needs to be pointed out that, from the beginning of the study, the central concept of 'metaphor' was in a constant state of flux. Its role initially was to encapsulate dominant learning characteristics of individual students, utilizing Connelly and Clandinin's (1988) methods to identify appropriate metaphors. Whilst promising at first (see p. 25), this personal metaphor approach began to lose its explanatory power (see p. 26). The notion of metaphor as a possible way to encapsulate a variety of scientific literacy notions surfaced based partly on my previous research utilizing two metaphors for scientific literacy, partly on my embryonic interpretations of the vignettes (Chapters Five to Ten), and partly on further reading of the scientific literacy literature. Ultimately, metaphor emerged as a unifying concept, as an actual frame of reference in its own right (see Chapter Three), after further reading of the literature on metaphor.

I begin, in this chapter, by considering previous research on scientific literacy, and research that has utilized metaphor. After identifying a direction for research, I propose how the research can be legitimated and specify the nature of the specific participant observer research, including the ongoing analysis and interpretation that this involved. Following this are issues of representing the research, including the plural writing genres utilized, the use of vignettes and the choice of students to research. This positions the reader to view metaphor as the emergent frame of reference in Chapter Three.

Relevant Previous Research

Previous Interpretive Research on Scientific Literacy

Interpretive research has been conducted on the development of scientific literacy utilising various types of laboratory experiences (Meichtry, 1992), collaborative problem solving (Palincsar, Anderson & David (1993), affirmative dialogue writing (Hanrahan, 1999) and a 'repertory grid' (Bezzi, 1999). There is a lack of interpretive research on scientific literacy that does not report on the

Roth (1993) engaged in action research utilizing the metaphor of a 'cognitive apprenticeship' in the planning and evaluation of teaching and learning in his own physics class. He rightly stated that 'one might expect to find instances of cognitive apprenticeship in our data sources... [and so] this form of analysis ran the danger of reifying the very concepts that should be subject to analysis' (p. 356). He therefore utilized a second level of analysis, conversational analysis, to overcome the bias of the metaphor-based analysis. My research did not utilize a second form of analysis, as the three metaphors did not inform or influence events that occurred in the classroom, in the way metaphor was intended to do in the studies by Thomas and McRobbie and by Roth. In these studies, the researchers utilized an a priori metaphor to facilitate an improvement in teaching and learning.

Tobin (1990) identified numerous metaphors that teachers used to guide their practice. He concluded from several research studies that metaphor can be utilized as a 'master switch' to facilitate teachers changing their roles in teaching and learning in the classroom (p. 6). Tobin and LaMaster (1995) utilized metaphor to facilitate change in teachers' practices. Connelly and Clandinin (1988) specified techniques to help identify personal metaphors that structure a person's experiences (see below). Some recent research suggested metaphor deeply structures our social meaning of philosophy and mathematics (Lakoff & Johnson, 1999; Lakoff & Nunez, 2000). I explored previously the use of two metaphors to make sense of four years of action research on scientific literacy (Willison, 1999). This research showed some potential to facilitate a dialectical tension between different notions of learning, concluding that 'it is important to have a framework that provides possibilities for dialogue about the differences. Metaphors, being perspective builders, and not statements of truth, can provide a framework which gives a common language for discourse' (p.124). This present research followed this utilisation of a metaphorical framework for scientific literacy and addressed a question that I raised in the previous research: 'are there other metaphors that can provide us with more useful ways of construing scientific literacy?' (p.124).

Research Question

The major research question was: *What are the effects of learning tasks in Science and in other subjects on student scientific literacy?* Student scientific literacy and the effects on it came to be understood in terms of the three-metaphor framework, as defined in Chapter Four. Therefore, whether students manifested the characteristics of student-as-recruit, student-as-judge, students-as-scientists, or otherwise, was the primary subject of the interpretation of vignettes. The vignettes were designed to illustrate students' active participation in the classroom, including their manipulation of equipment, conversations and writing. A secondary consideration - why students manifest the characteristics they do when engaging in a specific task - was the subject of interviews with students and their teachers.

Using the term 'task' is not unproblematic (Eisenhart, Finkel & Marrian, 1996; Posner, 1982). In previous research at Righschool, I had focused on planning types of classroom learning tasks that integrated 'hands-on' approaches with reading and writing (Willison, 1996). However, a variety of unexpected and sometimes disappointing student outcomes resulted (Willison, 1999).

In regard to analysing Science lessons, I focused on the hands-on experiences of students, and used Hackling and Fairbrothers' (1996) criteria for closed and open investigations to define 'tasks'. For these authors, investigations can be either 'closed' or 'open' in the three domains of problem determination, method used and solution arrived at. A fully closed investigation is one where the teacher determines the problem to be addressed, for instance by writing an experimental aim on the board, providing the steps to carry out the method, and having ready the answer that students should end up with. A fully open investigation allows students to pose their own novel questions, devise their own methods of answering these questions, and infer viable answers without 'fearing' that they have to find the correct one. Thus, investigations can be closed, partially open or fully open, in each of the domains. In this study, Science 'tasks' were analysed for the degree to which an investigation was open or closed.

Most Science lessons I observed that included investigations could be classified best as closed in all three domains. Therefore, one of the Science vignettes in each tale was based on a lesson involving a closed investigation, and so serves as an example of a typical science lesson. Hands-on investigations occurred in over 40% of all science lessons observed (65 forty-minute periods), and over 90% of these were closed (60 periods). However, very rarely (less than 10% of the time in Mrs. Breen's class (2 double periods), and less than 5% of the time in Mrs. Stubalm's class (1 double period), an investigation that was to some extent open was observed in each Science class. The most open investigation from each class was included in the other Science vignette of each tale. Including the two extreme ends of the spectrum of tasks in each classroom - one closed investigation and the most open investigation – resulted in the broadest range of student participation being portrayed, and, therefore, the broadest range of scientific literacy experiences being reported. It also resulted in both the synoptic and the unusual being represented, and in the research question constituting two sub-questions:

1. What are the effects of closed science investigations on student scientific literacy?
2. What are the effects of the most open science investigations on student scientific literacy?

As well, a third sub-question arose from the research question:

3. What are the effects of tasks in non-Science subjects on student scientific literacy?

Tasks in non-Science classes are, in this thesis, not defined, but rather left open to interpretation from the vignettes. Most of these classes were observed only once, and so provided merely a snapshot of life in those classrooms for the focus students. Non-Science lessons in either Vignettes Two or Four were included if, in one way or another, they contributed to an understanding of each student's scientific literacy.

Legitimation of the Research

What is an appropriate set of evaluation criteria to ensure the research is legitimate? Qualitative research of the first forty years of the Twentieth Century was conducted with a commitment to objectivism, finding out and reporting the perspectives, and 'the hidden realities', of those being researched. Denzin and Lincoln (1994) identified this perspective as the first of five 'moments' of qualitative research. The second, 'modernist', moment built on the canonical works of the first, but attempted to formalise qualitative methods. The third moment, beginning 1979, was characterised by 'blurred genres', with a full complement of paradigms, methods and strategies employed. In the mid-1980s began the fourth moment, the 'crisis of representation', and soon after, the fifth, defined by the double 'crises of representation and legitimation'. Each of these is still in operation today, so 'there have never been so many paradigms, strategies of inquiry, or methods of analysis to draw upon and utilise' (p.11).

In a recent development, a type of cognitive science ethnography by Lakoff and Johnson (1999) and Lakoff and Nunez (2000) utilised 'embodied realism' to consider the nature, pervasive influence and effects of conceptual metaphor (see Chapter Three). They argued that traditional forms of realism have created an 'unbridgeable ontological chasm between "objects," which are "out there," and subjectivity, which is "in here". Once the separation is made, there are then only two possible and equally erroneous, conceptions of objectivity: Objectivity is either given by the "things themselves" (the objects) or by the intersubjective structures of consciousness shared by all people (the subjects)' (p. 93). Their embodied realism rejects this dichotomy, but rather sees 'what has always made science possible is our embodiment, not our transcendence of it, and our imagination, not our avoidance of it (p. 93).

Whilst I admire and appreciate the viability of their claims, and have utilised metaphor as the frame of reference for this thesis (see Chapter Three), I also recognise the inherent complexities of mind, embodied in research with people. For example, I reject the notion of an objective and real 'scientific literacy'. The three metaphors of the framework each present a viable way of conceiving of scientific literacy, and are not objective realities of scientific literacy.

So, what minimum standard can I apply to my fieldwork and the reporting of it so a reader of this thesis may consider it to be a credible representation of an actual classroom? How can you, as the reader, judge the epistemic value of this thesis? I draw upon Chisholm's (1989, p. 22, cited in Fenstermacher, 1994) 'Thirteen Steps' for considering the epistemic status of knowledge claims, the first seven of which are, in order of decreasing confidence:

6. Certain
5. Obvious
4. Evident
3. Beyond Reasonable Doubt
2. Epistemically in the Clear
1. Probable
0. Counterbalanced

Fenstermacher (1994) says of these steps that:

> although for Chisolm, a proposition cannot be known until it attains the fourth positive step (evident) or higher, other epistemologists would entertain a proposition's having epistemic merit at the 'beyond reasonable doubt' level. At the fourth, or evident, step, the proposition meets modified standards for what is known as justified true belief. For other epistemologists, a claim is sufficiently justified to count as knowledge if it is reasonably believed by the holder, the holder having sufficient evidence to establish the claim against its competitors (p. 23).

How can I ensure this research attains, as a minimum standard, 'beyond reasonable doubt'? Or, as Denzin and Lincoln (1994) ask of any qualitative researcher, how will I legitimate my research and how will I represent my research? The legitimacy of the field work aspect will be considered first, and then, later, the representation aspect.

Credibility of the Field Work

I draw upon Guba and Lincoln's (1989) 'trustworthiness criterion' of 'credibility' to help you, the reader, determine the epistemic status of the fieldwork. This criterion is parallel to the objectivist 'internal validity' and so is relevant for evaluating the epistemic status of this interpretive field work. This is because 'instead of focusing on a presumed "real" reality "out there", the focus has moved to establishing the match between the constructed realities of respondents ... and those realities as represented by the evaluator' (p. 237).

Guba and Lincoln list six techniques as suggestions for 'increasing the probability that such isomorphism will be verified, or for actually verifying it' (p. 237). These techniques and the actual ways I approached them were: (1) prolonged engagement, where not only did I spend a full school year in participant observation of two Year 8 science classes, I also had previously engaged in three years of action research at the same school with the same year group; (2) persistent observation, by being involved with the same two classes all year and focussing on just four students, ensuring the most relevant elements of the research question were pursued; (3) peer debriefing, by engaging with a science educator friend who had no vested interest in the research, and with whom I discussed research issues and emerging understandings during both the research and writing up periods; (4) negative case analysis, evidenced especially in the interpretations at the end of Chapters Seven; (5) progressive subjectivity, evidenced elsewhere in this chapter, and in Chapter Ten; and (6) member checks, which varied in rigour from case to case, as explained later in this chapter.

A plurality of data generating techniques, including participant observation, videoing lessons, interviewing students and their teachers, and student work samples, all provided a rigorous triangulation (Cohen & Manion, 1994). In addition to the above techniques, the observation of non-Science classes provided information to help distinguish artefacts that were anomalies of Science classes alone, and those that were broader educational issues. For example, from my observations in Science, and my interviews with Tara and Shannon, I initially construed Tara's education to be described best as 'learning as fighting'. To my surprise, neither my observations in any non-Science class or interviews with any of her other teachers suggested anything but a sweet, well-behaved girl. Her argumentative attribute seemed to be a Science anomaly. The question was 'why?' Was it because Science stirred up her latent interests and desires to learn? Or was it because Science, or the class, or the teacher, frustrated her? The large range of data generation techniques, and the lengthy involvement with Tara, Shelly and their class, provided me with strong inferences as to why this might be the case. These multiple data sources are important, because this triangulation of results facilitated credible research. As Aldelman, Jenkins and Kemmis (1980) said, triangulation 'is at the heart of the intention of the case worker to respond to the multiplicity of perspectives present in a social situation' (p. 241, cited in Cohen & Manion, 1994).

You, the reader, are to evaluate the fieldwork component of this research by considering the strength of the 'match' between each subject's constructed perspective and my textual portrayal of it. Following are details of my research role as a participant observer, an aspect that makes visible to some extent how I constructed understanding in the field.

Participant Observer Research

Palonsky stated that participant observation allows the development of understandings by reducing the gap between researcher and subject, and that 'immersion to gain their perspective is the methodology' (1975, p. 89). However, as mentioned previously, gaining 'their' perspective is a problematic issue, due to the post-modern turn in qualitative research. Participant observation research had its origins in ethnographic research, namely anthropology. The foundational form of field work, as promoted by Malinowski (Van Maanen, 1995, p. 6), was to find out the typical, cultural ways of thinking and feeling, and to formulate the results in a most convincing way. The problematising of this practice led to the criticism of ethnographic realism 'from [people] outside ethnographic circles, who wondered just how personal experience could serve as the basis for a real bonafide scientific study of culture' (Van Maanen, 1995, p. 6). This discontent, and a heightened self-consciousness amongst ethnographers, led to emerging alternatives to the foundational, objectivist genre, such as 'confessional ethnography' (see below), which highlights the researcher's place amongst the researched.

When I engaged in full-time research in 1998, having taught at Righschool for the previous four years, I was already a well-recognized *participant* in the school community. However, the *power relations* of being 'less unlike his subjects' (Palonsky, 1975, p. 89) than in other forms of research were therefore an issue, because an ex-teacher, such as myself, researching twelve and thirteen year olds is quite unlike his subjects. This was a similar position to that of McPherson (1972) who adopted a participant observer rationale with a school she had taught at for five years, and of Thomas, a classroom teacher who conducted participant observer research (Thomas & McRobbie, 2001). This difference in status must be considered to have a significant effect on students in this present research, and indeed my involvement and influence on students is a feature of Vignettes Three, Four and Six, as well as their interpretations.

An advantage of previous familiarity was that I was well acquainted, at least tacitly, with Righschool culture and community, and students and staff were accustomed to my presence. This made it possible for me to start researching in Science classes from the first teaching day of the school year, and when I began to follow students into classes other than Science, my acquaintance with most of the teachers of other subjects facilitated an easy movement from classroom to classroom. Another advantage was that it became possible to gain fresh insights into very common events, making the familiar strange (Erickson, 1998). The actual type of participant observer role I adopted is presented next.

Three Nuances of Participant Observer

Palonsky (1975, p. 233) described three variations of the role a participant observer may take: *complete participation*, where the real purpose of the researcher is unknown to others, requiring a role pretense; *participant as observer*, in which case both the researcher and the researched are aware of the researcher's purpose and the participant observer attempts to be normal and acceptable to those he or she is researching; and *observer as participant*, with more formal observations necessitating that a distance is kept between researcher and researched. McPherson's (1972) research was in the category of complete participation, where, after having worked in the school for five years, she conducted research during her sixth teaching year at the school. She engaged in 'concealed participant observation' in a way that her 'colleagues did not know they were being studied and a dissertation written' (p. XI).

Like McPherson, I had previously been a participant in the school community that I was interested in studying further, and so could have found methods of concealing my observer status from the students, if not the teachers, involved in the study. However, I took on the role of being an obvious observer and requested permission from teachers, and from students and their parents, to conduct research on students' scientific literacy. I was often seen in class with a notebook in hand, on occasions video-recorded students, was involved in interviewing students and teachers, and also turned up in non-Science classes. Whilst there may have been some research benefits associated with remaining a secret observer, the ethics of the situation would not allow this. As McPherson asked: 'Can I avoid the ethical implications of my spying?... One hopes so, but there is the nagging sense of doubt' (p. 4).

I felt it was better to declare honestly my intentions to those I would like to research, and so I operated in Palonsky's (1975) second category, that of participant as observer. Cussick (1973) seems to be situated in this category, as he stated that he entered the research site by introducing himself to students as a researcher. 'However, as I gained increasing empathy with the group, I was accepted more as a member than as a researcher' (p. 233). I, too, shared his sentiment that acceptance by the people I was studying depended not on the explanations for my presence, but on the relationships I developed (Cussick, 1973, p. 7). The view of students' lives, less affected than might be the case for shorter-term or less empathetic research, speaks for the 'authenticity' (Guba & Lincoln, 1989) of this research. The Year 8 students tended to enjoy a good chat with me from time to time, especially about social issues. If they swore in the conversation they would sometimes recoil as if I was a teacher, and say 'you won't write that down will you?' At other times they would not seem to think about this issue. From time to time, students would come up and read my field notes as I was writing, to see if anything was written about them. They were free to do this, but were unlikely to be able to read my incredibly messy notes.

The Ongoing Analysis During the Research

Researching in the style of participant as observer, I necessarily tried to make sense of the students who were the focus of study. Erickson (1998, p. 152) stated that 'the plausibility of the author's final interpretation is greatly enhanced by showing the reader that the author's thinking did indeed change during the course of the study.' This 'dependability' (Guba & Lincoln, 1989) of the research is evident in the vignettes and their interpretations, as well as in the following presentation of how the research unfolded.

An ongoing research 'task is to discover and construct meaning in... [field] texts' (Clandinin & Connelly, 1994, p. 423). So, proceeding by 'analytic induction' (Erickson, 1998, p. 1164), I began to make tentative assertions about my field data during the time of focusing on Darrien, mainly in Term Two, 1998. I had decided that the use of metaphor as a means by which researchers assisted teachers to conceptualise (Tobin & LaMaster, 1995) could be usefully applied to my understanding of students' scientific literacy manifest in the science classroom. Connelly and Clandinin (1988) specified a technique for *identifying personal metaphors*, looking for rules that seem to direct student actions, looking for overriding principles that direct these rules, and then finding a guiding metaphor that unites the principles.

Initially, I recorded field notes of Darrien's actions and interactions in Science, and soon found rules, such as who to sit next to, when to work, and so on. This led me to think that a principle for Darrien seemed to be 'Fun start... fast finish'. When I followed Darrien into other subject areas, I found he followed this principle in most, but not all, subjects. In English and Social Studies he seemed to follow a 'do not get in trouble' principle. While I was 'reviewing evidence with my assertion in mind, revising the assertion in the light of evidence, and then reviewing the evidence again' (Erickson, 1998, p. 1164), I decided a metaphor that seemed to explain Darrien and his principles was 'communicating as fun'. After more recursive observations, I broadened this to 'life as fun', a metaphor which may seem at first glance to be too general to be of any significance in understanding a student's learning, but which turned out to explain satisfactorily much of Darrien's performance at school (see Chapter Nine for the significance of this metaphor to Darrien and his teachers).

Armed with the success of a metaphor for Darrien's learning, which I felt could inform me about his scientific literacy, I began to focus on Tara in the third term of the school year. Very quickly, I began to see patterns in her active participation in the science classroom, and soon believed I could understand these by the metaphor of 'learning as fighting'. I was surprised when I began to visit her other classrooms and could see, as mentioned earlier, no evidence, whatsoever, to suggest such a metaphor. Moreover, the three non-Science teachers whom I interviewed expressed that they had never seen any evidence for such a way of conceiving of Tara or ever thought of her in those terms, but rather found she was a quiet and cooperative girl.

This disparity between the Science observations and non-Science subjects made me stop and consider the value of a personal metaphor for each student. First, if a student seemed to need more than one metaphor to understand their participation at school, then any metaphor formed in Science classes alone was dependent on any number of unknown factors, such as interest in subject, classroom dynamics, relationship with the teacher, and so on. Obviously any of these factors could change and have a dramatic effect on the metaphor that best explained his or her actions.

Second, even if each student needed only one metaphor to understand his or her actions, the presence of up to 32 bodies in any Year 8 Science class meant that knowing each metaphor for each student was problematic. Better, I decided, to form assertions that explained, at the highest possible level, the greatest number of datum points (Erickson, 1998).

After the data gathering phase of the research finished, following the Term 4 observations on Jimmy and Shelly, the dilemmas of using personal metaphors made me consider an article I was writing for the Research in Science Education journal (Willison, 1999), which presented a mini-framework of two metaphors to understand the action research I conducted previously on the scientific literacy of students. The explanatory power of those two metaphors did not seem to be sufficient for the present research, and so I began to consider using a *three-metaphor framework*. This framework 'emerged' from a complicated mixture of reading Latour (1987, see Chapter Four), the metaphoric roots of the word 'science', and the writing of the above article. I originally devised three metaphor-couplets in the months after completing the field work:

1. Scientist as expert - student as (potential) protégé
2. Scientist as expert - student as confirmer/denier
3. Scientist as explorer - student as scientist

I immediately began to look at definitions in the scientific literacy literature, and found there was some 'fit', in that the three metaphor couplets could organise the literature definitions. Moreover, I started to interpret some of the more interesting vignettes and found some explanatory power when applying the framework. However, during peer debriefing, I was persuaded that the couplets were too cumbersome and incomprehensible, and so dropped the mention of scientists. Ultimately, I streamlined the framework until it contained the three metaphors presented in Chapter Three, and so 'working recursively back and forth between hunches and data' I arrived 'at new insights' (Erickson, 1998, p. 1165).

This framework of student-as-recruit, student-as-judge and students-as-scientists, presented so neatly in Chapter Four, emerged, therefore, in a more messy manner than suggested there. It now stands as a sieve of tales to make sense of the student scientific literacy found within. I chose originally to present only the tales of Tara and Shelly, as they highlighted the benefits of the framework, and demonstrated great explanatory power. However, the more problematic tales of Darrien and Jimmy are included in this dissertation, and they suggest, as you will see, that there are shortcomings in the framework.

Criteria of Representation

Earlier in this chapter, I mentioned the problematic notion of gaining the perspectives of those being researched. In addition, the representation of this perspective is also problematic. In addressing Denzin and Lincoln's first question about legitimating the research, the second question regarding representing it is concomitantly broached. This is to be expected, since these questions 'blur together, for any representation must legitimate itself in terms of some set of criteria that allows the author (and the reader) to make connections between the text and the world written about' (Denzin & Lincoln, 1994, p. 11).

As mentioned previously, I utilised vignettes written up from field notes to represent the field work. I utilised two genres in writing these vignettes, and a third genre for much of the rest of the thesis.

Three Writing Genres of Ethnography

This thesis utilises three of the ethnographic genres that Van Maanen (1988, 1995) described. These are 'realist', 'confessional' and 'dramatic' ethnographies. Realist tales are characterised 'by the almost complete absence of the author from most segments of the finished text', a strategy which is intended to reduce concerns about subjectivity. 'Only what members of the studied culture say and do and, presumably, think are visible in the text' (Van Maanen, 1988, p. 46). Confessional tales, however, move 'the fieldworker to centre stage and display how the writer came to know a given social world.' (Van Maanen, 1995, p.8). Dramatic tales 'reconstruct in dramatic form those periods the author regards as especially notable and hence reportable, and tries to keep both subject and object in constant view. The epistemological aim is then to braid the knower with the known' (p. 102).

In departing from the first and second 'moments' of qualitative research, mentioned above, elements of confessional and dramatic tales are utilised to depict the fieldwork. Fieldwork constructs are seen by many to emerge from a hermeneutic process, meaning fieldwork is more interpretive than observational or descriptive (Van Maanen, 1989, p. 93). Ways research is depicted should reflect this interpretive act, that is, by depicting the researcher as an integral part of the research. Therefore, I incorporated features of 'confessional ethnography' in the vignettes, which: (1) highlight my participation with the students, including disdainful attitudes and my attempts to understand, influence and help them (sometimes in ways that can be understood retrospectively as quite unhelpful); and (2) convey cultural information in a personal and historically situated fashion (Van Maanen, 1995, p. 9). In addition, I have utilised some features of dramatic tales, relating particular events 'of obvious significance to the cultural members studied' (p. 9) as unfolding stories, utilising various literary techniques.

Table 1

The purpose and application of three writing genres employed in this thesis

	Realist Genre	Confessional Genre	Dramatic Genre
Presence in Thesis	All but vignettes	Vignettes One to Six and parts of this chapter	Vignettes One to Six, especially Three, Four and Six
Researcher	Hidden, or I-as-researcher comments	Strongly present	One of the actors
Style	Propositional, logical, often ahistorical	Personal, historically situated	Personal, emotive, use of literary devices
Focus	Those being studied, and understanding them	The studied, the studier and their interactions	Dramatic unfolding of events and personalities
Epistemological Aim	Persuade through logical and credible information	Persuade using contextual, realistic and credible information	Emotionally involved for the sake of persuasion and to be memorable.

In keeping with a mandate to facilitate complementary usage of epistemologies, discussed in Chapter Three, this thesis is written utilising both a confessional genre and a dramatic genre in the vignettes and a more objectivist, propositional language genre elsewhere, 'holding these (incompatible?) styles in a dialectical tension' (Geelan & Taylor, 2001). Whereas the last genre provides a sense of propositional logic and coherent explanation, the first two serve quite a different purpose, as both features are important for transferability and verisimilitude, discussed below. Table 1 details the application of each genre in this thesis.

Transferability and Verisimilitude

In representing interpretive research, one important measure of usefulness is *transferability,* which involves criteria that determine the extent to which the case study helps readers to infer applications to their own educational situations. Transferability is somewhat parallel to external validity or generalisability. The transferability criteria include the presence of thick description, provision of vicarious experience, metaphoric power, and personal reconstructability (Guba & Lincoln, 1989, p. 206). 'The search for grand narratives will be replaced by more local, small scale theories fitted to specific problems and specific situations' (Denzin & Lincoln, 1994, p.11). This report is written primarily for those involved in educational research with teachers and for teachers themselves. Confessional and dramatic tales *impress* upon the reader certain ideas from the research, and as such can be useful tools to facilitate transferability.

Another criterion to assess the quality of the tales is *verisimilitude*, which asks 'are the representations in the text consistent with the real situations that exist in science classrooms?'(Denzin & Lincoln, 1994). To see if the tales fulfill the criterion of verisimilitude, you, the reader, may ask the questions; 'are the characters in the vignettes believable?' and 'do the experiences depicted ring true from your own experience?' In attempting to facilitate verisimilitude, I have tended to present chiefly the active participation of students, including physical engagement, speech and writing of students. This is so a reader can more readily identify with a representation of a classroom as they would encounter it, that is, through their own eyes and ears, rather than, say, through the perspective of students' inner thoughts.

Guba (1990) recognised four different types of imbalances in positivistic social science:

1) The imbalance between rigor and <u>relevance</u>: the better controlled the research setting, the less the findings fit actual situations.
2) The imbalance between precision and <u>richness</u>: precision provides prediction and control, whereas richness requires a depth of description.
3) The imbalance between elegance and <u>applicability</u>. Parsimonious theories are often very generalisable, but do not fit or apply to local situations.
4) The imbalance between verification and <u>discovery</u>: wherein theories that survive falsification take precedence over discoveries (pp. 21-22).

Verisimilitude criteria require the balance to shift towards relevance and richness, because, without these qualities, readers could not be induced to see the stories as believable. Transferability criteria demand a shift to richness, discovery and, especially, applicability.

I chose to write up the 'primary data' from the research, my field notes, as vignettes - the secondary data - to keep both the subject and object in view, in keeping with interpretive research (Erickson, 1986; 1998). Taylor (in press) used dramatic genre to depict his research on two educators' personal styles, and noted the significance of such texts in interpretive research 'is to establish a particular dialogic, or educative, relation with the reader... [which] engages, involves and requires a thoughtful response' (Taylor, 1997, p. 10). These texts do not define issues, but rather raise questions in the readers' minds.

Next, I will consider the means by which I began to make sense of my field notes and chose what became research text (Clandinin & Connelly, 1994) out of the corpus of possible data (Erickson, 1998).

The vignettes representing this research

The role of researcher is written very specifically into the text of the vignettes in this thesis. This feature enables the reader to identify some of the pervasive influences of the researcher on the researched. What is the epistemic status of the tales included in this research? Even though they have elements of dramatic control, I ensured that words 'put in subjects mouths were in fact spoken by those subjects. The ethics of textual production argue for the meticulous checking of verifiable facts; that one must be certain that statements depicted as quotes were in fact made. But more important, the ethnographer must take care when changing contexts and reordering events for dramatic purposes.' (Lincoln & Denzin, 1994, p. 578). Although I employed dramatic strategies on occasions, for their value for transferability and verisimilitude, I ensured that all statements in each vignette were written as I recorded them in field notes, maintained the context as I encountered it, and kept intact the chronology of the situation. Moreover, vignettes were provided to all participants (except Jimmy) and they did not express any desire to change comments or actions attributed to them. During the taking of field notes in Tara's and Darrien's class, I attempted to write down exactly what I heard in conversation. A similar use of field-notes occurred for Shelly's and Jimmy's class (except for Vignette One), in which I transposed directly dialogue from audio-visual footage.

Observing above criteria ensured that the tales of this research constitute a legitimate representation. Confessional tales convey 'a good deal of the same sort of cultural information and speculation put forth in conventional realist works, but in a more personalized and historically situated fashion' (Van Maanen, 1995). The big difference between realist vignettes and those in this research is that, implicitly (in the story itself) and explicitly (in interpretations of the story), the latter acknowledge the researcher's interactive presence, role as sense-making interpreter and pervasive influence on those being researched. 'The work at the coal face of ethnography goes on therefore in much the same way as it did before textuality came into vogue. Evidence must be offered up to support arguments whose pedigree must be established in a way that will convince at least a few readers that the author has something credible to say' (Van Maanen, 1995, p. 23).

I suggest the vignettes in this thesis are epistemically on the same level as realist tales because, in this case, they are attempts to record 'what actually happened', yet they highlight simultaneously researcher bias and influence. For example, as participant, I am presented as influencing the direction that students take in experimentation and in dialogue, and the explicit placement of researcher-in-text situates me as more than just a participant, but also as a learner, forging understanding of events as they occur. Moreover, a significant part of that influence is my role as editor, which functioned at three levels: what to record in field notes out of all the possible events; the selection of what comments and actions to focus on from the fieldnote conversion to vignette; and the choice of six vignettes out of a corpus of dozens, plus dozens more potential, but unwritten, ones.

Therefore, the interpretive act began with myself-in-classroom, continued with recording of field notes, writing of vignettes, selection of salient vignettes and rewriting of vignettes. Furthermore, the research was interpretive in that it utilised student interviews to provide students' perspectives of their participation in the classroom. Moreover, my warrants that the vignettes are credible representations of the classrooms they depict are based on the triangulation of these with students' and teachers' perspectives. That is, they are not intended to objectively represent real, historical incidents, but rather my involvement with, and understanding of, these incidents, plus the understandings of significant other participants.

In the two tales, my voice is not as expressive and dynamic as Van Maanen's (1988), not as reflective and self-revealing as Geelan's (1997a), and not as personal as Taylor's (in press). My voice aims, yes, to strongly braid in the strand of my participating, observing presence, yet it seeks to emphasise the students and their scientific literacy. The result of quoting verbatim is to limit the blurring of the knower with the known, and so to allow some discernment of each braid in the whole plait. In these tales, I have backgrounded the teachers and most members of the classes, in order to highlight focus students, their work partners, and often my interaction with them. This facilitated the main purpose of the research: to deepen understanding about scientific literacy in the classroom.

In the writing of the vignettes, I adopted Van Maanen's (1988) suggestions of literary devices for the writing of dramatic tales, which included: *fragmented knowledge*, where a novelistic style allows events to unfold in a way that shows my own learning process; *characterisation*, meaning that emotions are expressed, rather than objective disinterest portrayed, and that characters have names, motives and lines to speak; and *dramatic control*, which requires the use of present tense, contextual descriptions, fresh allusions, emotional stimulation and not giving away endings.

Choice of Students to Research

Participant observation in two different science classrooms meant potential access to about 55 students. The first issue to consider was how to address the research question about learning tasks affecting student scientific literacy? I spent the first term (ten weeks) in both classes, more as participant than observer, becoming acquainted with the class culture, dynamics and structure, much like Hanrahan's (1999) research on scientific literacy. At the end of the first term, when I felt I had Mrs. Stubalm's students' confidence, I asked them if they would be willing to take part in the research and, if so, to request their parents to sign a permission note. At that point, I was considering taking the whole class as a unit of study. However, only ten students returned permission slips signed by themselves and their parents, and so I was unable to research the whole class, but rather was forced to consider either smaller groups or individuals.

Of the ten students who returned notes, Darrien had stood out as a major contributor to classroom discourse, and as being able to communicate easily with me. Darrien was one of the academically less successful boys, in the same class as Tara, and often worked on his own agenda. Therefore, I began to focus on ways that learning tasks were affecting Darrien's scientific literacy, including his interaction with his regular work partner, Kevin. In many ways, Kevin was as involved in the research as Darrien, as his voice is often recorded in vignettes, he was in most of Darrien's non-Science classes, and he was present and participating in the interviews I conducted with Darrien. However, the interpretation focuses on Darrien, and Kevin's role becomes one of providing context and insight into understanding Darrien. Taylor (1987) tracked an 'exemplary teacher' through her school day in an early stage of his research to gain a sense of familiarity and to situate the teacher in the whole-day context. I adapted this idea, and began to track Darrien, not through a school day, but into various non-Science classes that he attended, in order to gain insight into his whole-school context.

Darrien and Kevin usually sat at the second-last desk in their Science lab, and so one of the best places to observe them in Science was the back corner of the room. However, this put me into close contact with Tara and Shannon, who sat at a rear desk. Whilst focusing on Darrien, it seemed that the academically more successful Tara participated in classroom activities in a way that was significantly different from his participation. Tara was reputed by her Science teacher, Mrs. Stubalm, to have been one of the brightest students in her class. Tara's class, however, was considered to be the lowest in terms of academic ability of the four Year 8 classes at Righschool, which meant that it was highly unlikely that she would make it into the ranks of those who are classified as scientifically literate. Moreover, since the two groups of students were proximal, it made it possible to focus on Tara, and yet keep Darrien in the background of my observations, a strategy I continued to pursue during Terms Three and Four. Darrien was also in most of Tara's non-Science classes, because they were in the 'lowest stream' of Year 8 at Righschool.

During Term One to Term Three, I maintained a more-participant-than-observer status in Mrs. Breen's Year 8 Science class. This was because my focus on Darrien in Term Two and Tara in Term Three occupied much of my time due to: vignette writing, following the student into other non-Science classes, and conducting interviews with the focus student and his or her teachers. In term four, I chose to focus on a boy and a girl in Mrs. Breen's class, thus obtaining a gender mix that reflected the Year 8 cohort at Righschool. Unlike Tara and Darrien, who were chosen from a limited number of those who returned permission slips, I selected purposively Shelly and Jimmy out of the 32 students in their class. I asked both students for permission to be a focus of my research after observing their participation in class for three terms.

Shelly demonstrated an interesting and intelligent scientific literacy that seemed quite different from Tara's and Darrien's. Shelly was considered by Mrs. Breen to be one of the top students in her class, the second of four academically-ranked Year 8 Science classes. Jimmy, a student who participated in Science in a manner very different from Shelly, received low grades for science and often was getting into trouble. Therefore, the four students were chosen progressively, and in a manner that attempted to identify quite different types of scientific literacy, as this provision of a range of cases is a purpose of qualitative research (Erickson, 1998). Tara, Darrien and Jimmy could be representative of the ninety-plus percent of the population who never seem to make the grade in a scientific literacy sense.

The narrowing of choices that compelled me to generate case studies of only four students was, it seems in retrospect, fortuitous, because the experiences of students in the context of scientific literacy seemed so diverse in each class that a class-wide case study would yield little clear, educationally significant understanding. The finer focus yielded, I believe, educationally more salient results. Ritchie, Tobin and Hook (1995) conducted a participant observer study in a Science class, and concentrated on one student's perception in order to provide the necessary detail for educational relevance. I, too, found it worthwhile and a source of rich understanding to conduct case studies at the individual student level. Ultimately, the choice of Tara, Darrien, Shelly and Jimmy provided tales and interpretations that depict as large a range of scientific literacy personas and experiences as I could find within the limitations of the research. Added to these students are their work partners, Shannon, Kevin, Katie and Adrian, who, whilst not students-of-focus, nevertheless have an important role and voice in the vignettes, and who provide further opportunities for you, the reader, to apply the metaphoric framework. The actual structure of the two tales about these students follows.

The Form of the Tales

Both tales are composed of three vignettes: the first and last are set in Science, and the middle vignettes are set in English, Mathematics and either Social Studies or Italian. As mentioned earlier, each tale contains one vignette of a science experiment that was more open than closed. This was an event witnessed rarely in either class: only observed once in Tara's and Darrien's class, and twice in Shelly's and Jimmy's class. These vignettes were included as they convey poignantly what could be, yet rarely is. They are important to include because they provide some sense of the range of experiences, and the more unusual events make the story 'worth telling' and more memorable (Van Maanen, 1988, p. 102)

The other Science vignette in each tale shows occasions in which teachers provided experiments that were more closed than open. These more common-place events also have their own poignancy, especially because they are part of mundane classroom life, and the responses of Tara, Shelly, Darrien and Jimmy to these events were vastly different.

For the non-Science vignettes, I included classroom encounters that seemed to have relevance to understanding each student's scientific literacy. All six vignettes provide very little sense of what types of previous activities led up to the lessons depicted in the vignettes. This is significant, because students seemed to encounter sometimes lessons in curriculum isolation, not recognising the links between lessons that teachers may have intended as obvious (see Chapter Ten). By omitting this aspect, I have highlighted the more immediate curriculum context: how non-Science classrooms rather than the previous Science classes affected each student. Most important, by using confessional, occasionally dramatic, vignettes, I had hoped to make the 'data' of the research readable, relevant to a broader-than-just-Science context, and more memorable, interesting and engaging, allowing transferability of aspects to other researchers' situations.

Interpretations using the three-metaphor framework follow immediately each vignette, which are found in Chapters Five to Ten. These interpretations are intended to provide a scientific literacy perspective. Obviously, a variety of interpretive frameworks could have been used which considered completely different perspectives on scientific literacy, such as those pertaining to gender and culture. Tobin and LaMaster (1995) stated that, in their study, the two researchers had different interpretive frameworks throughout the study, and these different perspectives influenced their interpretations of their vignettes. In fact, one strength of using vignettes is the potential for other researchers to use them as a source of primary data for further interpretation from a different orientation. For example, a feminist interpretation may consider salient the fact that I chose two girls who were academically more successful in their science classes, and two boys who were at the lower end of the success scale. This may be interpreted as an attempt to suggest subtly that gender equity issues have been redressed by the end of the Twentieth Century by using a blatantly staggered sample of students. Rather than intending the interpretations to limit understanding of the classrooms represented, I hope they can be a starting point for intelligent contemplation. I could not rely on the vignettes, themselves, to address the research question about affects of learning tasks on student scientific literacy, but needed some form of interpretation to achieve this (Erickson, 1998).

Member Checking

Tara, Shelly and Darrien underwent more thorough member checking than did Jimmy. The procedure I followed with the first three students included: writing of vignettes based on field notes immediately after class; providing the vignettes to the focus students, their work partners and to their Science class teachers; interviewing focus students, accompanied by their work partners, about Science and other subjects in general and about specific events that were detailed in the most salient vignettes; interviewing Science teachers, and the teachers of non-Science subjects that I attended; allowing the preceding techniques to shape the vignettes; and, finally, providing the focus students with the polished versions of the vignettes and, several days later, interviewing them about these representations. In the case of Tara, she and Shannon (her partner in Science classes) requested nothing be changed in the vignettes, but insisted that an amusing incident about Shannon (see Vignette Six) be inserted, and, in addition they suggested their own pseudonyms to be used in the vignettes. Mrs. Stubalm was provided with vignettes about her science classroom soon after they were written, and I asked her to suggest a title for the last vignette. She entitled it: 'You can't make them listen'. She, too, had the opportunity to remove, change or add anything as she saw fit, but was happy for the vignettes to remain unchanged.

However, with Jimmy I was unable to conduct 'member checks' due to time constraints of the research. Yet, the tale and interpretation about Jimmy are credible to some extent due to the techniques of prolonged engagement, persistent observations, peer debriefing, negative case analysis and progressive subjectivity. I suggest that they are, epistemically, at Chisolm's level three (see earlier), where I (the holder) believe the knowledge claims, and have sufficient evidence to establish the claim against its competitors. Therefore, the parts of Chapters Five, Six and Seven about Jimmy have a credibility that is 'beyond reasonable doubt'. Disconfirming evidence for tales and interpretations will be considered at the end of Chapter Seven and Chapter Ten.

Summary

A methodology in keeping with participant as observer was employed to make sense of four Year 8 students' scientific literacy. Extended and persistent observation, peer debriefing, negative case analysis, progressive subjectivity, member checking, participant interviews, teacher interviews and observations in other relevant contexts were used to make the field work credible. One tale for Shelly and Jimmy, and another for Tara and Darrien, both composed of two Science vignettes and one non-Science vignette, were written. These tales were written in a confessional and a dramatic genre to help make the research report fulfill transferability criteria and the criterion of verisimilitude. Having discussed the methodology of the research, I present in the following chapter metaphor as the frame of reference for this thesis. I have presented the methodology before specifying my frame of reference, because metaphor emerged 'post hoc' as the unifying concept of the thesis. Clarification in my own mind as to what I meant by 'metaphor' occurred well after the development and preliminary use of the three-metaphor framework. Chapter Three stands as a justification from the literature about my adoption of metaphor as a frame of reference in this thesis.

Chapter Three: Metaphor as Frame of Reference

Chapter Three
Metaphor as a Frame of Reference

Objectivism, personal constructivism and social constructivism seem to be highly significant influences on the various notions of scientific literacy (see Chapter Four). The purpose of this chapter is to present a complementary view of these three concepts, and, especially, to indicate metaphor as a *frame of reference* from which basis each may be held in dialectical tension with the others. Firstly, calls in the literature for differing perspectives that impact education to be considered, not as mutually exclusive, but as different insights into the learning process, are presented. Then metaphor is defined in three different ways, each of which reflects one of the above epistemologies. This lays the groundwork to define what objectivism, personal constructivism and social constructivism mean in this thesis. From this basis, devising a metaphoric framework is suggested as an appropriate course of action to provide the range of perspectives of scientific literacy. It must be remembered that the following notions about metaphor emerged progressively during the course of the research and writing-up phases, as pointed out in Chapter Two.

Complementary Perspectives

Notions that have significantly influenced conceptions of scientific literacy include objectivism (e.g., Bowyer & Linn, 1978; Cannon & Jinks, 1992; Dulski, Dulski & Raven, 1995; Mitman, et al., 1987; Zuzovsky, 1997), personal constructivism (e.g., Hand, Prain, Lawrence & Yore, 1999) and social constructivism (e.g., Anderson, Holland & Palincsar, 1997). Therefore, before dealing with scientific literacy itself in Chapter Four, I first deal with the issue of how these different positions that inform scientific literacy may operate, not in a competitive manner, but in a complementary one. Amongst the science education literature, there is an agenda for objectivism, personal constructivism, and social constructivism, amongst others, to be useful, complementary, mutually perspective-building ways of informing educators about learning:

> With regards to the different views of learning, we believe that rival positions emphasise different aspects of the learning process. Further research should not focus on the differences, but present an inclusive view of learning and conceptualise the different positions as *complementary* [italics added] features that allow researchers to address the complex process of learning more adequately than from a single position (Duit & Treagust, 1998, p. 3).

This thesis takes up Duit and Treagust's call to 'present an inclusive view of learning' which depicts 'the different positions as complementary'. Dewey provided a suggestion about how this view could be developed:

> It is the business of an intelligent theory of education to ascertain the causes for the conflicts that exist and then, instead of taking one side or the other, to indicate a plan of operations proceeding from a *level deeper and more inclusive* [italics added] than is represented by the practices and ideas of the contending parties (Dewey, 1938/1963, p. 5).

Dewey's main point relevant to scientific literacy in the early Twenty First Century is that a plan of operations must work from a deeper and more inclusive level than that represented by, in this case, objectivism, personal constructivism and social constructivism. However, he promoted *an* intelligent theory (singular), whereas Duit and Treagust specify 'positions' (plural), and it is plurality that is significant for complementary notions. These ideas, taken together, suggest a search for understanding from a deeper level that informs all the competing notions.

In a similar, inclusive and complementary vein, Taylor, Gilmer and Tobin (2001) called for the 'development of a *repertoire of referents* [italics added], including both those associated with objectivism and constructivism'. Their use of the word 'referents' relates to each as a relevant, informative position from which to view learning (Tobin & Tippins, 1993). Denzin and Lincoln drew on the metaphor of a *bricoleur* when discussing this notion of complementarity of referents: 'The researcher-as-bricoleur-theorist works between and within competing and overlapping perspectives and paradigms' (1994, p. 2). The notion of utilising a diversity of perspectives has been presented also by Taylor (1999), who conceived of the variety of constructivisms as forming together an n-dimensional polyhedron, and by various authors, such as Bloland (1989), Cobb (1994), Loving (1997), Reigeluth (1991) and Wildemuth (1993).

The complementary view presents objectivism, personal constructivism and social constructivism as being different tools in the one toolbox, as different 'ropes' that an educator may hold in dialectic tension. '*Communication* is the formation of a *community* of people who to some extent hold the same view' (Sutton, 1993 p. 1218), and in this case there needs to form a community who desire different viewpoints to complement one another, and who find ways to make dialogue meaningful. However, this complementary view is in conflict with the battle for a superior theory of learning, where there are 'culture wars' and the 'trenches have been deeply dug' (Kitcher, 1999, p. 26).

Is Dewey's dream of an 'intelligent theory of education' to 'ascertain the conflicts' and be able to work 'from a level deeper and more inclusive' than other theories possible? Geelan (1997b) expected that no 'metatheory' for uniting competing viewpoints will be developed, and, given the various ontologies and variant orientations of the competitors, this seems quite likely to be the case. The search for a superior theory, however, has an appealing parsimonious quality and many educators hold a view of educational theories competing with one another until the most superior reigns.

Competitive View

A competitive view generally depicts one conceptual framework as superior or inferior to others. From an objectivist perspective, Kragh (1998) stated her case against constructivism by saying it was 'philosophically unsound', had 'weak empirical support', was 'subversive ... to honesty and critical thought in general' and was 'a frontal attack on the entire edifice of science' (p. 242). From Kragh's perspective, objectivism, in the form of good science education, is competitive with, and superior to, constructivism. On the other hand, Guba and Lincoln (1989), from a constructivist perspective, abruptly said the objectivist paradigm 'needs to be replaced' (p. 43). From their perspective, objectivism was inferior. The fighting is not, however, exclusively between those favouring an objectivist referent and those favouring a constructivist one. Gergen (1995) stated that, from the perspective of social constructivism, the way earlier forms of constructivism depicted the mechanism of communication was a 'pitiful accomplishment' (p. 28). O'Loughlin went further to promote the superiority of social constructivism by claiming 'that the universalist, rational, disembedded thought valued by Piagetian [personal] constructivists is ... ideologically bound and must be rejected in favour of a more suitable ideology' (1992, p. 809). Fosnot, from a personal constructivist perspective, countered this argument and claimed that the social constructivist model was 'nihilistic, culturally relative, and dangerous' (1993, p. 1189).

In all of the references cited above, each author presents a competitive notion of a superior theory versus an inferior one. See Loving (1997) for a useful summary of the conflicts between objectivist and postmodernist perspectives. Even in Cohen and Manion's call for the utilisation of different learning theories in research, the underlying suggestion was about finding a superior theory: 'Few published works... discuss alternative theories after a study.... The investigator should be more active in designing his research so that *competing theories can be tested*' [italics added] (1994, p. 239). This is a notion of one theory versus another in the same research context.

There are three possible paths, at least, that lead from the notion of objectivism, personal constructivism and social constructivism as referents for *theories* of learning. One possibility is that 'paradigm wars' (Kitcher, 1999) will continue whilst ever people endeavour to understand learning. This means that competitive research programs will continue to provide conflicting opinions about the learning process. This does not seem to be a helpful way to inform educators about learning.

The second possibility is that one theory begins to out-compete other theories, and so the lesser ones will be rejected in the face of the most viable theory. The third possibility finds its precedence in the 'particle-wave' duality theory. In the early Twentieth Century, two competing theories about the nature of light - one that light is a particle, and the other that light is a wave - fought for pre-eminence over several decades. Both had viable research programs with predictive power, and both specified the other theory could not be correct, as they were mutually exclusive. Stepansky suggested that an important element was not the 'incompatibility itself, but actually coming to terms with ambiguity in science. For, in the end, ambiguous and vague interpretations of the same phenomena became part of science, where science was supposed to give a clear and unambiguous description of nature' (1997, p. 375). The ambiguous nature of light required that the term 'duality', from the sphere of philosophy and religion, be imported to explain the consensus that scientists eventually reached: light can be better considered, in some situations, to act as a wave, and in others to act as a particle. With this historical precedent, it is conceivable that theories of learning may ultimately fuse as an 'objectivism-constructivisms' plurality.

The latter two notions, I believe, are unlikely, due to the varying ontological perspectives of the different theories. For example, whereas objectivism and personal constructivism could be said to have a more realist ontology, social constructivism has a more relativist one (see later in this chapter). It is more likely that, by subscribing to the notion of educational 'theories', conflicts will continue indefinitely. Therefore, in order to facilitate a complementary notion, a different view of the relationships between objectivism, personal constructivism and social constructivism needs to be forged.

Objectivism, Personal Constructivism and Social Constructivism in Dialectic Tension

How may divergent, seemingly mutually exclusive, concepts be conceived of as functioning in a complementary manner? The sense of *complementary* features should not suggest only that there are similarities, but also must recognise and deal with contradictory features. These contrary aspects, that must be held in tension, are huge obstacles to complementarity, and include such issues as disempowerment versus empowerment, Truth versus relativity, and objectivity versus subjectivity.

The critical feature of any undergirding concept is that it must facilitate dialogue between competing ideas. This may not include dialogue with those who choose to pursue epistemological narrowness. However, the ability to communicate may open up a discourse amongst a significant proportion of educators who do not have a strong affinity for only one particular referent. Resulting dialogue needs to promote the differences between objectivism, personal constructivism and social constructivism as useful alternative facets of insight into the complex process of learning. If two quite contrary notions, held in dialectical tension, are necessary to understand the nature of light, as mentioned previously, then how many different referents may we expect to hold in dialectical tension to understand the complex human behaviour we call 'learning'? For education to focus sometimes on the phenomenon being learned about, other times on the processes inside a learner's head, and still other times on the social milieu a learner is immersed in does not seem to be a wild stretch of the imagination.

If the concept of 'theory' is bound to cause competition, what other concepts can come from a level 'deeper and more inclusive' to provide a complementary sensibility? Bloland suggested *irony* 'as a guide for illuminating the path towards acceptance of a multiple realities sensibility' (1989, p. 541). As mentioned previously, Denzin and Lincoln (1994) drew on the metaphor of a bricoleur when discussing this notion of complementarity. I now present why, in this thesis, the deeper and more inclusive level I make use of is the realm of metaphor. Before I suggest ways in which objectivism, personal constructivism and social constructivism can be considered as metaphoric, I first need to specify the nature of 'metaphor' as a concept.

Metaphor

Perspectives on Metaphor

Three prevalent views of metaphor are Aristotlian, conceptual metaphor and situated metaphor, each of which are explained below.

Aristotlian

The very common 'Aristotlian' definition of metaphor is 'a figure of speech in which a thing is likened to another, to which it is not literally applicable', or 'a carrying over' (Klein, 1971, p. 461). When a word is moved out of its usual, literal context, into a different, literally improper context, then this word is a metaphor. In this view: metaphor is a borrowing; the borrowed meaning is opposed to the proper meaning, that is, to the meaning that really belongs to a word by virtue of being its original meaning; one resorts to metaphor to fill a semantic void; and the borrowed word takes the place of the absent proper word where such exists (Ricouer 1977, p. 17).

However, many authors have found that the Aristotlian view provides a restricted or even misleading view of what metaphor is. One of the restrictions of Aristotle's concept is that it applies only at the level of 'word'.

Conceptual metaphor

Lakoff and Johnston (1980), Ricoeur (1977) and Seitz (1999), amongst many others, have conveyed the sense of metaphor pervading, even structuring to a large extent, our everyday language. Lakoff and Johnson (1980), in their book 'Metaphors we live by', state:

> Metaphors ... are not random, but instead form coherent systems in terms of which we conceptualise our experience (p. 41). We claim that most of our normal conceptual system is metaphorically structured; that is, most concepts are partially understood in terms of other concepts (p. 56). [And] ... consistent detailed metaphorical structure is part of our everyday literal language... so familiar that we would normally not notice it. (p. 43)

This suggests that metaphor is 'hidden' in our everyday encounter with language and that without metaphor, it would be very difficult to conceive of any but the most simple ideas (Lakoff & Johnson, 1980), and certainly not scientific concepts.

However, more significantly, these authors considered our whole conceptual system to be metaphorically based. 'The mechanism by which the abstract is comprehended in terms of the concrete is called *conceptual metaphor*' [italics added] (Lakoff & Nunez, 2000 p. 5) and this perspective considers metaphor to be the framing element of our understanding. Lakoff and Johnston (1999) stated that the structure of the brain and the sensorimotor system, and its situatedness inside human bodies, determines largely the nature of conceptual metaphors. They cite evidence that, whilst metaphors vary from culture to culture, language to language, there are basic characteristics in common that must therefore be symptomatic of our brains' embodiment. 'These conceptual metaphors are independent of language but motivate the meanings of many verbal metaphors and provide coherence to linguistic expressions' (Gibbs, 1992 p. 572).

In this view, the sensory system-based metaphoric structure of cognition is the framework from which hangs most, if not all, metaphoric concepts. It is the capsule that holds the meanings that resonate with language forms: 'For the most part, human beings conceptualise abstract concepts in concrete terms, using ideas and modes of reasoning grounded in the sensory motor system' (Lakoff & Nunez, 2000 p. 5) and from 'sensory-motor experience' (p. XII).

Considering metaphors based on the sensory-motor system, 'that's a clear argument', 'what's your outlook?' and 'I've got the picture' are literal examples that are: 'often seen as classic cases of dead metaphors' (Gibbs, 1992, p. 574). But these expressions are representative of metaphorical systems of thought that are very much alive. This is a 'metaphorical mapping of our knowledge about human vision onto the domain of understanding or knowing' (p. 574). They are examples of conceptualising and talking 'about intellectual activities in terms of vision (i.e., understanding is seeing) and this partially motivates why we talk about understanding or knowing in terms of seeing something'.

Gibbs stated that, amongst Indo-European languages, there are very few exceptions to words that mean 'see' coming to mean 'know'. 'The understanding is seeing metaphor, along with most other conceptual metaphors, actually motivates word meanings to change to become polysemous in regular ways that make sense to us as speakers' (p. 574).

Gibbs (p. 572) stated four kinds of evidence for the metaphorical nature of everyday thought: many literal expressions systematically come under a basic metaphorical system of understanding; conventional metaphors can be readily elaborated on; polysemous words, those that have multiple meanings, seem to be related to each other in terms of family resemblances; and psychological evidence.

Some who hold a conceptual metaphor view consider the Aristotlian tradition to be rather impoverished because it restricts understanding of metaphor to the level of word, and that 'Aristotles theory of metaphor was taken for granted so long that it came to be thought of as a definition' (Lakoff & Johnson, 1999, p. 124). These authors consider that the idea of the metaphoric structuring of much of the sub-conscious realm of the embodied mind provide a far deeper understanding of metaphor, of our immersion in it and our utilization of it in most thought, conscious or unconscious.

Situated metaphor

Another perspective on metaphor, more focused on interpersonal communication, was suggested by Eubanks: 'It is a simple but powerful idea, the idea that all utterances are always in dialogue with previous and future utterances. This recognition of language interconnectedness should cause us to reconsider nearly all that has been previously said about metaphor' (1997, p. 185), including Aristotelian and conceptual metaphor. Eubanks considered the Aristotelian view of metaphor as a two-part expression - something is something else – as being fundamentally flawed and leading to a wrong understanding about metaphor. 'Because a metaphor has two main discursive locations - the place where it has been and the place to which it has been transferred - it is necessarily composed of two parts. Had Aristotle continued to think about the discursive locations themselves rather than the duality they suggest, he might have come to different conclusions about the way metaphor works' (p. 173).

Context, then, is the hallmark for Eubanks in making sense of a metaphor. Where the metaphor came from and where it was going to are as important as the parts that make up the metaphor. He provided examples of metaphors, such as 'man is a wolf', that mean different things when applied to different contextualising conversations, and so his suggestion is that metaphor is highly dependant on language and cultural effects.

Complementary

Not surprisingly, the Aristotlian view, the conceptual metaphor view and the situated metaphor view jostle for supremacy, much like the competition specified earlier in this chapter. Furthermore, it is not surprising that these views have certain epistemological allies: the first with objectivism, as it provides a clear distinction between literal and figurative language, between objectivity and subjectivity (Lakoff & Johnson, 1999); the second view resonates with personal constructivism, as it has emerged from cognitive scientists, who, whilst acknowledging the pervasive influence of language, focus primarily on internal cognitive structures (Lakoff & Johnson, 1999); and the third with social constructivists, as the social/cultural/linguistic milieu provides the context for understanding metaphor (Eubanks, 1997).

Whilst Eubanks says '...we must discard persistent, misleading theories of metaphor' (1999, p. 172), again I am suggesting that a complementary understanding is more helpful. For example, the metaphor 'red herring' arose from a situated historic usage, which has been passed down as a byword for 'misleading'. Red herrings were used in the training of bloodhounds in Britain in the nineteenth century to develop the dogs skills at staying with the correct scent (Readers Digest Association, 2001). Each concept of metaphor can provide a reasonable and different understanding of 'red herring'.

Any one position provides some, but not all, of the insight into what metaphor is. Each concept is useful for understanding how metaphors may form and why they function as they do. I take each of these views of metaphor to provide a range of understanding about the properties and mechanisms of metaphor, at the level of word, of embodied mind and of socio-cultural interaction.

Metaphor as a Frame of Reference

Two ideas discussed earlier - Duit and Treagust's (1998) inclusive and complementary view of learning, and Dewey's (1938/1963) deeper and more inclusive level - resonate well with Agin's call for 'a frame of reference ... to help consolidate and summarize the many definitions of scientific literacy' (1974, p. 405). For the purpose of this thesis, a frame of reference is needed that promotes a complementary view, comes from a level deeper than objectivism, personal constructivism and social constructivism, and can therefore consolidate and summarise the range of concepts about scientific literacy.

What is a 'frame of reference'? Picture frames, door frames, window frames and reference frames all do the same thing, except the latter does it metaphorically. Frames provide a boundary where the picture, opening, glass or reference extends no further. Therefore, the metaphorical version provides an understanding of a boundary, a limitation of how far a reference's influence may extend. For example, personal constructivism is utilised by some as a frame of reference to provide a boundary of a picture about students learning science. The portrait does not, cannot, extend past the frame that sets its boundaries, which, in this case, primarily focuses on processes internal to the individual learner.

The notion of a frame is useful for providing researchers and their readers with an understanding of the conceptual boundaries of the research, yet the image is flat and two dimensional, and the metaphor is a dormant one. A similar metaphor, such as 'capsule of reference' or 'sphere of reference' could reactivate and amplify the metaphoric meaning and incorporate a sense of coming from a more encompassing level. Nevertheless, I will maintain the use of the contemporary term, 'frame'.

Metaphor is adopted as the frame of reference in this thesis, as I intend it to encapsulate objectivism, personal constructivism and social constructivism within its sphere of influence. This is not an exclusive encapsulation, as other 'frames' may hold these and others as well, such as 'theory' as a frame of reference. 'Theory' as a frame of reference is akin to a boxing ring, within which each theory competes with others. Metaphor as a frame of reference is more like an enclosed garden, where each different position is akin to a different species of flower, each able to cross-pollinate the others. Any frame of reference determines how the relationship between objectivism, personal constructivism and social constructivism is viewed. The frame of metaphor gives them equal, metaphoric, status, and so I turn now to consider how each can be considered as a metaphor and how dialectical tension can be facilitated amongst them.

Dialectic Tension Facilitated by Metaphor

If a statement intended as metaphorical is taken literally, miscommunication will occur. If during a conversation one participant exclaims, 'I see', meaning, 'I comprehend', and another turns to gaze in the same direction, then communication is only restored when the second person realises the metaphoric nature of the first person's comment. The point is, if one chooses to use objectivism, personal constructivism and social constructivism in a metaphorical sense, then communication will be difficult with those who use them in a literal sense. For each individual, this may be a decision of volition. However, I believe it to be unlikely that a complementary view that holds objectivism, personal constructivism and social constructivism in dialectic tension is possible if a literal position is taken, one which ultimately leads to a 'competing theories' notion of their relationship.

A prime benefit of utilising metaphor as an organising concept is that it can promote dialogue, as Seitz claimed metaphors provide a:

> unique way of negotiating difference.... While literalism responds to difference by putting things in their proper places, metaphor responds to differences by putting things together, not by merely juxtaposing them but by equating them despite, or even because of, their disparities. Through the lens of the literal we are presumed to see things as they "are" and where they "belong". Metaphor, by contrast, dispenses with the proprieties of literalism and takes the risk of merging elements and discourses that are supposedly incompatible: the metaphorical impulse might thus be described as dialogic (1999 p. 194).

It is this discursive, risk-taking, merging-of-the-incompatible nature that provides metaphor with the credentials to help facilitate dialogue from multiple perspectives. Some people may agree to disagree, but at least they will have a language with which to do so. A language, not of the competition of 'theory', but rather which views each as metaphoric in nature, and therefore of equal substance, worthy of equal consideration.

According to Lakoff and Nunez, metaphor provides more than a language-in-common. Rather, 'metaphorical thought is the principle tool that makes philosophical insight possible, and that constrains the forms that philosophy can take' (2000, p. 7). Lakoff and Johnson's (1999) view places objectivism, personal constructivism and social constructivism on equal footing because 'philosophical theories are largely the product of the hidden hand of the cognitive unconscious' (p. 14). Moreover, these authors point out that each philosophical theory typically chooses one metaphor as 'the true literal meaning of the concept. One reason there is so much argumentation across philosophical theories is that different philosophers have chosen different metaphors as the "right" one', yet they point out that 'the cognitive reality is that our concepts have multiple metaphorical structurings' (p. 71).

An educator who says, 'yes, objectivism, personal constructivism and social constructivism each can be considered to be metaphors as well as theories', is taking a step towards a complementary notion. He or she may value one metaphor above others, perceiving it to provide the greatest insight into the learning process, yet also will be more likely to understand someone else preferring a different metaphor. Therefore, metaphor is used as the frame of reference in this thesis, especially to facilitate a complementary notion in the context of scientific literacy.

It is necessary at this point to consider in what ways objectivism, personal constructivism and social constructivism are metaphoric.

Objectivism and Constructivism as Metaphors

The roles of objectivism and constructivism in education are similar, in that they provide understanding about knowledge and how students may 'gain' knowledge. As mentioned under the heading of *Conceptual Metaphor*, 'knowing' is often understood through 'seeing' metaphors. Taking this further, 'understanding' is a dormant metaphor from taking a (sensory) position from beneath with the implication of looking up (at the underside) of something. 'Illumination' and 'perception' have a sensory basis, now applied to knowing. It is possible that 'make sense' meant originally to have a variety of sensory input providing corroborative information about phenomena, for example, a heavy-looking rock that proves difficult to lift. Cognitive conflict may occur if we saw a large chunk of rock floating on water, as that wouldn't make (coherent the information from each) sense. Therefore, 'making sense' probably meant literally that there was coherence and corroboration amongst the senses. The term was then applied metaphorically to mean a coherence of logic, and so filled a semantic void that existed previous to the use of such a term. The term 'point of view' is a dormant metaphor for 'opinion'. The viewing point determines the view, yet the phrase has come to mean the view itself. Originally, however, the implication is that understanding depends on where you stand, and is therefore more closely allied to constructivism. 'To come at it from another angle', another expression of how to understand something, gives greater weight to the object in view, as if a partial circumnavigation of the object is required, to reach a different vantage point. The emphasis on the object is more closely related to objectivism. These perspectives both utilise a 'knowing as seeing' sense-based conceptual metaphor, yet lead to very different conclusions about knowledge and learning.

Objectivism

'Objectivism', now a dormant metaphor (Sutton, 1993), has, as its root, a noun 'the object', as opposed to a verb 'to object' (Weekley, 1967). The focus on the reality of the object led to a 'carrying over' of the idea into the realm of philosophy, to fill a semantic void. In objectivism, the object is pre-eminent and must be rigorously studied for people to slowly, progressively, communally and objectively discover the underlying reality. Objectivity relates to repeated and reproducible empirical measurements, facts independent of observers, perpetually confirmed laws and falsifiable theories about phenomena. A basic assumption of objectivism is that communities of scientists can be confident that, by utilising certain standards of methodology and integrity, they can come to increasingly more accurate knowledge about phenomena in the world.

A term used more commonly, and sometimes synonymously, is 'positivism'. This is derived from one of the developing senses of the Seventeenth century terms of 'positive, which denoted real or actual existence' (Williams, 1983, p. 200). I have generally avoided this term, as Williams pointed out that the effect of using this term '... dropped by those who actually defend the position being attacked, is often to distance the real conflict, or even to prevent its clarification. It becomes a swear word by which no one is swearing. Yet the real argument is still there' (p. 201). Whilst the term 'objectivism', too, is more likely to be used by the 'opposition', the valuing of 'objectivity' is still held as critical in camps that others would label 'objectivist'.

Under the umbrella metaphor of 'the object' comes metaphors related to truth, such as 'uncovering' facts and making 'discoveries' of knowledge. Bernstein defined objectivism as 'the basic conviction that there is or must be some permanent ahistorical matrix or framework to which we can ultimately appeal in determining the nature of rationality, knowledge, truth, reality goodness or rightness' (1985, p. 8). Some key elements of objectivism include: a realist ontology; a belief that humans can attain objective truth, at least in an intellectual community marked by integrity; and, therefore, a belief in the objectivity of the Western Scientific Canon (Harding & Vining, 1997; Kragh, 1998; Norris & Kvernbekk, 1997).

In terms of objectivism informing the learning process, it suggests that knowledge is an entity that is progressively accumulated and can be stored, for example, in memories and books. An objectivist view of learning often uses, implicitly or explicitly, metaphors related to 'knowledge transfer such as a conduit metaphor, in which knowledge can be transferred or poured from one person to another' (Jonassen, 1991) or education as a pipeline (Costa, 1993). Such a view of learning states that 'we can prepare students best for the future... by *giving* them *a framework of knowledge* [italics added] about each subject so they have something to build on in the future' (Harding & Vining, 1997, p. 974). 'Framework of knowledge' is a metaphor commonly used by objectivists, and is suggestive of something rigid, unyielding, hard, exposable, useful, non-subjective and unchangeable. A framework predetermines to a large extent the structure that may be based on it, hung from it, or supported by it. 'Framework of knowledge' suggests that the framework is made of knowledge, that is, knowledge is the substantial building material, as it is a true representation of reality. With this form of strength, it suggests one can be confident to rely on it, and indeed would be foolish not to. This relates closely to Lakoff and Johnson's (1999) 'thinking is object manipulation' metaphor, where:

> ideas are objects that you can *play with, toss around* or *turn over in your mind.* To understand an idea is to *grasp* it, to *get* it, to *have it firmly in your mind.* Communication is *exchanging ideas.* Thus you can *give* someone ideas and *get ideas* across to people. Teaching is *putting ideas into* the minds of students, *cramming* their heads full of *idea*s. To fail to understand is to fail to grasp, as when an idea *goes right over your head* or *right past you...* Just as objects have a physical structure, so ideas have a conceptual structure' (p.240).

Some may willingly see 'objectivism' as a metaphor, a literal carry over of a meaning from a literal thing, an 'object', to allow a conceptual void to be filled with a metaphor. However, they may also feel that, even though the idea has a metaphoric basis, it is now so well defined it has a literal meaning. This is because '...the traditional theory of metaphor goes hand in hand with the objectivist interpretation of the commonsense theory of language and truth' (Lakoff & Johnson, 1999, p. 120). For example, Muscari saw metaphors as critical in the formulation of new scientific ideas, and likewise for student learning of these ideas, however:

> they are not interminably an asset. They are necessary for cohering and igniting scientific efforts, and in disclosing where the problem resides, but once the machine is in high gear, such expressions become less essential and may in fact be a liability to keep around. The imagery of the speculative metaphor should gradually give way in science to the explicitness and rationality of more selective procedures (1988, p. 430).

The picture is one of objectivism utilising metaphor as a useful but temporary tool.

Roth and Roychoudhury (1994, p. 26) stated that objectivism is the 'default epistemology' for children in Western schools as it is the predominant or the only epistemology available. It also seems to be the default epistemology for many authors defining scientific literacy. What I am hoping is that some holding to an objectivist position may say that if the concept of 'objectivism' can be conceived of as being metaphoric in nature, maybe it is valid yet to think of objectivism as having a metaphorical basis. At least to permit a more learned understanding of the teaching and learning of science and the development of student scientific literacy.

Constructivism

When Kelly (1955) used the word 'construct', he used the action of building things that were apprehendable by the senses, such as bricks and wood, and carried it over to building thoughts, and as such is metaphorical (Spivey 1997). Thus, 'understanding', 'making sense' and 'construct' all have a sensory basis, now applied to some internal, unseen, cognitive realm. In many ways these all are very similar metaphors, but an appeal of the metaphor of constructivism is that it seems like a more dynamic metaphor, whereas 'understanding' provides a more passive, static, put-in-place sense. 'Making sense' and 'sense-making' are terms frequently used in constructivist literature, where the implication is that the mind is actively involved in manufacturing something. The term 'constructivism' has attracted numerous modifiers, and two of these are of interest here.

Personal constructivism

Personal constructivism can be rooted either in the work of Kelly (1955) or Piaget (1954) with their different nuances (see Geelan, 1997b), yet each branch focuses on the process of learning as the *internal* activities of *individuals* concerned with making sense of phenomena (Driver, 1997; Fosnot, 1993; Scott &

Driver, 1998; Watts, 1982). Personal constructivism has a realist ontology, yet emphasises that learners *construct* understandings to make sense of this real world:

> What pupils learn from lesson activities, whether these involve talk, written text or practical work, depends not only on the nature of the tasks set but on the knowledge schemes that pupils bring to these tasks; learning thus involves an interaction between the schemes in pupils' heads and the experiences provided (Driver, 1997, p. 1008).

As for informing educators about learning, personal constructivism has allowed the familiar and ordinary situations of learning to become sources of insight and inspiration (Solomon, 1994). For example, the ordinary observation of students being unable to 'absorb' content under a transmissive mode of teaching has given way to insightful research into why students have difficulty learning science content, under titles such as 'conceptual frameworks' (Duit, 1991; Watts & Pope, 1989), 'conceptual change' (Duschl & Gitomer, 1991; Dykstra, Boyle & Monorach, 1992; Scott, Asoko & Driver, 1992), 'misconceptions' (Gil-Perez & Carrascosa, 1990) or 'children's science' (Gunstone, 1990), depending on the authors' terminology. Moreover, personal constructivism has inspired techniques for teaching, such as eliciting prior knowledge, producing cognitive conflict and utilising different purposes of writing, have been utilised to enrich teaching and learning about science.

The word 'personal' (or Piagetian) modifies the metaphor to suggest that the construction occurs primarily in individual students' heads. Therefore the individual is the primary focus of study from the perspective of this metaphor. Research into scientific literacy utilising personal constructivism has been conducted by Hand, Prain, Lawrence and Yore (1999), who developed a writing in science framework. Secondary metaphors of personal constructivism include 'assessment as a window into students heads' (Tobin, 1990), 'gardeners', 'tour guides', 'learning councilors' and 'facilitators' (Roth & Roychoudhury, 1994).

Social constructivism

Social constructivism is often, but not always, considered to have arisen out of Vygotsky's sociocultural theories (Berk, 1994). Social constructivism highlights the *interpersonal* nature of knowledge (Anderson, Holland & Palincsar, 1997; Garrison, 1995; O'Loughlin, 1992; Solomon, 1994; St. Pierre Hirtle, 1996), in which sense making is mediated by culture and language. Social constructivism has a relativistic ontology, and, in relation to science, 'social constructivism is concerned with the contributions of social interactions to... one's construction of science' (Atwater, 1996, p. 827) as well as other areas of learning. Often, social constructivism highlights the disenfranchisement of students under an objectivist referent, and looks for evidence of the benefits of more socially-inclusive modes of teaching and learning. For example, research has shown that the quality of both classroom discourse and interpersonal relationships amongst teachers and students has a direct impact on the quality of the knowledge constructed (Taylor, Fisher & Fraser, 1996).

From the vantage of social constructivism, teachers ought to provide the types of activities that 'help students to develop a collective discourse on functional scientific literacy that includes characteristic activities, purposes, ways of using language, values and patterns of relationships among participants, not just ways of knowing and using canonical knowledge' (Anderson, et al, 1997, p. 381). This is because '... social interactions in the course of ongoing activities are the critical vehicle for learning and development' (Roth, 1993 p. 353). For more comprehensive reviews of objectivism, personal constructivism and social constructivism, see Geelan, (1997b) and Solomon (1994).

If some educators presently holding a narrow perspective of objectivism, personal constructivism or social constructivism were willing to accept the metaphoric basis of theirs and others' epistemologies, then a complementary notion may gather momentum in education. At this point, I am not advocating the use of more metaphors (though that may serve a positive educative purpose), but rather that a metaphoric frame of reference be utilised more often in the realms of learning. Moreover, it may be a useful frame to utilise sometimes when considering the entity called 'science'.

Metaphor in Science

'Science' - to know, is from a root word meaning 'to cut' (Klein, 1971) - a 'knowing through cutting'. To say scientists have been 'cutting into the fabric of the universe' is using blatant metaphoric language to suggest that they have been doing experimentation or theorisation about the nature of the universe. However, to say they are conducting 'scientific research into the nature of the universe' sounds literal not metaphoric. This latter phrase covers over the metaphoric origins of the word 'science' as the word has become a dormant metaphor, no longer viewed typically as a metaphor but as a literal term conveying a precise meaning. Yet, both sayings are equivalent, metaphoric and convey a similar idea.

Not only the origins, but the practice of science relies heavily on metaphor. 'Plum-pudding', 'solar system', 'wave' and 'cloud' have all been metaphorically applied, successfully or unsuccessfully, to the entity labeled 'atom'. However, diametrically opposed ways of conceiving of phenomena can and do exist because of fundamentally different metaphors used to achieve this. For example, Lakoff and Johnson state 'it is virtually impossible to think or talk about the mind in any serious way without conceptualising it metaphorically. Whenever we conceptualise aspects of mind in terms of grasping ideas, reaching conclusions, being unclear, or swallowing a claim, we are using metaphor to make sense of what we do with our minds' (1999, p. 235). We utilise a variety of metaphors that structure the very way we conceive of our brains, such as 'mind as body system', 'mind as builder', 'mind as computer', 'mind as container', 'mind as machine' and 'mind as person' (p. 235). Some of these metaphors give rise to incompatible perspectives on the mind, yet each has a certain viability and currency in its usage.

Halliday and Martin (1993) conveyed the importance of metaphor in communicating scientific ideas when they said scientific language is steeped in the use of *grammatical metaphor*. The register of science has a trackable increase in the use of nominalising active processes, that is, making verbs, such as 'moving', into nouns, such as the entity of 'motion' (Halliday & Martin, 1993). This process is called grammatical metaphor by Halliday and Martin, because '...a process, which was construed as a verb (the prototypical realisation of a process) then becomes reconstrued in the form of a noun (the prototypical realisation of a thing)' (p. 13). They state that the use of this grammatical metaphor is to treat processes '... as if they were things' (p. 15), and the effect of this is pertinent here:

> Isolated instances of this would by themselves have little significance; but when it happens on a massive scale the effect is to reconstrue the nature of experience as a whole. Where the everyday 'mother tongue' of commonsense knowledge construes reality as a balanced tension between things and processes, the elaborate register of scientific knowledge reconstrues it as an edifice of things. It holds reality still, to be kept under observation and experimented with and in so doing, interprets it not as changing with time (as the grammar of clauses interprets it) but as persisting - or rather persistence - through time, which is the mode of being of a noun (p. 15).

This, taken together with the metaphorical basis of language and thought, means metaphor is not just an important conceptual tool, but doubly-buried in the register of scientific English in its expressions and grammar. This *implicit* use of metaphor tends to make the scientific register seem like a foreign language (Mason, 1971), all the more bewildering because it seems to be familiar in many respects. In the context of science education, it is conceivable that, because metaphors have explanatory power without being rigidly bound to a simplistic definition, the *explicit* use of metaphor may make available forms of understanding that otherwise would remain buried. Therefore, when we come to scientific literacy in Chapter Four, the explicit use of metaphor serves the multiple functions of:

1. Emphasizing metaphor in daily language and thought
2. Highlighting the role of metaphor in science language

3. Providing a complementary view of objectivism, personal constructivism and social constructivism as they inform scientific literacy
4. Facilitating thinking, by resonating with metaphoric structures (conceptual metaphors) in our minds.

Conclusion

To carry out Dewey's (1938/1963) exhortation to approach conflict from a level deeper and more encompassing, notions such as 'theories' may be better backgrounded, in that they, by definition, tend to be competitive and mutually exclusive. Each research program under the auspices of objectivism and the constructivisms has collected (or generated) its own data, fortified its research program and refuted the other theories. The competition between each is understandable when 'theory' is the underlying conception of these influences on our understanding of learning.

Metaphor, multifariously conceived as Aristotlian, conceptual and situated, is a tool useful to facilitate a more complementary notion, to allow objectivism, personal constructivism and social constructivism to be held in dialectical tension. Regarding the use of fundamentally different metaphors that give rise to fundamentally different mathematics, Lakoff and Nunez stated, 'each mode of metaphorical understanding has different uses. And each is precise in its own terms.... But you do not have to choose. As long as you keep your metaphors straight, you can use whichever is most useful for a give purpose (2000, p.374). I take the view of objectivism, personal constructivism, and social constructivism as metaphorical in origin and substance, where each is significant, where together they are not mutually exclusive, but rather provide different viable and valuable understandings about learning. I attempt to 'keep them straight' in this thesis by representing each in a metaphorical framework developed in Chapter Four. This framework is intended to make sense of students and their involvement in Science classes, and so each metaphor is centred on students' active participation.

This chapter has engaged in identifying the link between metaphor not only informing our view of the world, but also very much shaping and forming our thinking, affecting the very way we can see the world. I have utilised metaphor as a frame of reference. Now, in turning to conceptions of scientific literacy in Chapter Four, I utilise a set of metaphors to represent the perspectives of objectivism, personal constructivism and social constructivism in that context, to the end of facilitating a dialogue of complementarity. Is it possible that metaphoric 'skewers' could hold simultaneously these three onto 'the rotisserie' of our understanding?

Chapter Four
A Metaphoric Framework for Scientific Literacy

The term 'scientific literacy' is used throughout this thesis because it is a frequently used contemporary term, and because its 'fuzziness' of meaning may be its most salient feature. If the lack of consensus about its meaning causes some to ask: 'why are there so many ways of conceiving of scientific literacy?', this may result in a deepening search for alternative ways of understanding. The many and varied opinions about the meaning of scientific literacy make it essential to provide some kind of definition: that is the main concern of this chapter is. The benefits of such a term with multiple nuances is that it provides a flexibility of meaning, and this flexibility is encapsulated in a metaphoric framework developed in the following pages. This flexible framework permits a fluid understanding of the experiences of the four students presented in Section Two.

The purpose of this chapter is to represent the scientific literacy perspectives of objectivism, personal constructivism and social constructivism in three fresh metaphors. First, different perspectives on scientific literacy are presented. Then the three metaphors that represent objectivism, personal constructivism and social constructivism are introduced. These metaphors compose a framework that is intended to span the breadth of scientific literacy notions. The explanatory power of the three metaphors in organising the literature on scientific literacy is examined, suggesting that the framework is viable for understanding a wide variety of perspectives. Finally, the relationship between each metaphor is made explicit. The chief purpose of this framework is to interpret the tale of Shelly and Jimmy, and of Tara and Darrien (Section Three) in order to address the research question.

The Term 'Scientific Literacy'

There is at least one significant feature in common with most attempts to define scientific literacy: they attempt to do so in a literal, sòmewhat absolute way, as if it were, should be or could be an absolute entity in itself. The defining process varies from author to author, yet I would suggest there are three main nuances, in keeping with objectivism, personal constructivism and social constructivism. Those definitions that value a more objectivist approach tend to focus on aspects of the Western Scientific Canon, including 'the acquisition of fundamental science concepts, process and problem solving skills, and informed attitudes about science (Meichtry, 1992, p. 437). Other definitions, more aligned with personal constructivism, prefer to foster the ways students make sense of science, and do not give such a weight of authority to it. In these definitions, students should 'evaluate the quality of scientific information on the basis of its source and the methods used to generate it... pose and evaluate arguments based on evidence and... apply conclusions from such arguments (Micikas, 1996, p. 432). Views utilising social constructivism focus on 'being willing as well as able to participate authentically in the social practice of a particular community. What students believe and how they feel are seen as significant factors in the process of learning science, which is viewed as a process of induction into the beliefs and values of the [professional] science community' (Hanrahan, 1999 p. 699). Numerous authors arrive at scientific literacy from one or two of these perspectives, and a few from all three.

In the forty years since Hurd introduced the phrase *scientific literacy* as a goal of science education (Hurd, 1998, p. 408), there have been unending attempts to reach consensus on its meaning. Not only is there a large variety of definitions of scientific literacy in the literature, but there is also a large variety of approaches to defining it. Some of these approaches include: develop a hierarchical framework (De Caprariis, 1993); provide a range of ideas and argue the best (Bingle & Gaskell, 1994); provide a range of ideas and suggest they all have a part (Rhodes & Schaible, 1989); summarise features in common with various definitions (Mitman, et al., 1987); provide a narrow focus and leave implicit the notion that this is the only real conception (Gutherie, 1983); provide a long list of behaviours of a scientifically literate person (Hurd, 1998); use the definition of a significant organisation (Cobern, Gibson & Underwood, 1995); tone down scientific literacy into an achievable alternative, for example, Devlin's (1998) 'scientific awareness'; reposition the idea, for example, Pollak's (1994) use of scientific literacy itself as a context for learning; and ignore any definition (Eiss, 1970; Rosier & Banks, 1990). More problematic than the variety, type or number of definitions, however, is that objectivism, personal constructivism and social constructivism provide theoretically different, and often incompatible, ways of conceiving of scientific literacy. In fact, the term 'scientific literacy' is used so broadly that there is some doubt about its usefulness. DeBoer stated that scientific literacy is a broad concept encompassing many educational themes that have changed over time, and that some writers have admitted that it may be no more than a useful slogan to rally educators to support the learning of science. 'If that is true, then to speak of scientific literacy is simply to speak of science education itself' (2000, p. 582).

The article with scientific literacy in its title most cited during 1999 (Institute for Science Information, 2000) was 'The myth of scientific literacy' (Shamos, 1996). It would seem that the claims of this author, that scientific literacy is an inherently 'fuzzy' term, and, therefore, should be replaced by a more useful term, resonated with a significant number of authors, such as DeBour (2000). Whilst I agree that the term is not well defined, I believe that this could be its redeeming feature. It has already a huge following as a 'banner' for science education reform. How much better, then, to utilize this adherence and its 'fuzziness' to facilitate the complementarity of different views of learning which have informed conceptions of scientific literacy?

When Hurd first used the term 'scientific literacy' (Hurd, 1998), he did so only two times in his text, and did not define it. Why did he, and others following, append the term 'literacy' to 'scientific' (or preface 'literacy' with 'scientific')? 'Literacy' does convey a concept that is more dynamic than 'education', and meant originally 'one who knows the letters' (Klein, 1971). This term has grown to embrace skills such as listening and speaking skills, as these are conceived of as precursors to reading and writing (Hasket, 1998). Added to this is the concept of 'visual literacy' (see Chapter Six for a definition) and, more recently, 'mathematical literacy' (Glynn & Muth, 1994; Steen, 1999), which has subsumed the concept of 'numeracy', and 'computer literacy' (Rafferty, 1999). Indeed, Rafferty suggested there are 38 types of 'literacy'.

It would seem that the term 'literacy' has come to mean 'being able to ...'. The implications of this shift of the word literacy from a narrow lexiconical (letters) sense to the broader sense of 'ability' may explain in part why there is such a broad range of opinions of what the breed of literacy labelled as 'scientific' actually entails. Some use the term in the original narrower sense of literacy, that is, reading and writing about science. For others, there is a much broader sense, where scientific literacy means 'being able to do science'.

A Framework for Scientific Literacy

More than a quarter of a century ago, Agin stated that 'a frame of reference should be established to help consolidate and summarize the many definitions' (1974, p. 405) of scientific literacy. Various authors have attempted to 'frame', or categorise scientific literacy, often with the end result of providing a constricted view of what it entails. An influential article by Bybee (1995) presented the range of conceptions of scientific literacy in an organised manner. Bybee's article, entitled 'Achieving scientific literacy', was amongst the top ten cited articles with 'scientific literacy' in the title, during 1999 (Institute for Science Information, 2000).

Bybee attempted to distinguish the 'domains' of scientific literacy from its 'dimensions', and listed components of each, yet he did not specify exactly what he means by these terms. The article becomes less clear when Bybee's examples of 'domains' are compared to his 'dimensions', as there is a great deal of overlap between the two groupings. For example, whilst describing the dimension of conceptual and procedural scientific literacy, he states that this concerns '*conceptual ideas* that *unify* [italics added] the disciplines...and understandings relative to the procedures and *processes*' [italics added] (p. 29) of science. Yet, he lists the National Science Education Standards, 'Content Standards', as 'domains of scientific literacy' (p. 29) when one of these 'domains', 'Unifying concepts and processes', contains the identical idea to the above 'dimension'. Table 2 summarises the domains and dimensions that are, in Bybee's article, almost identical.

Table 2

Bybee's (1995) 'dimensions' and 'domains' that are, in effect, indistinguishable.

Dimensions	Domains that have a similar sense
Functional scientific literacy Vocabulary	None
Conceptual scientific literacy Relate information and experiences to conceptual ideas that unify the disciplines and fields of science	Unifying concepts and processes (p. 42)
Procedural scientific literacy Abilities and understandings relative to procedures and processes	Processes of science (p. 30) Skills associated with science (p. 30)
Multidimensional scientific literacy Perspectives of science and technology that include history, nature and role of science in society and personal life	Science in Personal and Social perspectives (p. 42) History of science (p. 42) Appreciate the socio/historical development (p. 30)

I suggest that attempts, such as Bybee's, to categorise scientific literacy have failed to communicate any significant consensus about scientific literacy, as they have done so utilising literal, rigid definitions. One interesting aspect of Bybee's article is it does provide many different perspectives of scientific literacy, and that in a seemingly well-organised fashion. However, the organisation that is apparent actually masks his failure to comply with the basic purpose of the article, which was to specify what scientific literacy actually entails. He does not organise usefully the range of views of scientific literacy, or provide a structural framework by which they can be readily understood. Bybee, as with others who have used literal categories (e.g., Laugksch, 2000) to conceive of the different realms of scientific literacy, seems to have added to the confusion about the concept. Such literal, relatively inflexible categories seem to lack coherence, and have not helped to clarify understanding about scientific literacy nor provide a coherent direction for research into the concept. Moreover, they do not really address Agin's (1974) call for a 'frame of reference'.

However, is it possible that a non-literal type of classification could capture the otherwise slippery, almost ethereal nature of scientific literacy in the literature, and more importantly, in the classroom? In Chapter Three, I mentioned that different, often mutually exclusive metaphors have been utilised to conceive of the mind. Next, I suggest that three different metaphors may, likewise, help to conceptualise scientific literacy. The three metaphors of the framework are *student-as-recruit*, *student-as-judge*, and *students-as-scientists*. The three metaphors exist, not as individual options, but corporately as a *set* of interconnected conceptions that could promote dialogue across the differing positions of objectivism, personal constructivism and social constructivism.

A Metaphoric Framework for Scientific Literacy

The failure of the Science Education community to come to any clear agreement about, or any broadly encompassing coherent understanding of, scientific literacy has led some to realise that our understanding of scientific literacy:

> is open-ended and ever-changing. It is organic, not static. Because its parameters are so broad, there is no way to say when it has been achieved. There can be no test of scientific literacy because there is no body of knowledge that can legitimately define it. To create one is to create an illusion. The goal of scientific literacy is achieved when the public learns about science and about the scientific enterprise in the many different ways that can be accomplished' (DeBour, 2000, p. 597).

When he considered the lack of consensus about scientific literacy, DeBour suggested that we need either a narrower definition of scientific literacy or to do a better job of addressing all aspects. Then he stated that both efforts would be futile and that '...we should accept the fact that literacy is simply synonymous with the public's understanding of science and that this is necessarily a broad concept' (p. 594). I agree with deBour that no body of *literal* knowledge may define scientific literacy, but that does not mean that it cannot be understood in other ways. The idea of an open-ended, ever-changing, organic, broad, untestable, indefinable concept of scientific literacy suggests that it needs an equally organic conceptual scheme to define it (in an open-ended sense) in such a way as to aid our understanding of what it is and involves. Metaphor, as promoted in Chapter Two, is the flexible type of tool for the job. Therefore, metaphor can serve the seemingly double purpose of coming from a deeper and more inclusive level to allow objectivism, social constructivism and personal constructivism to be held in dialectical tension, whilst flexibly encompassing the dynamic range of conceptions about scientific literacy. Of course, ultimately these are one and the same thing, because different notions about the nature of scientific literacy arise out of implicit or, less commonly, explicit underlying epistemologies.

Conceptions Enabled by a Metaphoric Framework

Whilst authors such as Bybee (1995) have attempted to frame or categorise scientific literacy, this is not the remedy that Agin (1974) specified: his desire was for a 'frame of reference'. The emphasis of this phrase is a place from which to view all the notions of scientific literacy, one that would somehow provide insight into all of them. This request is quite similar, in a sense, to Dewey's 'deeper and more inclusive' level from which to rise to provide insights into differences in understanding. As mentioned in Chapter Two 'metaphor' is the 'frame of reference' for this thesis, a place from which to view and make sense of differing concepts of scientific literacy. As a figure of speech, metaphor can facilitate the flexible 'carrying over' of a concept in an educator's mind, and allow it to be applied, in this case, to student scientific literacy. Metaphor's strengths for this purpose include the fact that not only is metaphor buried in our everyday grammar and in scientific language, but the very referents for learning that inform notions of scientific literacy can be viewed as metaphorical in origin.

The usefulness of metaphor in education has been utilised on numerous occasions. For example, Tobin (1990, p. 6) suggested that if a teacher changed metaphors of how he or she performed in class, then a 'host of changes follow'. Tobin and LaMaster (1995) utilised personal metaphors to empower teachers to provide dynamic learning environments in their science classroom. Roth (1993) utilized the metaphor of *cognitive apprenticeships* when conducting action research with his own science class. Costa (1993) argued that *school-science-as-a-rite-of-passage* was a powerful metaphor to make sense of learning science.

The use of two specific metaphors in the context of learning was suggested by Sfard (1998), the first of which is *learning as acquisition*, which pertains to a concept of knowledge as if it was a commodity to be gained by a learner. Sfard's second metaphor was *learning as participation* where learning a subject is conceived of as a process of becoming a member of a certain community. I have reported elsewhere (Willison, 1999) on the use of Sfard's two metaphors to understand scientific literacy in my own classrooms. However, this two-fold metaphor set seemed to provide a rather artificial 'either/or' separation when used to interpret the participant-observer research reported in Section Three. I decided to maintain the sense of Sfard's two metaphors, and include another metaphor that would fill something of the conceptual gap between them, and so utilised three metaphors in a framework for scientific literacy. Scribner (1986) used three metaphors - literacy as adaption, literacy as power, literacy as a state-of-grace - to portray the fullness of general literacy. I, too, found that a third metaphor was needed to organise the literature and make sense of the scientific literacy portrayed in the tales of Section Two.

The instances above emphasise metaphors as tools of conception for specific concepts. Whilst I likewise utilise three specific metaphors for scientific literacy, the role of metaphor in this thesis goes much deeper: metaphor is the unifying concept underlying this thesis, as a frame of reference. Therefore, I could be thought to be aligning myself with cognitive scientists who have developed ideas of our embodied minds being organised metaphorically (Lakoff & Nunez, 2000), and so I may be closely relating to personal constructivists; or with social constructivists, who make much of metaphor in its role in language and culture (Eubanks, 1999). However, this does not rule out my simultaneous alignment with objectivism, considering that a valid perspective to take is to consider metaphor, language, culture and processes inside the mind to be merely tools we use to reach out for understanding of real phenomena, whose existence is independent of ourselves and our tools. Another frame of reference that could have been chosen was 'theory', as outlined in Chapter Two. However, this would emphasise differences and promote the notion of a superiority hierarchy, instead of a complementary view with differences held in dialectical tension.

The Three-Metaphor Framework

One of the following three metaphors is explicit in some science education literature, and the other two implicit in various scientific literacy notions.

Together, they attempt to provide a sense of the full range of understandings depicted in the literature, from an objectivist notion to a social constructivist one, from knowledge-in-the-textbook to students mutual sense-making of phenomena. The critical issue for these metaphors was their ability to function as tools to interpret the tales of Section Three, and so each metaphor needed to evoke a powerful image of how students do or could participate in science classes. If a metaphor requires much explanation, or doesn't readily imply some connection to students in classes, then it loses its metaphoric transferability, just as a joke loses its humour if it needs to be explained.

The three metaphors focus on the ways in which students may act in class and are: *student-as-recruit*, *student-as-judge* and *students-as-scientists*. These three metaphors emerge from Latour's (1987) 'ready-made-science'/'science-in-the-making' dichotomy. By asking: 'who ready made it?, By whom is it in the making?' three answers, at least, are conceivable: the idea behind student-as-recruit is that professional scientists have ready-made science; the idea behind student-as-judge is that professional scientists are involved in science-in-the-making; and the idea behind students-as-scientists is that of students themselves participating in science-in-the-making.

Using these metaphors shifts the focus of scientific literacy from a definition of some abstract entity towards student participation. This combats the subtle and mystifying effects of utilising grammatical metaphor, where the skills of engaging in various ways in science are nominalised to the label 'scientific literacy'. Subtle and mystifying in this case, because it seems that even though the noun 'scientific literacy' enjoys vast patronage in discourse, no one knows what the other person means when it is used. 'De-nominalising' the term (see Chapter Three) by utilising ways of conceiving of student active participation, makes it more accessible to human minds.

Surprisingly, 'even in the constructivist literature, the focus is often upon constructivist teaching and creating environments in which students can construct knowledge. Seldom is the focus upon students and learning (the actual process of constructing the knowledge) as the active agents' (Kyle, 1997). The metaphoric framework clearly puts students in the spotlight; whilst teachers and the tasks they provide are important, it is the ways that students respond that are most salient. The focus of the metaphors is, therefore, on the active participation of recruits, judges and scientists, rather than other attributes such as their clothing or salary scales. So, for example, students and judges share skills such as weighing evidence, but not those of wearing garments that symbolise authority or calling the court to order.

Metaphor One: Student-as-Recruit

Student-as-recruit makes fresh the dormant metaphor of objectivism (see Chapter Three), and specifically applies it as a referent for learning. The parallels between these two metaphors, especially as they impact notions of scientific literacy, are as follows. Evans, from an objectivist perspective, stated that the scientifically literate person 'has faith in, and values, logical reasoning...[and] accepts conclusions when supported by data' (1970, p. 82). This characteristic of acceptance is the nature of a recruit, who comes under the authority of an institution, and is drilled to learn its procedures. It is typical of institutions, when they take a (large) influx of recruits, that they expect them to *absorb* a lot of knowledge in a short time: sales recruits must pick up a lot of information about their products; banking recruits must learn many procedures; and army recruits must learn attitudes, such as unquestioning obedience. Furthermore, this process is often used to screen out weaker or unsuitable persons. In the metaphor of *student-as-recruit*, the basis of students working in science is to *appropriate the content* of the Western Scientific Canon (Anderson, Holland & Palincsar, 1997), at least as depicted by classroom-science. By *classroom-science*, I mean the specific teaching of science content and skills that is particular to one teacher with his or her science class. How closely this reflects or should reflect the notion of the Western Scientific Canon cannot be specified: the critical element of classroom-science is the learning tasks (see Chapter Two) that are actually provided in class, including the nature of dialogue that an individual teacher engineers. For example, if a teacher presented science using predominately textbooks as the learning medium, the 'classroom-science' image engendered in their students would be quite different from a teacher whose main teaching vehicle was to provide students with scientific experiments and demonstrations. The recruits may be volunteers, or may be conscripted into service, but either way their role is to learn the ways of the classroom-science.

Metaphor One requires two main characteristics of learners: they must seem to *accept* the truth or validity of classroom-science; and they must acquire skills to *appropriate the knowledge* presented as classroom-science. The purpose of experiments for student-as-recruit is to *confirm*, and aid in memorising and understanding classroom-science. There are two major facets of this metaphor: teachers can intend and plan tasks for students to work as recruits; and students can seem to work as recruits, regardless of teacher intentions. This metaphor is similar in nature to Sfard's (1998) acquisition metaphor and Scribner's (1986) adaption metaphor, since, from this perspective, students must acquire the knowledge of the Western Scientific Canon by adapting to the Science classroom culture. Student-as-recruit implies Science lessons involve students taking part in 'ready-made-science' (Latour, 1987, p. 4). A composite view of literature that supports this perspective says '"facts" are the bedrock of scientific literacy' (Raymo, 1998, p. 752) and so it is 'largely a matter of teaching them [students] how to read scientific materials' (Gutherie, 1983, p. 287). We just need 'scientific literacy-enriched ... teaching of content' (Mitman, et al., 1987, p. 613) so there will be a 'meeting of certain desirable standards' (Olorundare, 1988, p. 153). This metaphor alludes to the more historical notion of literacy that entails writing, and especially reading, about science. Students could be considered also as recruits in other learning areas, such as Mathematics and Social Studies. It is closely aligned with the metaphor of formal education being a 'pipeline', where the foci are issues of recruitment and retention (Costa, 1993).

Metaphor Two: Student-as-Judge

Student-as-judge represents the interests of personal constructivism as an explicit metaphor that conjures strong imagery of internal cognition processes. In a long-hand way, it could be written as student-as-individual-constructor-of-understanding. Thomas and McRobbie (2001) utilised the metaphor of 'learning is constructing', and their usage is similar in nuance to Metaphor Two. However, student-as-judge makes it explicit that students are making sense of *other* people's knowledge claims (whereas Metaphor Three emphasises students making their own knowledge claims). A judge evaluates knowledge claims, an action which requires 'the habit of weighing evidence' (Evans, 1970, p. 82). This metaphor is the middle ground between Sfard's (1998) two metaphors of acquisition and participation. When students participate in Science as judges, they *evaluate the knowledge claims of others*, especially of classroom-science. Ultimately, they *are persuaded* one way or the other about the validity of a claim, and, for the purposes of this research, need to participate in a way that suggests the passing of a judgement in order to be considered as acting in accordance with student-as-judge. For example, Tara in Chapter Five declares, 'I told you science was stupid, 'cause you never know if you are right'. The evidence, as she construes it, points to the stupidity of the classroom science presented on that day, and thus she judges it so. Judgement or critique need not necessarily be so extreme, but within the scope of this metaphor it does entail students considering the merits of classroom science or other students' claims, and manifesting some sort of informed agreement or disagreement, as 'the first and last marker of scientific literacy has always been doubt' (Lienhard, 1998, p. 2).

If a teacher intends for students to work as judges, the purpose of experiments would be to provide opportunities for students to find evidence for or against knowledge claims, and to base judgements on increasingly rigorous criteria, where students are able to state why they do, or do not, agree with the claims of classroom-science, or the claims of other students. In this metaphor, students *construct* understandings of phenomena from experimentation, and reading, writing and listening tasks. The student-as-judge metaphor highlights the role of students making sense of other people's knowledge claims, and promotes awareness that each student's construal of these claims may be far removed from the intended meaning of the persons who made them. This metaphor conveys the idea of 'science-in-the-making' (Latour, 1987, p. 4) by professional scientists, whose knowledge claims are tentative, and must be evaluated by students of science.

The student-as-judge will 'appreciate that ideas are continually subjected to validation by test' (Agin, 1974, p. 406), and so will 'evaluate the quality of scientific information on the basis of its source and the methods used to generate it' (Micikas, 1996, p. 432). Students acting in this manner will be 'engaged in a process of deciding whether a claim would have been different if the science was conducted and evaluated by different scientists in a different context' (Bingle & Gaskell, 1994, p. 187). Moreover, they 'can be taught to look for the human voice behind a scientific account, and to read the words as evidence of thought, not just a report of information' (Sutton, 1993 p. 1225).

A warning at this point is that I run the risk of confusing my audience, because personal constructivists have utilised 'student-as-scientist' (singular) as a metaphor. I suggest this metaphor does not reasonably represent the cognitive emphasis of personal constructivists, where sense making is emphasised as internal constructions, with individual students, whilst surrounded and influenced by myriad social influences, making sense of all these things in their own mind. Rather, one of the significant features that makes a 'scientist' is that she or he participates in a scientific community, open to conjecture, debate and refutation. Maybe this could be an underlying reason that Duit and Treagust (1998) felt that the metaphor did not parallel the way students could work in a personal constructivist framework. In addition, 'the model of the child as mini-scientist... means that children are not taught to access the genres science has evolved to store information which leads to a tremendous inefficiency in the science curriculum' (Halliday & Martin ,1993, p. 201). Student-as-scientist (singular) as a *model* has the connotation of a fixed representation and alludes to the search for one superior way of learning in science. The metaphor of 'judge' is part of a framework of equally important metaphors, and encapsulates many implicit personal constructivist metaphors, such as 'weighing the evidence', 'internal sense-making', and 'personally constructing understanding'.

Metaphor Three: Students-as-Scientists

Students-as-scientists is a metaphor written in the plural form for two reasons. First, and most important, it explicitly represents social constructivism at a metaphoric level, and so the plural is highly suggestive of the salience of social processes, as compared to internal cognitive ones. Second, student-as-scientist (singular) is a commonly used metaphor, as specified above, and the use of the plural form may help to distant its application, as suggested here, from its past usage. The metaphor could be written something like this: student-as-socially-immersed-constructor-of-understanding-of-novel-phenomena.This provides the sense of socially immersed individuals, however, it is not only cumbersome, but has little or no metaphoric power.

The metaphor of students-as-scientists is demonstrated when students develop their *own knowledge claims* about phenomena and attempt to *persuade* others about the validity of these claims (Sutton, 1993, p. 1219). Developing their own knowledge claims will usually require them to ask their own questions, devise their own experiments, and produce their own results and conclusions: 'Effective education for science literacy requires that every student be frequently and actively involved in exploring nature in ways that resemble how scientists work' (Nelson, 1999). Students-as-scientists conveys a more social notion than do the other two metaphors because, although some students may individually design experiments, and develop lines of argument and standards of evaluating claims, they must function socially to convince others about the viability of their knowledge claims. A 'lone scientist' makes little sense, as a hallmark of science is not just making discoveries, but also communicating these to a community of scientists. Therefore, the metaphor is suggestive of (but not prescriptive of) students working together often to design and implement experiments. In this metaphor, communication with the intent of *persuading* others is paramount, and so it is significant that students '... understand that language works as a *medium of interpretation and persuasion*, and not simply a *system of descriptive labelling*' (Sutton, 1993 p. 1215). The students-as-scientists metaphor is closely aligned with Sfard's (1998) second metaphor of 'participation', and conceives of students themselves conducting 'science-in-the-making' (Latour, 1987, p. 4).

Implicit in the students-as-scientists metaphor is the use of imagination as part of the process of asking questions and finding ways to answer them. The students-as-scientists is always breaking new ground (at least for themselves) as they are not strictly following any one else's set agenda, nor trying initially to make sense of what others are claiming. Einstein valued the use of the imagination in science, stating: 'Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world' (Einstein, 2000, p. 1). In addition, he said: 'The intuitive mind is a sacred gift and the rational mind is a faithful servant. We have created a society that honors the servant and has forgotten the gift' (p. 1). Students-as-scientists use imagination *and* rational thinking to ask questions, devise experiments, produce results, draw conclusions, and communicate their findings. Imagination is critical, but it does seem necessary that it be channelled increasingly into a process by which students generate knowledge claims that have persuasive merit.

The interpretations (Chapters Five to Ten) that utilize students-as-scientists, however, tend to focus on individuals, such as Tara, partly because the field work was completed and vignettes were written before the three-metaphor framework was devised. Therefore, the role of imagination and rational thinking in constructing novel knowledge and in utilizing techniques that persuade others about the viability of those claims are most salient in the interpretations using students-as-scientists. This does tend to neglect, to some extent, the more blatant social acts of, for example, students discussing or arguing to determine what to research, how to research it and how to persuade others about the viability of their conclusions.

I emphasise that I am not presenting three possible separate views, but a *set* of metaphors that attempt to encapsulate the width of opinion about what scientific literacy entails. It is necessary to now consider the different perspectives provided by the three metaphors.

Contrasting the Three Metaphors

The three metaphors provide different perspectives on the status of knowledge. Student-as-recruit provides a perspective where the status of knowledge is settled, student-as-judge as undecided and contentious, and students-as-scientists as fabricated by co-learners who generate knowledge claims. As mentioned in Chapter Three, the word 'science' has as an early root a word meaning to 'divide' or to 'cut' (Klein, 1971, p. 662), thus giving the sense of looking deeply into something by reducing it into simpler parts, a knowing through cutting. If 'science' can be understood as a type of 'cutting' then we can ask, '*who* is recognised as an able cutter?' The three metaphors provide three different answers. The student-as-recruit perspective views the community of professional scientists, past and present, as the ones with authority to cut into reality, and present their findings. Therefore, classroom-science presents the temporal distillation of this cutting process, including the knowledge gained by cutting, as well as the way to cut. Student-as-judge provides a perspective where each student needs to be convinced about knowledge claims made by *others* (usually the scientific community and science teachers, but also other students) who do the cutting. Students-as-scientists suggests learners themselves are empowered to cut, often collaboratively.

That students are working as judges could be evidenced by written or spoken statements such as, 'that fits the evidence', 'that is ridiculous' and 'why does it say that?' For students working as scientists we may hear statements such as, 'we did it this way as....', 'the answer to our research question is...' and 'no, it is correct because...' Student-as-recruit may display passive acquiescence or dynamic agreement, saying such things as 'I remember that', 'I did it the way you showed us' and 'what is the conclusion the teacher wants for this experiment?' I would suggest that students could be considered as recruits unless proven otherwise because the appropriation of classroom-science notions sometimes seems to occur as a quiet, passive process, whereas for the other two metaphors, specific actions, including statements, are necessary as evidence of working in either of these roles. Table 3 presents the perspective that each metaphor provides on the source and epistemic status of science knowledge, and the educative purpose of classroom experiments, science text books, assessment and Science classrooms.

Table 3

The status and purpose of science knowledge, classroom experiments, science text books, assessment and Science classrooms from the perspective of students participating according to each of the three metaphors

	The perspective of student-as-recruit	The perspective of student-as-judge	The perspective of students-as-scientists
Science knowledge	Exists independently of knowers, is confirmed as correct over time, and can be appropriated from sources such as text books and teachers.	Is tentative, and must be evaluated according to its merits. Students construct understanding of others' concepts, and may develop quite different notions than teachers intend.	Is developed by students asking their own questions, devising their own experiments and developing their own claims of knowledge. They should persuade others about claims.

Classroom experiments	Provide insight into, and make memorable, classroom-science. Students follow existing procedures.	Provide phenomena by which classroom-science may be evaluated. This is not just a 'test' of classroom-science, but an interaction with student prior knowledge, integrity, and so on.	Utilise experimentation based on their own questions to develop knowledge.
Text books	Contain stable knowledge.	Represent understanding as open to debate.	Useful reference for possible understanding, and stimulating ideas.
Assessment	Tests retention of classroom-science knowledge.	Considers development of evaluative skills and reasons for belief.	Considers ability to ask research questions, devise appropriate methodology and provide persuasive evidence for claims.
Classrooms	Provide the resources to access classroom-science knowledge.	Provide a forum for the presentation and evaluation of classroom-science knowledge.	Provide a forum for imagining, trialing, experimenting and discussing developing ideas.

Roth (1993) utilised the metaphor of *cognitive apprenticeship* as a framework for conceptualising new learning environments. The three major aspects of this metaphor, as he saw it, were *modelling*, *scaffolding* and *fading*.

Modelling, an aspect that is dominated by the teacher, has parallels with the student-as-recruit metaphor. Scaffolding (providing a certain amount of support) and fading (removing teacher-support) likewise could be considered as congruent with the metaphors of student-as-judge and students-as-scientists, respectively. However, there is a significant difference in the *agency* of Roth's metaphor compared with the three-metaphor framework. *Modelling*, *scaffolding* and *fading* refer to teachers' roles, and so actions of teachers must be salient in Roth's use of the cognitive apprenticeship metaphor, whereas the three-metaphor framework clearly highlights student participation. This feature of the framework means that it is not teacher actions that are paramount, but rather the effects of what teachers facilitate in the classroom, that is, the participation of students.

Focus on students is significant if the framework is to facilitate dialogue between different camps. Unlike the values implied by, for example, a progression from modelling to fading, with the above focus, there is no value statement embedded to suggest any one metaphor is superior to the others. This could be contrasted with, for example, Tobin's (1990) use of metaphor to inform teachers, where some metaphors are considered to be less fruitful in facilitating learning, such as *teacher as miser*, compared to other, more fruitful metaphors, such as *teacher as social director*. All three metaphors constitute the framework, and, whilst having very different manifestations, each is not in itself of greater or lessor value than the others. Such preference values may be added (Taylor 1998) by the user of the framework, but in doing so, an appreciation that others may value metaphors differently from oneself is important. It should be noted, however, that by emphasising students, there is an implied value in the framework that learning is of more significance than teaching, that student participation is more important than teacher intention, and that *curriculum as currere* is more important than traditional delivery images of curriculum (Schubert, 1986).

It is instructive to consider the perspective provided by each metaphor about the other two. From the student-as-recruit perspective, the student-as-judge metaphor places too much emphasis on the importance of cognitive processes in apprehending, or even manufacturing, truth. The subjectivity of the students-as-scientists metaphor has nothing to do with the confident predictive power that science generates. Furthermore, students do not have the training of professional scientists, and so are better off learning established knowledge, not trying to create new knowledge. From the student-as-judge perspective, where even the science presented by teachers remains falsifiable, student-as-recruit does not enable students to perceive the fallibility of science. From this perspective, Metaphor Three does not perceive the enculturation into scientific processes necessary for students to actually do science. The view from students-as-scientists is that Metaphor One has an epistemology that perceives that knowledge can be transmitted, a position which has been brought into question by educational research. Furthermore, it, along with Metaphor Two, privileges the few who graduate into the ranks of recognised scientists. Both neglect the central role of language and culture in interpersonal sense-making about phenomena.

Opposition is Healthy

The critical feature about the students-as-scientists metaphor is that it encapsulates the way that *some* authors perceive scientific literacy to be, or would like it to be. Remember that these three metaphors together form a framework which embraces as many divergent notions of scientific literacy as possible. The metaphor of students-as-scientists is part of a scientific literacy framework which may enable educators to conceptualise learning from the vantage of several different referents. Therefore, opposition is healthy, but must not become oppression or annihilation. For a framework to provide a vibrant set of concepts for discourse, there should be the potential for a dialogue of disagreement, and the student-as-scientist (singular) metaphor has attracted criticism possibly because it can facilitate cross-paradigmatic communication. It must be made clear that students-as-scientists is a metaphor and doesn't suggest students *should* act as scientists. This metaphor represents one possible way among the framework's three ways of students participating in class. Someone considering learning from an objectivist perspective, may believe that if students are allowed to work as if scientists this will be not only inefficient, but have detrimental effects on their learning. For such a person, this metaphor can promote some dialogue with others who hold different views, albeit a dialogue of disagreement. Having some conceptions in common is important to facilitate this dialogue. It is not enough to agree to disagree, people must be able to communicate why they disagree. To some extent all educational theory is bound to entertain controversy, and it may well be healthy for it to do so (Solomon, 1987, cited in Bianchini, 1997, p. 1042).

By specifying how the three metaphors should be understood, my argument has moved into the realm of analogy. The previous clarification given is necessary for each reader to understand what I mean, which is especially important as I begin to interpret the vignettes about students using the metaphoric framework. However, it must be pointed out that the metaphors also will maintain the metaphoric nature of implying different nuances to each reader, depending on his or her culture, language, experience, and so on. I have temporarily clarified the fuzziness associated with metaphor, but realize this fuzziness will return (Seitz, 1999), especially as readers themselves begin to use the metaphors to interpret the vignettes.

How do Objectivism, Personal Constructivism and Social Constructivism Relate to the Three Metaphors?

Even though objectivism, personal constructivism and social constructivism are each represented by the three metaphors of the framework, this does not mean that there is not some overlap between their realms of interest. Even though I have, so far, prescribed what I mean by each metaphor, and how it should be understood, each is metaphoric, and, therefore, ultimately defies tight definition. As you, the reader, apply the three metaphors, your own conceptualisation of recruits, judges and scientists will become increasingly more significant. Ultimately, you may evaluate the framework for its success or failure in eliciting appropriate images, in your mind or conversations, which are useful for thinking about, and researching, scientific literacy.

Student-as-recruit embraces many aspects of objectivism, because, in its brief, scientific literacy requires familiarity with and the appropriation of the knowledge, procedures and values of the Western Scientific Canon, at least as represented by classroom-science. However, the metaphor of student-as-judge is permissible from an objectivist perspective to the extent that it encourages students to see the soundness of the classroom-science as they weigh its benefits. However, if students acting in this manner find the classroom-science in 'error' due to their own poor experimental skills and reasoning, it can be quite detrimental, and even dangerous to scientific literacy, so 'when students do an experiment that does not work, and they do not see the expected result, they should not be allowed to think that they have disproved the theory on which the experiment was based' (Harding & Vining, 1997, p. 973). From the perspective of objectivism, students do not have the capacity yet to work within the rigorous standards required *of scientists*, but some day some of them will make the required standard. Therefore, students-as-scientists should be, in the main, discouraged, if not opposed, at least at the high school Science level.

The perspective from *personal constructivism* is that the student-as-recruit is a necessary concept to allow the provision of fundamental scientific language and practices. However, it is only when students act as judges that they are challenged on their existing ideas, and are able to be assisted in their conceptualisation about classroom-science knowledge. The benefit of students-as-scientists, in endeavouring to generate their own knowledge claims, is that students may more readily make sense of established scientific procedures and values when they out-compete student ideas.

Social constructivism provides a perspective that the Western Science Canon has developed out of culture, language and certain scientific values. To recruit students into this can often be culturally inept, not only to students from non-Western cultures, but also to students from Western countries who are not immersed in the values of science (see Cobern & Aikenheads', 1998, concept of 'border crossing'). Therefore, the role of student-as-recruit should be minimised, if not eradicated. Student-as-judge allows the values and social mores that students bring with them into the classroom to be a framework with which they weigh the evidence for and against the canon. These values may well suggest that the 'cold reason' (Taylor, 1997) of the Western Scientific Canon is irrelevant for life. Best of all, however, is students-as-scientists which sees students not only generating their own knowledge claims, but also value-inclusive standards by which to evaluate their claims. Figure 1, below, is intended to provide a sense of the comparative worth ascribed to each of the three metaphors from the perspectives of objectivism, personal constructivism and social constructivism.

Figure 1.

The relative value accorded to each metaphor by objectivism, personal constructivism and social constructivism.

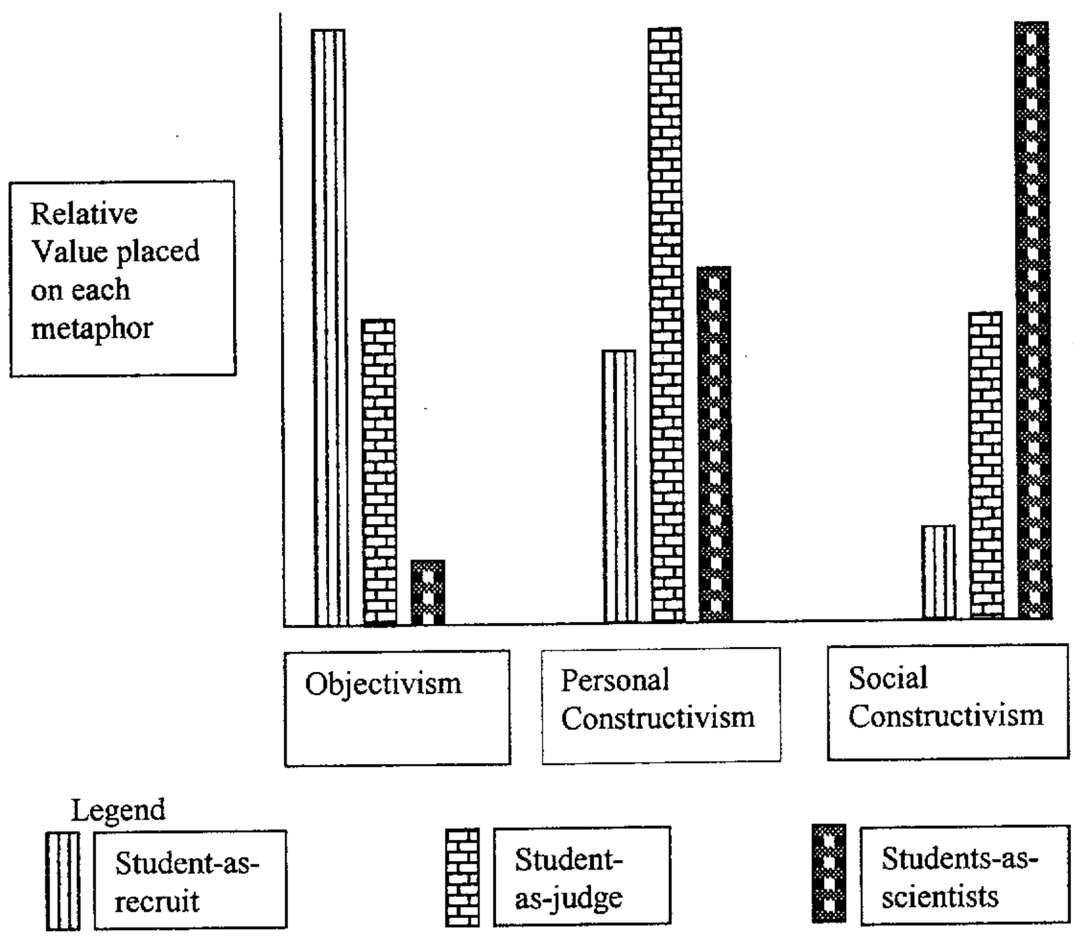

Figure 1. suggests that any one perspective may recognise, to a greater or lesser extent, some validity of metaphors that do not represent specifically that position. Remember that the motivation for the discussion about utilising metaphor in Chapter Three was based around calls for competing educational ideas to complement one another. The three metaphors are provided so that educators may hold in dialectical tension concepts that are mutually exclusive (when taken literally), and may conceivably, in an individual's esteem, help allow objectivism, personal constructivism and social constructivism to be held with somewhat equivalent status, facilitating complementarity. Moreover, to be viable, the three-metaphor framework needs to organise usefully the literature on scientific literacy.

Using the Three-Metaphor Framework for Scientific Literacy

Viability of the Metaphoric Framework: Organising the Literature

This metaphoric framework was produced in response to a need to answer the research question about effects on student scientific literacy whilst attempting to provide a language for dialogue amongst conflicting perspectives on learning. The viability of the framework will be considered first in terms of its usefulness for 'summarizing the many definitions of scientific literacy' (Agin, 1974). If the framework is viable for this process, then this suggests it is also a viable framework to interpret the vignettes of the research. Below, I attempt to fit into the tricotomy of the framework the definitions of 'scientific literacy' from referenced articles that used this term, or the term 'science literacy', in the title. This choice was intended to ensure that only referenced articles that considered scientific literacy as the major theme be included.

A search to fit the above criteria, utilizing the ERIC data-base, found 108 articles in March 2001. In order to reduce this to a number that would be a fair representation of the range of conceptions of scientific literacy, and yet useful to read in tabulated form, I included: the 10 articles most cited in the year 1999, according to the Social Science Citation Index (Institute for Science Information, 2000); including all the articles from the top 4 ranked science education journals (Web of Science, 2001) and the Research in Science Education journal, (which is not included on that database); a proportional representation from the 1970s and 1980s; and at least half of the articles from journals that have contributed two or more articles that has scientific literacy in the title. Tables 4 through to 9, below, situate each article's definition of scientific literacy under one or more of the metaphors.

Table 4

Articles with a single conception of scientific literacy in keeping with student-as-recruit (n=18)

Knowledge of basic concepts and nature of science (Bowyer & Linn, 1978, p. 209).
The basic information needed to thrive in the modern world and must be commonly shared throughout the society (Cannon & Jinks, 1992, p. 197).
An information base organized in a way that makes the information applicable to situations encountered in the workplace, and to civic responsibilities as well as to academic problems. Reasoning processes necessary to apply scientific information in all contexts (Champagne & Newell, 1992, p. 844).
Communicating good scientific ideas clearly (Downie, 1983, p. 303).
The importance of being able to understand and explain the meaning of fundamental science concepts is central to science literacy (Glynn & Muth, 1994, p. 1058).
A matter of teaching how to read scientific materials (Gutherie, 1983, p. 287).
Use and communicate scientific information (Jane, 1990, p. 152).
We cannot then expect students to articulate an understanding of scientific concepts until we assure ourselves that they are functionally literate in this language (Kurland, 1982, p. 575).

Three degrees of 'learned', 'competent' or 'able to function minimally as citizens' (Laugksch, 2000, p.82).
Three dimension of understanding of; the norms and methods of science; key terms and concepts; and of the impact of science and technology on society (Laugksch & Spargo, 1996, p. 122).
The acquisition of fundamental science concepts, process and problem solving skills, and informed attitudes about science (Meichtry, 1992, p. 437).
No single definition of scientific literacy prevails, the many existing definitions share several features: for all; acquaintance with facts and concepts; understand the importance and meaningfulness of science (Mitman, et al, 1987, p. 612).
The meeting of certain desirable standards of information on scientific matters among non-scientists (Olorundare, 1988, p. 153).
The scientifically literate is characterized as one with an understanding of the basic concepts of science, nature of science, ethics of the scientists at work, interrelationships of science, society and humanities, and difference between science and technology (Pella, O'Hearn & Gale, 1966, p. 206).
"Facts" ... are the bedrock of scientific literacy (Raymo, 1998, p. 752).
Return to the practice of only rigorous courses in science and technology (Shamos, 1984, p. 333).
Acquiring some of the information they must have in today's world to make decisions and understand the environment will mean an increase in general scientific literacy! (Shrader, 1976, p. 262).
A firm knowledge of the nature of science and the interaction between science, technology and society, a range of investigative skills and an ability to communicate (Wilkinson, 1999, p.386).

Table 5

Articles with a single conception of scientific literacy in keeping with student-as-judge (n=4)

The scientifically literate person will appreciate that ideas are subjected to validation by test and appreciate the scientist's scepticism (Agin, 1974, p. 406).
Includes understanding science and the general culture and their mutual impact on each other (Atwater, 1998, p. 375).
Evaluate the quality of scientific information on the basis of its source and the methods used to generate it, pose and evaluate arguments based on evidence and apply conclusions from such arguments (Micikas, 1996, p. 432).
Understanding of the reciprocal impact of science and the general culture on each other (Norman, 1998, p. 365).

Table 6

Articles with a single conception of scientific literacy in keeping with students-as-scientists (n=3)

Being willing as well as able to participate in the social practice of a community. What students believe and how they feel will be seen as significant factors in the process of learning science, since it then becomes a process of induction into the beliefs and values of the science community (Hanrahan, 1999 p. 699).
Scientific practice to encourage empirical standards, logical arguments, skepticism, and rules of evidence may be incongruent with cultural interactions that favour cooperation, social and emotional support, and consensus (Lee, 1997, p. 221).
Students engage in multi-disciplinary analysis of a single problem and to bring into confrontation the divergent results of these analysis (O'Hearn, 1972, p. 25).

Table 7

Articles with one conception of scientific literacy in keeping with student-as-recruit and another with student-as-judge (n=13)

Article	Definition fits student-as-recruit	Definition fits student-as-judge
Bingle & Gaskell (1994)	Consensus in the scientific community is not necessary to produce facts, it confirms whether or not a scientist has uncovered one (p. 190).	Citizens decide whether a claim would have been different if it was conducted and evaluated by different scientists in a different context (p. 191).
Bybee (1995)	The technical words of science and technology is functional scientific literacy (p. 29)	Learners develop perspectives of science and technology including the history of scientific ideas, the nature of science and technology, and the role of science and technology in personal life and society (p. 29)
Cobern, et al., (1995); Eisenhart, Finkel & Marion (1996); Jackson, (1993)*	Being familiar with the natural world, recognising its diversity and unity, understanding key concepts and principles, understanding ways in which science, maths and technology depend on each other.	Knowing that science, math and technology are human enterprises with strengths and weaknesses, having a capacity for scientific ways of thinking, using scientific knowledge and ways of thinking for individual and social purposes.
Cross (1995)	Scientific knowledge is unproblematic, superior and independent of the humans who produced it (p. 153).	Scientific knowledge is a human endeavour, influenced by human thought (p. 154).
Devlin (1998)	Pointless to define scientific literacy in terms of any body of scientific knowledge (p. 559).	We have to rely on experts. But how do we evaluate the experts? (p. 559).

Dulski, Dulski & Raven (1995)	Employs science and technology concepts (p. 169).	Makes rational decisions based on a rational review of available evidence (p. 169).
Evans (1970)	Objectivity, has faith in and values logical reasoning, rejects myths and superstitions, accepts conclusions when supported by data (p. 82).	Skeptical and critical, habit of weighing evidence uses the methods of science to solve problems when the methods are appropriate (p. 82).
Hamm (1992)	Recognises, understands, has a capacity, and uses scientific patterns of thinking (p. 6).	Curiosity, an openness to new ideas, and skepticism in evaluating claims and arguments (p. 7).
Hurd (1998)	Recognise scientific researchers as producers of knowledge and citizens as users of scientific knowledge (p. 413).	Distinguish expert from uniformed; data from myth; evidence from propaganda and knowledge from opinion; recognises when one does not have enough data to ... form a reliable judgement (p. 413).
Lumpe & Beck (1996)	Knowledge of science (p. 149).	Science as a way of thinking and investigating (p. 149).
Zen (1992)	Not confusing theory, which is falsifiable, with data, which we are beyond challenge and neutral in interpretation (p. 19).	Attitude towards learning and toward dealing with contrary views, relating technical knowledge to personal values (p. 23).

* all drawing on American Association for the Advancement of Science (1989).

Table 8

Articles with one conception of scientific literacy in keeping with student-as-recruit and another with students-as-scientists (n=5)

Article	Student-as-recruit	Students-as-scientists
Maarschalk (1988)	Spontaneously engage in scientific dialogue and thinking, reflected in reading, viewing and listening habits and also hobbies and social life (p. 139).	A scientifically literate person will engage in wonder and be on the lookout for scientific endeavours (p. 139).
Maienschein (1998)	Training immediately productive members of society with specific facts and skills (p. 917).	Scientific ways of knowing and the process of thinking critically and creatively (p. 917).
Palincsar, Anderson & David (1993)	The ability to apply scientific knowledge or concepts in principled ways and facility with the language of science that enables the interpretation as well as production of spoken and written text (p. 644).	Given the inherently social nature of scientific activity, collaborative skills that promote constructive social interaction (p. 644).
Pollak (1994)	Our educational system seems to be stuck on the point of view that scientific literacy consists of "having" a diversity of scientific knowledge (p. 89).	It is in the context of "inventing models" held with doubt, as possibility, that facilitates children's conceptions and the pupils to function as scientists (p. 95).
Willison (1999)	Students working in science as if they followed recipes (p. 112).	Students working in science as if they devised recipes (p. 112).

Table 9

An article with conceptions of scientific literacy in keeping with student-as-recruit, student-as-judge and students-as-scientists (n=1)

Article	Student-as-recruit	Student-as-judge	Students-as-scientists
Koballa, Kemp & Evans, 1997	Understanding at these levels involves mostly rote recall rather than connected understanding of scientific concepts and ideas (p. 28).	Judging scientific claims made by others (p. 28).	Goes beyond following steps of the scientific method to include designing and conducting a fair test and proper questioning (p. 28).

In addition to the above references, three references contained no definitions or statements about what scientific literacy is or entails (Eiss, 1970; Mayer, 1997; Pool, 1991). One author (Shamos, 1996) stated that the term is vague and that there is no consensus on what it means. Furthermore, the definitions from two articles were difficult to fit into the conceptions of any of the metaphors. One of these stated:

> The scientific literacy of the average person can be evaluated adequately only with a definition that involves thinking processes and ignores test taking skills. I have in mind a list of skills that represent tasks that people in society do, or conceivably might do. This list should be graduated, to encompass a wide range of abilities, and the graduations should represent different cognitive levels (De Caprariis, 1993, p. 142).

This definition highlights internal cognitive processes, and whilst De Caprariis has 'in mind a list of skills' (p. 142), he does not state what these are. Because in this definition student participation cannot be inferred, it does not fall into the scope of the three-metaphor framework. The second article with a scientific literacy definition didn't fit into the three-metaphor framework (Jackson, 1993) focussed on the sayings of Richard Feynman and how they could be utilised to flesh out 'Science for all Americans' (American Association for the Advancement of Science, 1989). Table 10 (below) summarises the articles that were able to be organised by the three-metaphor framework in Tables 4 to 9. It shows that, of the articles organised by the framework, about 80% of authors present a student-as-recruit concept, and half of these do so as if it is the only way of thinking about scientific literacy. Student-as-judge is represented by about 40% of the authors, and students-as-scientists by about 20%. Only 1 out of 44 authors presented notions of scientific literacy broad enough to be encapsulated by all three metaphors.

Of the articles on scientific literacy that fit the selection criteria, all but two definitions can be understood in terms of one, two or all three of the metaphors from the framework. However, it may be that there are more useful metaphors that act together as a framework to make sense of scientific literacy in the classroom and of the literature definitions. Let the above metaphors, then, be a starting point for discussing scientific literacy from a variety of perspectives. However, I suggest that, in their present form, their capacity 'to organise the literature', and thus fulfil Agin's (1974) criteria, shows a high level of viability and therefore warrants the use of the framework to interpret the vignettes of Section Two.

Table 10

The number of articles on scientific literacy, from Tables 4 to 9, that hold notions in keeping with those of student-as-recruit, student-as-judge and students-as-scientists.

Number of conceptions	Contain student-as-recruit	Contain student-as-judge	Contain Student-as-scientist	No. of articles
1	18	4	3	25
2	18	13	5	18
3	1	1	1	1
Total	37	18	9	44

Conclusion

In this chapter, I have suggested some reasons why scientific literacy has been a fuzzy concept. I then presented a framework for scientific literacy that is composed of three metaphors: student-as-recruit, student-as-judge and students-as-scientists. Some may consider the presence of all three metaphors in the classroom to be unlikely or ungainly, because they may believe student-as-recruit and students-as-scientists, for example, to be mutually exclusive. However, to embrace all the definitions of scientific literacy in the literature all three should be considered together as a complete set for conceiving of how students participate and could participate in Science classrooms. The plurality of metaphors guards against dogmatism and, therefore, facilitates significantly a complementary view of different perspectives of learning. Arguments for the need for all three metaphors are presented in Chapter Twelve. The framework proved to be useful for organising scientific literacy definitions from the literature, which suggests that it is viable for interpreting the fieldwork. The three-metaphor framework clearly puts the focus not on teacher or curricular intentions, but on the active participation of students.

Now the methodology and the theoretical framework for the research has been specified, the tales about Tara, Shelly, Darrien and Jimmy follow. The interpretive framework will then be utilised to consider the effects of learning tasks on these students' scientific literacy.

Section Two

Tales and Interpretations of the Research

This section is devoted to the two tales of the research, and their interpretation. Tale One, composed of three vignettes, features Jimmy and Shelly in different learning situations, represented in Chapters Five, Six and Seven, that provide insight into the effect of classroom learning tasks on their scientific literacy. Vignette One presents Jimmy and Shelly in their Year 8 Science class, engaged in a closed investigation, an event typical of this class. Vignette Two is set in three non-Science classes: Italian, Mathematics and English. This vignette provides a deepening understanding of the ways Shelly and Jimmy may take part in activities that, whilst not occurring during formal Science lessons, nevertheless have a bearing on their scientific literacy. The third and final vignette of Tale One is set once more in Science. However, this time the students are provided with an open-ended investigation task, an event rarely witnessed by me in their Science classroom.

Tale Two, about Tara and Darrien, is similar in composition and also contains three vignettes: Chapter Eight contains a vignette that is concerned with an open-ended Science investigation; Chapter Nine's vignette is about events in English, Mathematics and Social Studies lessons; and the Chapter Ten vignette is about a closed Science investigation. The differences and similarities of each event and the two students' response to these, as interpreted by the three-metaphor framework, provide some useful insight into the ways classroom learning tasks can affect student scientific literacy.

Figure 2.

Righschool students involved in a closed investigation. Having removed tea leaves, staple, and string, they ignite the remaining tissue-tube of their tea bag rocket.

Chapter Five

Shelly and Jimmy in a Closed Science Investigation

This chapter presents the first of the three vignettes that comprise Tale One, featuring Shelly and Jimmy. The chapter also begins the use of the three-metaphor framework to make sense of the scientific literacy experiences of these students. As mentioned in Chapter Two, this vignette is typical of many Science lessons as it represents a closed investigation, a task that occurred frequently in class. Therefore, there is more of the typical than the unique, and this tale is, as such, very important for providing insight into the effects of tasks on Shelly's and Jimmy's scientific literacy.

Vignette One: Teabag Rocket

Shelly carefully pulls the staple out of a teabag. She, along with her work-partner Katie, Jimmy, and the whole class, have just finished watching a demonstration about removing staple, string, tag and tea leaves from a tea bag, leaving a tube of tissue-paper, which is the basis of a 'rocket'. Each group has been instructed to stand the tissue-tube vertically, and to find the best place to ignite it so that the 'rocket' takes off. I am curious to see how students go about launching their rocket, and what they think causes it to fly.

Shelly struggles to light the match, striking it repeatedly on the box until it flares into life. She lunges the match somewhat fearfully at the base of the awaiting tissue paper tube, but knocks the thing over before it can ignite. Katie, inactive until this point, restores the tissue-paper tube to the vertical, and once again Shelly places the match at the base. As the tower bursts into flame and collapses onto their desk, the girls recoil in shock.

Jimmy, after a similar experience, runs to Mrs. Breen's desk and exclaims to no one in particular: 'Mine blew up on the launch pad'. He grabs another tea bag, returns to his desk and begins to prepare for the second launch.

'Give me the match box', he demands of Adrian.

Adrian holds the tissue-tube steady as Jimmy lights it from the bottom. As it begins to burn, Jimmy throws the inferno into the air.

'What are you doing, you idiot?' cries Adrian.

Shelly and Katie soon recover composure and start setting up their second tea-bag rocket. Shelly silently demonstrates to Katie what she wants her to do, holding the tissue tube vertically, so that its base is a few centimeters off the desk. Katie follows this cue, takes the tissue-tube, and holds it in the manner indicated by Shelly. Shelly ignites the tissue from the base once again, and the resulting flame quickly envelops the tissue and almost scorches Katie's hand. Katie hastily drops the tissue-paper inferno, which falls onto the desk once more, and Shelly instinctively blows on it. The burning embers whirl in the air towards Katie.

Shelly apologizes: 'I was trying to blow underneath that ...' She stops in mid-sentence, attacked by the ashes swirling back towards her.

Jimmy balances a tissue tube on top of a pile of tealeaves. He lights the tube from the top, and watches the flame burn downwards, until some tealeaves start smouldering and the ash-tube takes off. After admiring its seemingly leaf-boosted flight, he re-gathers the partially-scorched tealeaves into a neat pile.

The girls clean up the mess from the second rocket, and once again attempt lift-off. They light another tissue tube, this time from the top, and the rocket almost hits the roof. The girls' mouths drop open in surprise.

When I come up to the girls to ask about the experiment, they tell me that they lit the tissue at the bottom, the top and the middle. 'Write down what happened each time', I softly command them as I walk off.

Shelly writes for her observations: 'That once the teabag had burnt from the bottom it went very high.' For an inference she writes: 'The flame draws cold air in and the cold air rushes in under the hot air which makes it rise.'

Shelly reads an explanation on the Science worksheet about how the rocket works, then she dutifully answers all the questions. The final part of the worksheet asks for students to write down any questions they have after doing the experiment. Shelly writes: 'Why is cold air "heavier" than hot air? If cold air is all around the outside of it and hot air is inside, is the reason it rises purely because it is more spread?'

Jimmy completes this final section, writing: 'How high can it go? Can we modofie it? Can we do it with something else?'

The Effects of a Closed Investigation on Shelly's and Jimmy's Scientific Literacy

Vignette One represents students involved in a task that was closed in terms of selecting the problem, choosing a method and arriving at a solution. The students were set the problem of finding how to launch the tea bag rocket (see Figure 2, p. 102), given a procedure to follow and finally provided with the explanation of why the tea bag took off. What is the effect of this closed investigation on Shelly's and Jimmy's scientific literacy? For this interpretation, remember the defining characteristics of the first and third of the metaphors of the framework I am using for the interpretation of the vignettes: student-as-recruit attempts to appropriate the classroom-science being presented in the lesson; and students-as-scientists endeavour to produce novel claims to knowledge through experimentation.

Shelly as Recruit

Shelly acting as a recruit, appropriating classroom-science knowledge, is demonstrated in two chief ways. First, she seemed to be actively engaged in a process that I call 'confirming classroom-science knowledge'. Second, she employed a number of classroom-science strategies whilst conducting and reporting experiments. This demonstrates she successfully accessed this knowledge and believed in the use of it.

Confirming classroom-science knowledge in experiments

In this vignette the students were asked merely to find the best way to launch their rocket. Shelly, however, seemed to turn it into a major exercise to confirm some sort of classroom-science knowledge. First, her actions suggest that she believed the tissue-tube must be lit from the base, as shown by her attempts to do this, even with increasing risk to herself and Katie. This is in accordance with her statement to myself as interviewer (John).

John: Were you expecting- when you first got the tea bag and were unpacking it - were you expecting it would take off if lit from the bottom.

Shelly: Yeah,

John: And what did you think when it kept falling over?

Shelly: That the experiment was pointless (interview, 1/7/99).

Pointless, I suggest, because this experiment did not confirm what she believed it should. It did not occur initially to her to light the tissue paper tube elsewhere, but only that the experiment did not show what it was supposed to. An experiment was pointless if it did not provide access to the fundamental ideas needed in classroom-science. Shelly considered the usefulness of Science, in this her first year of high school, 'was OK. We were just learning the introductory things' (interview, 1/7/99). When she perceived a task did not provide the access into these introduction-to-classroom-science things, Shelly felt 'you don't really need to know them' (interview, 1/7/99). Conversely, it was important to know the things that related to classroom-science knowledge, including the evidence provided by experiments that 'worked'.

The second aspect suggesting that Shelly was trying to confirm some sort of classroom-science was found in her written observation, which stated 'That once the teabag had burnt from the *bottom* [italics added] it went very high'. Shelly wrote this despite evidence that her teabag rocket never left the ground when lit from the base. Third, after reading Vignette One, and watching the video that shows her involvement in this activity, Shelly could not account for why she wrote 'from the bottom.'

John: See how you wrote: 'When it was lit from the bottom; it went up', now you've seen the video, do you still think that?

Shelly: From the video it didn't look like it went up; it only looked like the bits that were burned.

John: Why do you think you wrote it then, when what happened was it just fell over?

Shelly: I'm not sure (interview, 1/7/99).

Shelly reported that the teabag rocket rose when it was lit from the base, a statement that conflicted with the video record. However, it fits the concept of theory-laden observations (Chalmers, 1982) where students, and indeed all people, may observe what their preconceived ideas lead them to expect, despite what actually happens. Shelly seemed to expect the teabag rocket to launch when lit from the base, and endeavoured to make this happen. Even when she was unsuccessful at launching the rocket by lighting it from the base, she still wrote that the rocket rose when lit from the base. These three points suggest that Shelly had in mind during the practical that their rocket *should* be lit from the base. Believing this, she endeavoured to find a way to confirm this in practice, a confirmation that may perhaps have provided evidence for some, up to that point, unidentified classroom-science concept. It may have been a common-sense notion, such as flames burn uphill, that she felt she should confirm.

Conforming to classroom-science notions

Shelly not only sought to uncover and confirm classroom-science notions, but also actively employed canonical notions in her explanation in a manner that I call *classroom-science speak.* By this, I mean saying things that fit what she believed should be done in Year 8 Science. In this first Vignette there is an instance where Shelly seemed to say one thing and do another as if to provide the sense that she was working in a scientific manner. This is typified by her statement about where she lit the rockets, suggesting that she used a methodical approach.

Methodical approach

Towards the end of the investigation into tea-bag rockets, Shelly stated to me that they: 'Lit the tissue at each end, and the middle.' (Note: any quote without a citation is from a vignette in the same chapter as the quote.) From the video record, it appeared they lit two teabags from the base, and one from the top, yet Shelly worded their actions as if it they had acted in a methodical way, by making attempts purposively at three different sections of the teabag rocket. However, she discredited her classroom statement and confirmed her actions:

John: When did you decide to light it at other places?

Shelly: After it didn't work, we just wanted to see if it would work at other places (interview, 1/7/99).

It is possible that, having done the task, Shelly realised a methodical approach would have them lighting each section. With this retrospective thinking, did she then pitch her response to me to seem as if she was acting as a good recruit of classroom science; one who acts in a methodical manner?

The types of questions she wrote down after finishing the experiment further corroborate that Shelly took on the role of recruit. These questions search for clarification of the concepts presented on the worksheet: 'Why is cold air 'heavier' than hot air? If cold air is all around the outside of it and hot air is inside, is the reason it rises purely because it is more spread?' These questions seek for more detail, but do not challenge or question. This can be compared to the type of questions that Jimmy asked, which are questions that explored new territory, as I explain below.

So, in summary, Shelly seems to experience the closed experimental task of tea bag rockets as an attempt to uncover classroom-science, thereby conforming to the practices of classroom-science as much as possible. In other words, her response to this closed task was to participate as a recruit: she accessed or attempted to access classroom science knowledge. Is this also the response of Jimmy in the same situation?

Jimmy as Scientist

Jimmy's involvement with this 'closed' experiment is very different from that of Shelly. Jimmy does not seem to be concerned with finding out the knowledge being presented in the science classroom that day. He finished the lesson by asking very different types of questions compared to Shelly. Whereas Shelly's questions were seeking clarification or explanation of classroom-science issues, Jimmy's questions were about what he could do to extend the experimentation: 'How high can it go? Can we modofie [sic] it? Can we do it with something else?' These questions are those that pursue new knowledge; they do not clarify classroom-science. As such they are the questions of students-as-scientists.

In Vignette One, Jimmy is given the same explanation of what to do, and is occupied with the same materials as Shelly, yet seems to be concerned with the use of tea leaves, possibly as additional fuel to launch the rocket. He had been quick to 'modofie it', suggesting that the relatively closed investigation inspired possibilities in his mind. Jimmy is far more outspoken than Shelly, rushing to the front desk, shouting out excitedly, and speaking rudely to Adrian. Shelly, on the other hand, apologises in the midst of disaster, and shows rather than tells her partner what to do. Where Shelly flinches from disaster, Jimmy revels in it, trying even to amplify it. Jimmy is not of the classical-scientist lineage, conducting controlled experiments, but he is using his imagination to attempt to generate fresh knowledge claims. Consider his question 'Can we do it with something else?' If given resources and time, what would Jimmy have done? Would he attempt to launch different types of paper, such as newspaper and brown paper?

Summary

In summary, the learning task provided access to both students to function in ways that demonstrate scientific literacy according to the three-metaphor framework. Does this mean there is an equity of outcomes when both students are compared and contrasted? Certainly, Jimmy develops as scientist, and Shelly as recruit. One major factor that makes the answer to the previous question 'no' is the method of assessment practised in Mrs. Breen's Science class. It was chiefly composed of written activities, and many of those demanded recall of classroom-science content (field notes, 1998). If Jimmy was sometimes rewarded for his work as scientist in closed investigations, and this was reflected on his report card, then there may be grounds for claiming equity. However, only Shelly's scientific literacy as recruit gave her good final grades. Jimmy's work as scientist seemed to be largely unrewarded by Mrs. Breen. Whilst Jimmy may have been developing some very useful skills, he did not as readily access the classroom-science knowledge, and so suffered in terms of teacher perception and grades. In the next chapter, I present Jimmy and Shelly in subjects other than Science, for these provide a deepening insight into their individual scientific literacy presented so far.

Chapter Six: Shelly and Jimmy in Subjects Other than Science

Chapter Six

Shelly and Jimmy in Non-Science Subjects

This chapter presents Vignette Two of Tale One, in which Jimmy and Shelly attend Italian, Mathematics and English classes. I visited non-Science classes only once in each of the cases of Shelly and Jimmy. However, the experiences were included in Vignette Two because of their salience to scientific literacy. In each classroom, some significant event occurred that helped me to deepen the understanding of each student's scientific literacy developed so far.

Vignette Two: Knitting for the Aliens

'Get your text books, Radichi. Turn to Page One One Six. You have five minutes to study', commands Signorina Giovana.

Shelly puts the text on the desk, and focuses on it with a lowered head. After a few minutes a neighbour of Shelly tests her: 'Il galle'.

Shelly muffles her answer in the book: 'Rooster.'

Signorina Giovana asks the students to rearrange their desks. 'There are rules', she pontificates hastily. 'Rule one is: any talk and you get zero, which is nothing. Rule two: don't call out. It is important you don't turn to Page one one seven. Turn to Page one two six. If I catch anyone turning the page, it's a zero, even if the fans turn it. So you must be responsible. Darrien, that's a zero.'

'Why?' he asks meekly.

You'd think at the end of Year 8 you'd be mature enough to know what to do. Get paper out. If you're writing anything, it's zero.'

The test begins as Signorina Giovana starts the tape recorder: 'Numero uno. Cock-a-doodle-dooooooo.' Shelly smiles as she writes her answer.

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As Jimmy enters Signorina Giovana's Italian class, she announces: 'Last time we had a game with the animals. You have five minutes to practice the animals on page one one six, with your group', says Signorina Giovana.

Jimmy has his cap and an old, tatty cricket ball on his desk, and is sitting with Mark. Mark asks Jimmy: 'What's Loco? What animal, or thing. Whatever?'

Jimmy responds: 'I don't know. What is it?' But he looks in the text, not waiting for Mark to respond, and says: 'It's a whale... Find some in there, and I'll see if I can say without looking.'

'Loopo', challenges Mark.

Jimmy opens the book and reads frantically. He eventually says: 'Wolf?'

'Yeah, cheater', Mark responds.

Signorina Giovana addresses the students: 'OK, Radichi. Two people up to the board.'

The game involves drawing the correct animal when its Italian name is called out. Jimmy puts his hand up high and is chosen to go to the board. He takes his book up with him, and stands close to it, peering at it.

Ms. Giovana tells him 'You don't need a book.'

Jimmy keeps looking at the book, waiting for someone to call out an animal name in Italian.

'You can't do this properly', explodes Signorina Giovana on a short wick. 'OK boys. Go to your desk. Turn to page one one seven. Do this by yourself.'

The class is quietly but definitely disappointed. Jimmy has wrecked their chance at some fun in Italian.

Jimmy sullenly rips a page out of an exercise book and starts writing.

At the top of his list, Jimmy writes 'il cavallo del crico': The horse in the cricus.

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Shelly sits on the sparse mathematics classroom floor with her group, composed of a new girl in the class, a boy and herself. It seemed to me that their group is destined to fail in their brief to build the tallest structure possible from the materials provided. They are one of the last groups determined and assembled by Mr. Ovens, and time is slipping by. Jimmy is nearby, also sitting on the floor with his group. They, too, do not look like they are in the race to build the tallest tower. Shelly sits sorting through toothpicks, looking a little miserable. Mr. Ovens comes up and asks their group: 'OK what's happening?' The boy in Shelly's group is already folding and cutting into a cube shape the only piece of paper they are allowed to use.

Mr. Ovens asks 'Are you going to discuss? Are you sure that's all you're going to do with it? Use it all in one hit? What did you do last time?'

'We used triangles to make it strong', answers Shelly.

'Very good' he commends, and then calls out to the whole class '...OK people, 15 minutes'.

After Mr. Ovens walks off, Shelly's group continues to work separately on their own mini-towers. Mr. Ovens returns to them in a little while and asks: 'How are you using the paper?'

Shelly answers him uncertainly: 'We don't know yet.'

'You don't know yet, but you've cut the paper', he says, somewhat disgruntled. He goes off to another group and says: 'That looks worse than your previous structure. Forty two centimeters was what the other class got.' Then he calls to the class: 'Ten minutes left.'

Shelly makes a single stack of vertical matchsticks. Her single file tower starts to lean at a height of four matches.

Jimmy is working on a structure with a six-legged-horse base. He is sitting near his group members, but each works alone. 'How high is that, sir?' He asks the passing Mr. Ovens.

'Each dot is one centimetre. Measure it', says Mr. Ovens, referring to the dotted graph-paper.

As Jimmy counts the dots, his head nods for each one added.

So far, I've stayed in the shadows in this class. Even though this classroom is very roomy, even sparse, I don't feel I should intrude very much on Shelly's group's space. Mr. Ovens comes over to me to chat about the class. 'They don't seem to be improving on their last efforts, even though the bottom tens have a noticeable marked improvement each time. I think it's because the top kids don't seem to be working together well as a group. This group works well', he says motioning towards a group. 'This group works separately.' Shelly looks up and he confirms his statement: 'Yes, Shelly.'

Jimmy, still working separately from his group, lays on his side and just manages to construct a 10 centimetre cross by the time Mr. Oven commands everyone to pack up.

After the students pack away their equipment, and return to their normal seats, Mr. Ovens says to them: 'I am concerned not many people were putting in an effort. We'll have to work in groups more often. I'm concerned that the highest mark in this activity was about a level four, which isn't good enough. I'm sure some people didn't even speak to their group members. Maybe next time we'll do it as an individual assessment.'

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Ms. Cream addresses her top English class: 'Listen, I want you to work alone, because I must check your work. I can't check if you are talking. I will enforce the "no talking at all rule", because that seems to make you whisper.' Shelly is sitting at the back of the outer horseshoe of desks, with Katie next to her. The students are to finish either their comic strip, due tomorrow, or a book review, due after the weekend.

Shelly and Katie have finished their comic strip in an earlier lesson. I come over and read Shelly's comic strip, which is about two earthlings, Ollie and Sally, who are abducted by Chykkan Aliens. The aliens want the Earthlings to knit jumpers for the Chykkan race. Ollie and Sally complain that they can't knit on an empty stomach. After being offered grass, the humans declare: 'We eat Happy Burgers.' The aliens fly back to Earth, suck up a McDaisy's take-away hamburger store into their flying cup and return. In the final frame, Ollie asks: 'What took you so long?', as they tuck into a happy burger.

Shelly continues to work quietly and happily on the book review until the end of the period, many minutes later.

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Jimmy and Adrian sit next to each other in English.

'Today we are looking at your visual literacy. What is that... Jimmy?' asks Mr. Sarco.

'What you see. Videos', Jimmy responds.

Mr. Sarco starts the video, *The Gods Must Be Crazy*. Adrian and Jimmy exchange brief, happy smiles. Wildebeest appear on the screen and Jimmy waves his hands in the air around his head, as if he had a big, bushy mane. A Kalahari bushman kills a snake, and Jimmy imitates the act of whipping a snake so that its neck breaks. When the bushman apologises to a gazelle for killing it, Jimmy turns to Adrian and does the same.

As the film flashes to Johannesburg, it comments on the complexity of modern society: 'It is so complex, students are sentenced to 10-15 years to understand it.' Not one student bats an eyelid. Soon bullets are flying in a gun battle between government and guerrilla forces as the film flashes to Botswana. Jimmy puts his arm up, as if to protect his face. Two bazooka-operators blow up a helicopter, and Jimmy explodes in his seat. I'm amazed at Jimmy's level of physical involvement, as he reenacts the vivid frames of the video. He stands out in stark contrast to the rather bland body language of the rest of the class.

With a few minutes before the siren, Mr. Sarco turns the TV off.

'OK, which country is it in?' he asks

Jimmy responds first: 'Nambia'.

Then Jimmy corrects himself at the same time as others say: 'Botswana'.

'What other places? What city is in it?

Jimmy says: 'New York'.

'Always giving it a go', I think, 'and fortunately Mr. Sarco seems to encourage him.' His participation far outweighs anyone else's. He emanates a confidence here that I suspect is almost a bluff.

'Starts with a J', prompts Mr. Sarco.

'Johannesburg', says Jimmy.

'Well done Jimmy. J for Jimmy. J for Johannesburg.'

Impact of Non-Science Subjects on Shelly's and Jimmy's Scientific Literacy.

You will recall that each lesson represented in Vignette Two was included because it provided extra insight into the scientific literacy of Shelly and Jimmy. Therefore interpretations consider factors from the vignette that may influence the type of scientific literacy that both students manifest.

Jimmy in English

The language of English was the medium in which Jimmy discussed and thought about science. In the school subject dedicated to this language, it was Jimmy's non-verbal cues, especially his body language, that were salient. It is the theme of 'visual literacy' that provides significantly more insight into Jimmy's scientific literacy.

Jimmy's visual literacy

The International Visual Literacy Association defined visual literacy as follows:

1. A group of vision competencies a human being can develop by seeing and at the same time having and integrating other sensory experiences
2. The learned ability to interpret the communication of visual symbols (images) and to create messages using visual symbols;

3. The ability to translate visual images into verbal language and vice versa;
4. The ability to search for and evaluate visual information in visual media. (Kirrane, 1992).

There is evidence in the vignettes that Jimmy was attaining some measure of visual literacy, as defined above. In English Jimmy, while watching the video, 'creates messages using visual symbols' by using his body language. In Science (Vignette One), he 'integrates other sensory experiences' with his initial visual experience, by devising further related, but different, experiments with the teabag. Furthermore, he translated these experiments with their 'visual images into verbal language' with a range of observation statements, and was able to 'search for and evaluate visual information in visual media' by asking relevant questions that could extend the whole activity in a meaningful way. In applying the above definition in this way, I am taking a two-dimensional 'image' notion and applying it to the three-dimensional visual experience of an experiment. Kirrane (1992) interfaced scientific literacy to visual literacy with the term 'scientific visualisation'. The notion of scientific visualisation helps us to make sense of Jimmy as scientist during closed experiments. The step-by-step instructions provided for the teabag rocket experiment, including a demonstration, provided Jimmy with a significant amount of visual input. This made the experience parallel, in terms of visual literacy, to watching the film '*The Gods Must be Crazy.*' Both experiences provide the visual, and Jimmy's redepicts both in visual ways. From this visual basis, he was able to scientifically visualise further possibilities about teabags, and so launch out from a prescriptive teacher-directed experiment to other potential experiments.

In this realm, a student who is visually literate is not necessarily literate in the written word, and therefore this literacy may pass un-noticed, or at least ungraded. This raises questions about the impact of 'visual literacy' on Jimmy's scientific literacy. For example, when Jimmy was provided with opportunities that give a strong visual input in Science, such as the tea-bag rocket experiment in Vignette One, did it provide him with an avenue of information that he could reprocess in a way that was so meaningful to him that he could imaginatively adapt it into related, yet quite different, experiments? What would Jimmy's response have been to an open-ended experiment (such as is presented in the next chapter) that did not provide initially much visual input, but rather relied on written and oral information for students to implement the activity?

Some implications for Jimmy's scientific literacy include the idea that any written or oral aspects may have not provided access for Jimmy to enter into participation. Science lectures, worksheets, textbooks, even class-wide discussion may not have helped his understanding as much as pictures, demonstrations, reenactments and a variety of hands-on tasks could have. An important feature about English was that it provided Jimmy an opportunity for expression, and he was actively encouraged by his teacher to risk answering questions. I interviewed his English teacher, Mr. Sarco, about his involvement:

John: Very interesting, the way Jimmy was so expressive when you were watching the video. What relevance does that have if you are talking about literacy in general?

Mr. Sarco: First off it shows that he's involved and he's interested. Secondly, because he's able to take in, process, synthesise and evaluate and retell, he's going through the process... so yes it's extremely important.

John: In science his scientific extensions of experiments seem to be better than almost any one.

Mr. Sarco: His reasoning skills are good. It's the written expressive skills that are the weakest. But he realises that. At the start of the year, his written expression was terrible. So somewhere in primary school he got way behind, and it's hard to catch up that big a gap in such a short timeframe, unless that's all you are doing. He's doing OK- I'm quite pleased with his progress this year- he's only a borderline C student. At the start of the year, he was a borderline D student (interview, 3/11/98).

From Mr. Sarco's perspective, Jimmy was gaining ground in terms of written literacy, and was being rewarded for his improvement with a 'C' grade. However, whilst Jimmy's role as scientist seemed to be augmented by his visual literacy, would his 'weakness' in written literacy impair the recognition of him playing this role in Science?

Jimmy in Italian

There was a significant parallel between Science lessons and Italian lessons, as both can be considered a new language to learn (Kearsey and Turner, 1999; Mason, 1971). In the Italian lesson depicted in Vignette Two, Jimmy showed a heavy reliance on the text. First of all, in the game he played with his work partner, Jimmy was not willing to resort to his memory, or even guess what Italian words may be. He searched for the correct meaning in the text each time. This tendency became more graphic when Jimmy was given a turn in the whole-class game. Here he approached the board clutching onto the text as if to guarantee success at the drawing game. These two incidents suggest that text did not remain readily in his memory, but, for Jimmy, reliance on the text bred more reliance on text. Possibly, a more visual rendering of the teaching of Italian may have provided increased access into Italian literacy. The vignette suggests that Italian fostered a text-reliance in Jimmy, and so it is ironic that he failed in the game because text access was denied him at his time of need. It seems that the text did not provide an avenue for retention of Italian terms, but rather served as a security blanket to ensure a correct answer.

Even when copying from the text, Jimmy showed his reading/writing weakness by writing in a dyslexic manner 'del crico'. As Mr. Sarco commented in the interview mentioned above, Jimmy definitely needed writing experiences, but for him a main medium for learning seemed to be visual. In the next chapter I consider the effect on Jimmy's scientific literacy of an open-ended learning task that provided initially little visual input.

Jimmy in Mathematics

The mathematics lesson was highly relevant to scientific literacy issues, because mathematics is a language or tool of science, used to communicate parsimoniously number-based ideas. However, the lesson did not emphasise number, but rather spatial orientation, design and motor-coordination skills. Jimmy is depicted generally as being physically more horizontal than vertical in the Mathematics activity. He is graphically described as lying besides the cross he has built, symbolically dead to the tower-building activity. Why was he so alienated from this activity? One reason suggested by the vignette is that he did not appreciate the other students with whom Mr. Ovens insisted he work. His response was to work independently on a separate project. Second, the verbal instructions Mr. Ovens provided prior to starting construction may not have provided Jimmy with much understanding about what the activity really involved. Without initial visual stimulus, Jimmy stayed 'off task' during the time allocated to construction.

Discussion about Jimmy's Scientific Literacy

The issue of visual literacy raises the need for learning styles to be fully accounted for. The apparent dominance of the visual over the written word in Jimmy's case has important implications, not only for learning tasks, but also for assessment. Whilst the written word, in the form of board-notes, handouts and text books, was dominant in science classes, this mode of learning might exclude visually literate students, like Jimmy. Considerations of inclusivity demand learning tasks with a range of learning modes to provide a greater equity of access to scientific literacy. For example, by facilitating and valuing visual literacy in Science classrooms, avenues of learning may open to those who otherwise are denied access.

For visually literate students like Jimmy, whenever text is emphasised, such as in the Italian lesson, or whenever visual explanation is minimised, such as in the Mathematics lesson, there may be systematic failure by students to carry out tasks in a manner that teachers intend for them. Enhanced visual stimulus, such as in the English lesson, may be the only way to provide some students with access into learning tasks. And so, the textual type of tasks often given to help students appropriate classroom knowledge may exclude students like Jimmy.

Shelly in English

In English, Shelly portrayed in cartoon form the notion of enforced work for no personal gain. In her cartoon, the two main characters were captured by aliens and forced to knit jumpers for them. This could be considered as being symbolic of school life in general, where students are seemingly compelled to manufacture products for prison-guard aliens, and for no personal benefit. However, her two characters in the comic were able to swing a deal with their task-masters and, instead of eating grass, they end up being provided with 'happy burgers'. It is possible that Shelly experienced English lessons as a place of negotiation, where some power may have been exerted by students to have their needs fulfilled: even if they were still forced to 'knit' for their teacher, they were able to get something more than 'grass' out of the deal. In other words, perhaps Shelly felt that she was able to gain something beneficial from the enforced creative writing tasks in English. Was she left feeling like this after Science activities, or did she feel as though she was compelled to 'eat grass'?

English seemed to be comfort time for Shelly, with emotional space and time to be creative. I asked Shelly about her preferred subject at school:

John: Which subject did you like best last year?

Shelly: English

John: What did you like about English?

Shelly: I don't know. It was fun to me (interview, 1/7/99).

If Shelly's Science experience, portrayed in Chapter Five, was characterized by feeling rushed and anxious (see also Chapter Seven), whilst her English experience was a relaxed, fun time, how would this contrast affect her perception of Science and development of scientific literacy?

Shelly in Italian

The Italian lesson provided a format that facilitated students taking on a role, similar in nature to student-as-recruit, of absorbing content in classroom Italian: learning in class based on text and workbook; unfamiliar vocabulary that had to be rote learned; and memory recall mode employed in tests. Shelly, like many other students in the class, crammed in some last minute study during the 5 minutes before the test. She smiled as the test began because she had the fortune of having just memorized the answer to the first question. This was especially fortuitous, because Shelly significantly reduced her effort in Italian during the second half of the year. She said: 'My theory on Italian is "why learn it if you are not going to go there?"' (interview, 1/7/99). Half-way through Year 8, Shelly began to regard Italian as unnecessary, and her grades, which changed from As in Semester One to Cs in Semester Two, reflected her attitude. One question that comes to mind is: 'Will Science continue to be relevant to Shelly?' It would seem that Shelly could not envisage herself going to Italy. What if Shelly could not envisage herself being involved in a career in science? Would she say: 'My theory on science is "Why learn it if it's not going to be my vocation?"' This is a virulent thought, opposed to notions of the *science for all* (Fensham, 1988; National Science Teachers' Association, 1990) movement. If a successful Science student like Shelly, who is able to get straight As through Year 8 Science, eventually regards science as a place she will never go to in her career path, then would her motivation to develop her scientific literacy diminish significantly?

Shelly's Italian experience highlights a trivializing effect of the provision of learning tasks that facilitate students working something like recruits only, in a particular subject area. Many students may be like Shelly in seeing little or no value in accumulating knowledge in an area of little apparent relevance. It is possible that, if students are explicitly helped to see their role in classrooms as comprising more than just the notion of recruit, with its narrow emphasis on classroom knowledge acquisition, then they may attribute greater value to their learning experiences. For Shelly, at least, her role as a recruit in Italian seemed to be going nowhere, and so she pulled back to achieving merely pass grades.

Shelly in Mathematics

Because mathematics is a language of science, some would argue that a person without mathematical literacy cannot be fully scientifically literate. In Vignette Two, spatial notions in Mathematics were being facilitated by the use of tooth-pick towers. However, Shelly encountered some major barriers to working in a way that would 'impress' her teacher; she didn't seem to enjoy the other members of her small group; she seemed to be very rushed; and she seemed to be unwilling or unable to apply her own theoretical knowledge about using triangles in their structure. This last point suggests a gulf between knowledge and application, yet the reasons for this seem to be social rather than technical in nature.

Like Jimmy in the same class, Shelly found the teacher-determined small group makeup to be demotivating (interview, 1/7/99). Teachers often determine small group composition to facilitate students learning to work and communicate with a variety of people. For Shelly, however, very little communication took place, and so the multiple notions of why small groups are useful vehicles for learning seemed to lack application here. Anderson, Holland and Palincsar (1997) suggested that small group discourse is often dominated by the more powerful individuals, or can generate a lot of off-topic conversation. Furthermore, forcing individuals into a small group does not guarantee they will communicate at all.

Summary

Salient in the non-science lessons for Jimmy's scientific literacy were: his visual literacy demonstrated in English; his dependence on the physical presence of the written word for success in the text-based world of classroom Italian; and his cross to bear when working in effective isolation in Mathematics. Jimmy's preference for the visual raises questions about the nature of learning tasks that Jimmy encountered in school. Did tasks provide him with access to learning experiences, or did the high frequency of non-visual tasks often prevent him from engaging in a meaningful way?

The success of Shelly as recruit in Science can be contrasted with her success in English, and compared to her participation in Italian and Mathematics. Was the rush and bother of working as recruit in Science worth it when compared to the space and time Shelly had in English? Did her experience of Italian suggest to Shelly that if she had decided not to go in the direction of a career in Science then she could minimize her efforts? Would her apparent inability to apply science principles in Mathematics (and mathematical principles in Science, as shown in the next chapter) ultimately detract from her scientific literacy? I continue to utilize the learning from the non-science subjects in the next chapter, which presents Shelly and Jimmy involved in an open investigation in Science.

Figure 3.

A Righschool student involved in an open investigation into parachutes. In Shelly's and Jimmy's class, students were invited to ask their own individual research question about parachutes, design their experiment and present in a report their novel results and conclusions.

Chapter Seven

Jimmy and Shelly in an Open Investigation in Science

This chapter presents Vignette Three, the final part of Tale One, detailing Jimmy's and Shelly's involvement in an open investigation, an event that occurred rarely in their Year 8 Science experience. Shelly's rather frantic involvement is interpreted, utilising the three-metaphor framework, as participation in the manner of students-as-scientists. Jimmy's lack of engagement at any level with this task is partly understood by considering his visual literacy and his social interactions. Themes from the previous two chapters are brought together with those of this chapter to portray the nature of Shelly's and Jimmy's scientific literacy.

Vignette Three: Parachutes Squared

'Continue on with your steps for your parachute,' calls Mrs. Breen addressing the class during double period before lunch. 'Then draw up an observation table. We have material in plastic bags, string of two different strengths, thick and thin. If you want to use plasticine instead of rubber, that's OK.'

Shelly puts up her hand and holds it there, waiting. Soon she is waving, trying to get Mrs. Breen's attention, who, meanwhile, is enveloped by myriad classroom management difficulties. Jimmy is in trouble even before he comes in the classroom, and has been left to fidget outside. Shelly, still waving, now stands. Jimmy is allowed in and sits at his usual desk, albeit alone. Adrian sits with another group of boys, claiming he does not want Jimmy to get him into trouble again.

Mrs. Breen calls everyone to sit and then explains the worksheet to the class. Jimmy briefly looks at the sheet, turns it over and rummages for a pen. He starts filling in blank spaces on the back, while Mrs. Breen is still explaining the first side. During a long explanation and class discussion about the experiment Adrian moves back to Jimmy's desk, and attempts to get his earring back in. Eventually, Jimmy moves around the table to help.

'Put up your hand', requests Mrs. Breen, ' if you have finished.'

Katie puts up her hand to join Shelly's still-raised arm. Mrs. Breen gives the two girls permission to begin. Shelly takes a compass, and attempts to draw a circle on some plastic, using a pen. Once Shelly has cut out a sadly misshapen circle, Katie uses it as a template for her own experiment. Katie cuts out a piece of plastic and a piece of cotton.

Shelly works on some calculations for a while, and then comes up to me and says: 'I don't have enough plastic.' Her expressed intention is to make a square parachute of the same area as the round one. I am shocked when I see how much plastic Shelly has left. There seems to be ample to make ten square parachutes of the same area as the round one she is holding.

'I need a square one hundred and eight by one hundred and eight centimetres', she informs me. My mind reels at the size of this square. It would have a surface area greater than her work desk and yet is supposed to be the same area as the circle she has cut, a circle only a little larger than her hand. How could she not see the anomaly, the seeming stupidity of this request?

'Show me how you worked out the area', I ask, wanting to find out how she could make such a ridiculous miscalculation. Shelly puts pi-r-squared into action, and her calculator reads: '433.5'. So far, so good. Then, to find the length of a side of the square, she hits the division button, followed by the four button. 'One hundred and eight', she exclaims. 'See? It doesn't fit.' Sure enough, her sheet of plastic would be dwarfed by such a square and therefore she thinks she doesn't have enough material. How can the power of mathematics bewitch her so?

I brace myself, remembering that Shelly is actually a very bright girl. But how could I account for the obvious lack of any logic? Maybe I'm thinking of her 'equal size' parachutes, and she's thinking of making mathematical equations work?

I begin: 'The area of the circle is right, but the square is much too large. You just found the length of the side if 433.5 were the perimeter.'

'I don't know how to do it,' she says looking up at the clock.

'What is the area of a square with sides of two centimetres?' I ask in a Plato-like manner.

'Four centimetres squared,' Shelly answers.

'What are the sides of a square sized nine centimetres?'

'Three?'

'What did you do to get it?'

'Divide by itself?' asks Shelly in answer.

'Sort of', I respond, thinking she is getting close.

'Find what and what... like square roo... like you..?'

I write: '$\sqrt{9}$', annoyed that Maths teachers never seem to help students apply mathematics to real situations.

'I don't know how to do that,' Shelly laments.

I show her the symbol on her calculator, amazed. It is Term Three of Year 8 and Shelly is in the top Mathematics class. She does not know how to find the length of the sides of a square when given an area. She does not know how to find the square root of a number, even using a calculator. Worst of all, she never thought for a second that there could be something wrong with the size of the square she had calculated. And she was an 'A' grade student in Maths.

Shelly finds the square root to be 20.5, runs to her desk and immediately starts to rule up the plastic. There was now plenty of material to make a square parachute, with sides measuring 20.5 centimetres.

Mrs. Breen comes up to talk to Jimmy, but he refuses to work alone.

'If you're not doing this, you must work from the textbook. Otherwise I can't give you any marks.'

'I do want to do the experiment, but there's no one to work with,' Jimmy insists.

'I told you before, it's an individual experiment.'

'I'm not doing it.'

Mrs. Breen leaves him to stew, and goes to the doorway to speak to a number of students dropping parachutes outside: 'Alright everyone, back in.'

As Shelly hears this, she says: 'Shivers,' to herself, grabs both parachutes and heads for the door. She almost makes it outside, when Mrs. Breen waves everyone back to their seats. 'I want everyone to listen.'

Back at her seat, Shelly works hastily to make sure her parachutes are ready to test.

'I know most of you have done the experiment...' Shelly works at a more frenzied pace, '...but I also want you to do a bar graph.' Mrs. Breen draws an example on the board.

Katie begins to do some test drops with her two parachutes. She is comparing the drop time of a cloth parachute and a plastic parachute. They float to earth in a satisfying parachute-like manner. Shelly grabs the stop-watch, and starts to drop one of her parachutes. However, the string pulls off the plastic.

'Mine doesn't work. It's crap,' she sulks to Katie.

Katie measures the height of the leg of their table. Shelly stops her own repairs to show Katie how to use the timer. But time is of the essence and Shelly quickly repairs the round parachute and drops it. In the results table, under the column heading 'round', Shelly writes: '0.68,' then crosses it out. Next to this she writes: '1.12,' after another drop. Then she crosses this out. She drops again and writes: '0.93,' yet changes the nine to a six, so her only number in that column reads '0.63'. This dropping, erasing and writing process continues for several minutes.

Mrs. Breen passes, and asks: 'So what happened? Is it OK?'

'Yep', says Shelly, 'the round one takes longer to hit the ground.'

'Did you use several measurements?'

'Yes.'

Mrs. Breen smiles, extremely pleased with Shelly's success.

Katie interjects into the conversation, while she is still dropping her parachute: 'I am shocked that the material one wins.'

'Why? What did you predict?' asked Mrs. Breen, glad for Katie's enthusiasm.

'That the plastic one would fall slower. But I'm shocked the material one works at all.'

'So what would you use, if you were parachuting?'

'Cloth'

'Why? Do you want to hit faster?'

'Yes. I'm really amazed that it worked at all.'

Adrian has a timer, and moves back to sit with Jimmy. They try to start and stop the stop-watch in as short a time as possible. Jimmy bangs his timer rhythmically on his desk. He then says: 'I know. See who can get closest to a minute.' They start the stop-watches, and stare at the digital displays.

Mrs. Breen explains to the whole class: 'In the conclusion, list what went wrong, and how you could improve.' Katie decorates her parachutes. Shelly grabs a triple arm-balance and weighs the plasticine that acted as a weight for the parachutes. She struggles to make it balance. She then returns the balance carefully and gets to work on the conclusion of her report. She writes:

> If the key factors are the same the parachutes should come down at the same rate as it was not proven here I have come to the conclusion that the shape <u>does</u> matter to the time.

Katie works on improving her cloth parachute. She drops it and coos: 'Cool,' as she watches its smooth flight. As it floats gently to earth once more, she says abstractly: 'I hate maths with a passion.' Shelly echoes her sentiment: ' I hate maths too.' Mrs. Breen asks the class to pack up: 'Put your parachutes into the report and hand it in.' When the class is dismissed, Shelly walks up and hands in her report plus parachute. Jimmy runs for the door.

Shelly as Scientist

Shelly showed some hallmarks of students-as-scientists in Vignette Three: designing, conducting and reporting on her own experiment, and generating her own persuasive knowledge claims. However, the students were obliged to work individually, and therefore some of the more social aspects of students-as-scientists were missing from Shelly's participation. Shelly's participation as a scientist in the open investigation presented in Vignette Three is evidenced most obviously by her two knowledge claims. The first of these was verbal: 'The round one takes longer to hit the ground'. The second was a written statement: 'If the key factors are the same the parachutes should come down at the same rate as it was not proven here I have come to the conclusion that the shape <u>does</u> matter to the time'. Viewed through the metaphor of students-as-scientists, Shelly, during most of Vignette Three, was occupied with manufacturing data that she used to produce and support the two claims, a process which imparted a persuasive value to her claims.

The direction of the investigation on parachutes depended on personal choice, within the bounds set by Mrs. Breen and was therefore relatively open. First, Shelly determined the research question: 'Does shape affect the time of falling of a parachute?' Second, she chose her experimental method: Compare the time it takes a square parachute and a round parachute to hit the floor. She determined to keep the surface area of the parachutes, the weight connected to the parachutes, and the drop height, all constant. Third, the conclusion Shelly was able to draw was not restricted by needing to find the 'correct' answer. Therefore, the experience depicted in the third vignette can be considered a reasonably open investigation.

Most other students chose to find how drop time varied with the height of drop, presumably because this was suggested as an example by Mrs. Breen (Field notes, November, 1998). It was to these students that Mrs. Breen said: 'I know most of you have done the experiment...' (Vignette Three). They had completed already their empirical work because they chose to follow the teacher's prescription. However, Shelly and Katie were hard-pressed to finish conducting their more original experiments. That Shelly chose to design a more involved experiment shows that she had some confidence in her own ability to conduct open investigations. The students' research had the scope to address many questions about parachutes, and Shelly chose a question that was personally interesting and relevant, as she said:

John: You know when you did the parachutes, how did you end up researching the effect of shape on parachutes?

Shelly: Because at parachute shows they are all different... so which one was best? (interview, 1/7/99)

In order for Shelly to conduct an experiment to address a question of personal relevance, with a strong platform for her knowledge claims, she applied a broad range of classroom-science notions. Shelly, interpreted after Vignette One as a student who attempted to access classroom-science knowledge in the manner of a recruit, also applied classroom-science notions in her work as a scientist. Her use of classroom-science procedures seemed to strengthen the more creative, risk-taking role of students-as-scientists.

Knowledge Claims Bolstered by Classroom-Science Procedures

The manner in which Shelly seemed to work as a scientist in Vignette Three involved applying some of the standards used in Year 8 Science teacher-directed experiments to her own experimental design and report. There are four occasions in the vignette where Shelly used such standards in her experimentation. At these times Shelly showed familiarity with classroom-science concepts, and it is possible that she used them because she believed them to be appropriate standards for use in Science and therefore to have persuasive value for bolstering her knowledge claims. It is also possible that she utilized these because of mere familiarity, and did not conceive of other ways of conducting her research.

Controlled variables

The first classroom-science notion that Shelly used in her work as scientist was that of *controlled variables*, and this is visible in Shelly's conclusion, which included the statement 'if all the key elements are *the same*' [italics added]. She is depicted in Vignette Three using strategies by which she attempted to keep three variables controlled.

In the first of these variables, Shelly went to great lengths to keep identical the area of the square parachute and the round parachute, using a significant amount of the precious time remaining to calculate mathematically (see below) the dimensions of a square, so it would have the same area as the circle. We shall see later that she did not believe she accomplished this. The second example of Shelly controlling variables occurred when she tried to ensure the conditions for each drop were identical, such as the height from which the parachutes were dropped. She did this by eliminating unreliable results:

> In the results table, under the column heading 'round', Shelly writes '0.68', then crosses it out. Next to this she writes '1.12', after another drop. Then she crosses this out. She drops and writes '0.93', yet changes the nine to a six, so her only number in that column reads '0.63'. This dropping, erasing and writing process continues for several minutes.

Or, at least, she claimed that she eliminated unreliable results:

> John : I wrote in there that you had several readings that you crossed out. What happened to those readings that you crossed out?

> Shelly: I'd write it down, then I'd realise it wasn't equal to the other one, or it didn't fall properly (interview, 1/7/99).

For Shelly to eliminate unreliable results suggests a quality control of the experiment in which only accurate results were maintained. This provided an extra air of believability about her results.

The third example occurred when 'Shelly snatches a triple-arm balance off the shelf and weighs the plasticine she used as weights for the parachutes'. She generated evidence for the control of the weight used on the parachute, even though she had very little time remaining to write up her report and hand it in. These three strategies conveyed the idea of controlled variables, and so fostered reliance in the results of Shelly's experiment, therefore giving her report more persuasive impact.

Mathematical equations

The second classroom-science notion which Shelly used in her work as scientist is depicted in Vignette Three, when she applied mathematics to calculate the correct area for her parachutes. She did not merely estimate an approximately similar area for the two parachutes, but rather took the trouble to calculate the areas using two mathematical equations. This allowed her to state her conclusion, backed up by evidence, that she not only controlled relevant variables, but did so by using procedures approved of in classroom-science. The use of mathematics was, however, somewhat problematic for her. Having carried out calculations with what she felt presumably were the relevant mathematical equations, she faced a dilemma: she did not have sufficient plastic. It seems that Shelly believed that it was appropriate for mathematics to be used in her experiment, and that having applied the relevant equation, she must follow what it dictated. Therefore, she sought to make a square that was many times larger in area than her circular parachute. That there was a size anomaly, and that the mathematics may have been in question, did not appear to occur to her:

> 'I need a square one hundred and eight by one hundred and eight centimetres' she informs me. My mind reels at the size of this square. It would have a surface area greater than her work desk and yet is supposed to be the same size as the circle she has cut, a circle only a little larger than her hand.

It seems that the maths equation was trustworthy to Shelly, even when disputed by anomalous evidence, such as a rather large size difference. Shelly did measure the piece of plastic she had available, and found it fell far short of the dimensions she was after, even though it dwarfed the circle she had made previously. This is an instance where a student working as scientist, constructing knowledge claims, did not discern a valid claim from an invalid one. Could the value of knowledge gained from using a mathematical equation eclipse any other consideration? Did Shelly automatically consider the use of an equation as providing a correct answer? She was able to discriminate when it came to her data generation (as shown above), a potentially important facet of working as scientist. That she did not show discrimination about the information provided by the equation suggests an inordinate respect for what she may have perceived to be related to classroom-science knowledge.

Nevertheless, Shelly's use of measurement and mathematical equations, rather than a mere estimate of size, fitted well with classroom-science practice, and so provided further substantiation of her experiment and conclusion.

Repeat trials

The third usage of classroom-science concepts when working as scientist was where Shelly used repeat trials. In the vignette Shelly was portrayed as writing down and crossing out many measurements, and finally retaining only one measurement for each parachute shape. She explained why she did this:

> John: But how many drops did you actually do at the end to measure the square one?
>
> Shelly: I think I did a few, because it was not working properly, so I had to keep repeating it.
>
> John: I wrote in there [Vignette Three] that you had several readings that you crossed out. What happened to those readings that you crossed out?
>
> Shelly: I'd write it down, then I'd realise it wasn't equal to the other one, or it didn't fall properly.
>
> John: Oh yeah. So when you had your final times of falling, how many proper drops did you actually do?
>
> Shelly: Probably only did one, cause I had to get the weight the same (interview, 1/7/99).

Evidently, Shelly did use several measurements, in accordance with classroom-science notions of repeat trials, yet also recognised that most of these were invalid. In the end, she had time for only one useable measurement. She displayed integrity here as, although time constraints were squeezing her, she voluntarily removed trials where one 'wasn't equal to the other'.

However, she answered Mrs. Breen's question: 'Did you use several measurements?' with a reassuring 'Yes.' This affirmative answer sounded like she had conducted repeat trials, and therefore was resonant with classroom-science practice.

Null hypothesis

The fourth use of classroom-science notions is found in Shelly's conclusion, 'If the key factors are the same the parachutes should come down at the same rate as it was not proven here I have come to the conclusion that the shape matters to the time' (Vignette Three). This is worded in a 'null hypothesis' format, which tends to remove a sense of researcher bias. Paraphrased, it could read: 'I didn't intend to prove that a round parachute falls at a different rate than a square one, but this happened, so I have to report it to you.' This written form sounded even more convincing than her oral claim: 'The round one takes longer to hit the ground.'

These four factors taken together show that Shelly produced an armoury of classroom-science based strategies that, intentionally or otherwise, had power to persuade her audience about the correctness of her knowledge claims. When Shelly used classroom-science terms and techniques, such as a methodical approach, when acting as a recruit, it may be like saying: 'I have an understanding of classroom-science, so reward me (as a recruit) with good marks.' When she used classroom-science strategies, such as repeat trials and a null-hypothesis, when acting as a scientist, this served a different function: 'My results are trustworthy because they are procured using authoritative procedures from classroom-science, and you should believe that my conclusions are valid.' This was the effect on Mrs. Breen who 'smiles, extremely pleased with Shelly's success' (Vignette Three).

It must be remembered that, in addition to wanting to provide Mrs. Breen with a convincing report showing the validity of her experiment, Shelly may well have genuinely wanted to find out an answer to her own question.

Shelly's Retrospective View

Shelly's parachute experiment seemed to me to be far less trustworthy than its representation in her report. Shelly's experiment was rushed, made of irregular shaped, and possibly different sized, plastic parachutes, conducted from an insignificant height with possibly different weights and involved only one valid measurement for each shape. Yet, because it was fashioned on classroom-science methods it was highly plausible, and Mrs. Breen was pleased with her claims. Shelly commented on the reliability of her experiment:

> John: In the way you were able to do the experiment in the end, would you believe the results?
>
> Shelly: Not really 'cause I don't think the experiment worked properly.
>
> John: What sort of things were not correct about it?
>
> Shelly: I don't think the weights were properly the same. I don't think the size was the same.
>
> John: What made the size different?
>
> Shelly: The shape. Like, you've gotta make sure the area is the same for both surfaces. I don't think they were.
>
> John: Is that because of the cutting or the measuring or the calculating?
>
> Shelly: Probably both.
>
> John: What, both the calculations may have been wrong?
>
> Shelly: Yeah.
>
> John: And the cutting itself wrong?
>
> Shelly: Yeah (interview, 1/7/99).

Many of these concerns were not raised in her report on the parachute experiment. Perhaps she felt they would make the report less 'scientific', or that she would get a lower grade for it.

Four Important Elements of Shelly-as-Scientist

There are at least four factors evident in Vignette Three that enabled Shelly to act as a scientist. The first of these is a *genuine and relevant research question,* meaning that students were given a reasonable amount of scope to choose what to research. As mentioned previously, Shelly chose her research question based on personal interest, making it a relevant one to address.

The second factor that enabled Shelly to act as a scientist was *ongoing freedom of experimental design and implementation.* Shelly maintained the freedom to conduct her experiment as she intended (this will be contrasted to Tara in the open-ended investigation featured next chapter). As suggested above, her familiarity with, and application of, canonical terms is one significant factor that enabled her to do this without intervention by her teacher.

The third factor is *discriminating empirical data generation.* Shelly generated empirical data, and actually discounted invalid readings. She showed discrimination by crossing out each datum that she believed was 'not equal', which therefore meant her data had at least one hallmark of validity, namely discernment of invalid data.

The final factor is *persuasive reporting.* Shelly's experiment was based on controlling variables, mathematical language and repeat trials. Furthermore, her final conclusion was written in the form of a disproved null-hypothesis. Together, these elements added up to a report that had power to persuade.

This is not to say that these are prerequisites for every student to work as scientist. Jimmy, begrudging the individual nature of this activity, and possibly finding difficulty in visualising what to do, did not take on the role of a scientist. He seemed to require quite different features of a learning activity to facilitate his work as scientist, as discussed in Chapter Five.

Interaction Between Shelly as Recruit and Shelly as Scientist

It is difficult to say whether Shelly used classroom-science concepts when she acted as scientist because she genuinely believed these notions to be superior, because she had thought of no other criteria, or because she felt its use would convince her teachers that she was operating in an appropriate manner. However, one effect of using these concepts, such as 'controlling variables', when operating as a scientist is that they can take on a far greater depth of meaning to students as they apply them. This raises an important issue, that of familiarity being to some extent a precursor to better understanding theory (see Chapter Twelve). In designing and conducting her own experiments, Shelly was able to consider the value of classroom-science notions as they applied to the specific case of her experiment. The use of repeat trials, mathematical formulas for areas and null-hypotheses in her experiment meant that these concepts were, as a result, more tangible and more relevant because they had been applied in her own investigation. Shelly adapted typical cartoon structures in English and creatively utilised them to convey her own message. She did the same in Science; creatively applying classroom-science methods, and so presenting her experiment in a rigorous manner.

Whilst Shelly was frantically involved in acting as scientist in this open investigation, Jimmy related to this learning task in a very different way.

Jimmy in an Open Investigation

Jimmy's actions in Vignette Three are in stark contrast to his energy and creativity of Vignette One. They could be summarised by the phrases: 'Jimmy is in trouble', 'sits ... alone', 'I'm not doing it' and 'Jimmy runs for the door.' Why did he act so differently in these two vignettes? There seems to be at least two major reasons why this occurred.

Social Engagement

Jimmy not only enjoyed his friend Adrian's company in Vignette One, and in the English class of Vignette Two, but his way of relating to him seemed to fuel his imagination. However, Mrs. Breen clearly specified the way that Jimmy should work in Vignette Three:

> 'If you're not doing this, you must work from the textbook. Otherwise I can't give you any marks.'
>
> 'I do want to do the experiment, but there's no one to work with,' Jimmy insists.
>
> 'I told you before, it's an individual experiment.'

Many students were collaborating with each other in their experimentation, as indeed were Shelly and Katie, who were helping each other. However, Adrian stated that he was generally keeping clear of Jimmy, so he wouldn't get into trouble himself. Mrs. Breen's argument to Jimmy was along the lines that he must do the experiment, regardless of being alone, because it was an experiment to be conducted individually. Whatever kind of experiment it was, Jimmy was not keen to do it by himself. This situation seems reminiscent of Maths in Vignette Two, where Jimmy was placed into a group chosen by the teacher. He acted separately from the group and prepared his cross, a visual metaphor of the way he felt. Likewise, in Vignette Three, Jimmy's interaction with this individual activity was minimal.

Students who favoured social interaction for learning were found in significant numbers at Righschool (Waldrip & Giddings, 1994), and Jimmy would seem to be amongst these. To have been able to talk to Adrian about ideas, and feed off each other's imagination, may have been helpful. Possibly, Adrian could have helped interpret instructions provided primarily in textual and spoken form. Yet none of these things happened.

Jimmy was in trouble from the moment he lined up outside the classroom. Adrian kept clear of him most of the time. This social setting for Jimmy was not conducive to healthy learning. He did not design, conduct or conclude anything about parachutes, and so finished by running out of the classroom door at the end of the class, a temporary escape from the perils within. In addition to the social aspect, there is a second reason, linked to his visual literacy.

Non-visual Tasks

An emphasis in the interpretations of Vignette Two was that Jimmy demonstrated a strong propensity for visual forms of literacy. This made sense of his actions in the closed investigation of Vignette One, in which he participated imaginatively in the activity as a scientist. One would expect the open-ended experiment of Vignette Three to be irresistible to him. However, the lesson was presented with textual and oral explanations only. There were no demonstrations of parachutes being made or dropped, and there were no videos, slides or photographs of parachutes. Perhaps this lack of visual input made it very difficult for Jimmy to comprehend what the teacher wanted him to do. This same theme emerged in the Maths lesson of Vignette Two, where the explanation for the lesson was merely oral. Jimmy may not have had any idea about what a tower could or should be like if made out of toothpicks. He reverted to constructing familiar shapes and symbols. When text was emphasised and visual input de-emphasised, Jimmy struggled to take part. The converse is true: where the visual was emphasised and text was secondary, Jimmy seemed barely able to control the imaginative, creative expression that flowed from him. Removing the social, not providing the visual, and expecting an original experiment, may have been for Jimmy the equivalent of blindfolding him, blocking his ears, and expecting him to paint a masterpiece inspired by a musical score.

Disconfirming Evidence

There are several considerations that provide disconfirming evidence for the interpretations that I have made. Previously, I suggested that Shelly described her approach to the teabag rocket experiment (Vignette One) in a methodical way, even though her actions, as recorded on video-tape, did not seem to match this. I claimed from this that Shelly was endeavouring to portray herself as a recruit to classroom-science knowledge. However, when I asked her about this:

> John: There was a time on the video when I thought you said you lit the tea bag from the bottom, the middle and top.
>
> Shelly: Yeah, I did do that (interview, 1/7/99).

Shelly claimed that she had done as she had said in the vignette. However, in my interpretation, I gave more credence to the video record of Shelly's actions, lighting the teabag repeatedly from the base, than to Shelly's own statement. This is because I felt that Shelly was wanting to be considered a successful recruit in class, and that her interview statement flowed from that desire. It may be, however, that the video-tape record missed one of the girls' attempts, and so Shelly's words and actions were consistent in this case. Shelly's very determined attempt to launch the teabag from the base, and her statement that she did successfully launch it from the base when that seemed clearly to be not the case, suggested to me that she sometimes saw things as she believed they should be rather than as they were.

The interpretation of Shelly performing as scientist and *persuading* an audience could be questioned. However, whether Shelly was *intending* to be persuasive or not was not determined in this study. What is more important is that her work did have elements that would persuade an audience about its validity.

Assertions Based on Chapters Five, Six and Seven

When the vignettes and interpretations about Shelly's and Jimmy's scientific literacy experiences are contrasted, it is difficult to ignore the major difference in their learning styles. When provided with the 'same' learning tasks, very different outcomes occurred. For these students pedagogical 'equity' does not imply the provision of identical learning tasks, but rather the provision of appropriate learning tasks that match their different learning styles. Emerging from the research, the issue of equity of access to scientific literacy seems to be salient, and to be problematic in the classroom. I consider there to be seven main assertions, arising from the analyses of Chapters Five, Six and Seven, that relate to the issue of equity of access. These assertions pertain to Shelly and Jimmy, but may prove, with further research, to have wider application.

1. *Shelly and Jimmy reacted very differently to the 'same' learning task in the same classroom.* In this study, tasks provided differing amounts and differing types of access. For example, the open-ended task of parachute testing promoted Shelly to work as a scientist, but failed to engage Jimmy, possibly because he was required to work individually. Moreover, the closed task of the teabag rocket facilitated Shelly participating as a recruit but Jimmy more as a scientist. Of course, on a different day, both may have responded quite differently to open and closed investigations, depending on their own interest, expertise and mood.

2. *The fact that Shelly successfully engaged with learning tasks does not necessarily imply that the learning tasks were suitable for the majority of the class, or that some students had not been excluded from participating fully.* Mrs. Breen needed to look at Shelly's *and* Jimmy's quality of involvement in order to understand the success, or otherwise, of the impact of her pedagogy on student scientific literacy.

3. *When given the scope to work as a scientist, Shelly used many classroom-science notions.* Utilising the mode of operation of the students-as-scientists metaphor may facilitate student learning of classroom-science knowledge, thereby enhancing the role of student-as-recruit.

4. *Jimmy was alienated when he followed the teacher's instruction to work alone.* Jimmy's response suggests that, regardless of the task structure, a student who prefers social interaction for facilitating his or her learning may not engage in opportunities to act as recruit, judge or scientist, if he or she is required to work individually.

5. *Jimmy seemed to demonstrate a low reading and writing literacy but a high level of visual literacy.* This suggests that some students may require a significant amount of visual input, in the form of, for example, demonstrations, videos and pictures, in order to be able to fully engage in learning tasks. A visual style of learning can be catered for in assessment schemes by providing students opportunities to represent visually their findings, for example, through demonstrations to the class, drawings or video records.

6. *Students in Mrs. Breen's class were observed to be experiencing tasks that facilitated most students working as recruits for the vast majority of the year.* As argued in Chapter Twelve, the hegemony of student-as-recruit may be a narrow and restrictive way of developing scientific literacy. The use of multiple metaphors (possibly made explicit to students in Science classes) that help describe different approaches to developing scientific literacy, may enlarge the number of motivations and avenues to learn.

7. *Non-Science subjects may influence the scientific literacy of students, and informed me about aspects of the nature of scientific literacy.* For example, Jimmy's relatively high visual literacy, demonstrated in English,

and low lexicographical literacy, particularly in Italian, seemed to shape Jimmy's scientific literacy. This suggests that teachers and researchers can pursue the notion of scientific literacy outside of science classes and science texts. It is possible that a whole-school community context is necessary to understand fully student scientific literacy. Factors that exclude students from gaining scientific literacy do not necessarily occur in Science alone.

A final consideration is that the interpretations of Vignettes One, Two and Three have focused only on student-as-recruit and students-as-scientists. Therefore, it must be asked: 'What is the value of the student-as-judge metaphor'? It had little place in making sense of Shelly's and Jimmy's scientific literacy, and so perhaps it is redundant. However, another perspective is that it is highly significant that these two students showed no evidence of student-as-judge. Are there some ways of acting in Shelly's experience that could further enhance her scientific literacy, ways conducive to working as a judge? I explore this question in Chapters Eight, Nine and Ten, where I focus on two other students, Darrien and Tara. It was Tara who exemplified, at times, working as a judge, and her manner of working provides a deeper understanding of the possibilities of scientific literacy.

The effects of learning tasks on students' scientific literacy continue to be explored in the following three chapters. The theme of equity of access in scientific literacy emerges more strongly as Tale Two is interpreted in terms of the three-metaphor framework.

Chapter Eight: Tara and Darrien in an Open Investigation

Chapter Eight
Tara and Darrien in an Open Investigation

This chapter presents the first vignette of Tale Two, which features Tara and Darrien, two students in Mrs. Stubalm's Year 8 Science class. The students are engaged in an investigation that was more open than any other I observed in this class, and so was rather atypical of their experiences. Tara, and her work-partner Shannon, embarked on the design and implementation of a simple experiment, only to encounter forces that limited their participation as scientists. Darrien, initially involved in class discussions, seemed to lose motivation as he engaged in experimentation, showing a tendency to participate minimally as a recruit.

Vignette Four: Cooling Off

Shannon and Tara sit at the rear student table. Directly in front of them Darrien and Kevin wrestle over a chair. I am ready for the usual action.

'OK ladies and gentlemen. You guys settle down. I wasn't here on Monday, so what did you do?', demands Mrs. Stubalm.

'We boiled oil and water', Darrien responds enthusiastically.

'What happened?', she probes.

'The water boiled', he says without hesitation.

Unperturbed, Mrs. Stubalm presses on: 'Why did you do it?'

'I don't know. Maybe to see which heats up faster.'

Mrs. Stubalm changes the direction of the conversation.

'What material do you have your coffee in at Macca's? Plastic or foam?'

'Foam', someone calls out.

'Does that affect the cooling?'

Mrs. Stubalm writes on the whiteboard: 'Material around the water' and 'the amount of water in the container'. She places arrows in front of both these statements and then goes and gets some equipment. As she re-enters the room, she calls: 'Boys! Darrien one more time, and you're out.'

'You need to choose one or the other', she says, indicating the two arrowed problems written on the board. Each group must choose whether to research the effect of material type or of the amount of water on the cooling of water.

Tara hits Shannon, then tries to write on a handout sheet, while Shannon retaliates.

'OK, once that's done, tell me why you think it happens. Once you've done that, you must decide what to do,' directs Mrs. Stubalm.

Mrs. Stubalm comes down to the girls and talks to Shannon about where she's up to. She's behind, so Mrs. Stubalm tells her to hurry up. 'You should have done that already.'

When she goes, Tara and Shannon ruffle each other's hair.

Mrs. Stubalm addresses the class once more: 'For your results, think of how often you are going to take your temperature reading. This is an example. Guys, listen.'

Mrs. Stubalm draws a table on the board looking something like this:

time	30ml	60ml	90ml
0	100	100	100
1			
2			

'Hopefully, they will start at the same temp. You don't have to do it the same time as this. So, you need a table to note the different temperatures. Do it now', admonishes Mrs. Stubalm.

Tara writes her hypothesis on her worksheet: 'The material around the water affects how fast it cools down.' Then she writes her experimental method: 'I'm going to get two cups, one foam, one plastic and heat water, and find the time for each to cool.'

Kevin answers the question on his worksheet that asks: 'What will happen?', by writing 'Plastic cup will stay hotter,' and for his reason, 'Foam is a cold substance.'

I ask Kevin to explain what he meant. 'When you hold it it feels colder', he says to me.

Darrien writes: 'It (foam) will cool faster.' And his written reason is: 'Because it keeps heat.'

I ask him what he means.

'You know, plastic heats up really hot.'

As they start Darrien comes and asks me: 'Sir, how do I measure 100 millilitres?', while he is holding an 80 millilitre beaker in his hand.

'You could estimate... or get a bigger beaker.' He goes to get one.

Kevin does his group's time recording between social chats with Darrien, who sits idly by.

I ask them: 'So you think this foam will cool first?'

Kevin responds: 'Well, we did, but when I felt the plastic it was colder. So it will cool first.'

Tara and Shannon boil water at their customary work-station. Tara wears a neatly repaired school-issue jumper and a smile.

She pours the boiling water into two cups, one made of foam, the other of thin plastic, and Shannon starts the timer. As I watch, I notice they show no concern that the water was not the 100 degrees they had already attributed to it in their records. I read the thermometer as 72 degrees and climbing. So I ask them: 'When do you think timing should start?'

They just shrug.

'How *often* will you time?' I ask.

Tara says: 'We'll stop at room temperature.'

It seemed to me that the girls had it all wrong. They had started timing before the water temperature stabilized. They had recorded the starting temperature as 100 degrees, and I was sure it would only peak around 90. And, worst of all, they planned to record merely the time for the water in each cup to completely cool to room temperature.

'Why don't you record the temperature of both containers once *every minute* for ten minutes?' I ask, intending to persuade them to be more scientific.

Tara seems aggravated by my comments.

Mrs. Stubalm comes and, when she hears Tara and Shannon's plan, suggests to them that my idea of taking the temperature every minute is probably more appropriate. Then it suddenly occurs to me what the girls are trying to do. They want completeness of cooling to be the independent variable, and their dependent variable to be the time it took for each cup to cool to *room temperature*. So, trying to modify their original idea, I suggest to them: 'Why don't you record the time at different *temperatures* - 70 degrees, 60 degrees, and so on.' Mrs. Stubalm left me to explain. I hope she didn't think I was interfering with her teaching too much. I was trying to foster the way the girls thought about doing a scientific experiment.

To my dismay, and embarrassment, the girls take only one time reading, at 70 degrees, for each container, sullenly pack up and sit down. Mrs. Stubalm comes to them, and tries to persuade them to be more thorough.

'But I don't want to do it again', complains Tara.

Mrs. Stubalm remonstrates with her: 'But that's what science is all about. How could you convince people it is right? You've got fifteen minutes. You could do it again.'

The girls are unyielding. In the face of conflicting interests, Tara stares blankly at her workbook.

'At least tell me how you can do it again to improve it', implores Mrs. Stubalm.

As she leaves, the girls set to work on the experiment report.

I wander back over to Darrien and Kevin.

Kevin informs Darrien: 'In eight minutes it went down to 68 degrees. Incredible... In ten seconds we do another time reading.'

Kevin does the timing. He also does the reading, and records the temperature. Darrien is sitting lazily, a little distant from the experimental site.

I ask Kevin about the comparison between the plastic and the foam. When I look at Kevin's data I am confused by it. He explains that he recorded some numbers in the wrong column, and has drawn arrows to indicate where they should go.
He interprets the data to me: 'The plastic is cooling faster.'
'Is that what you expected?' I ask
'Yes, the plastic felt the coolest, so I said that'd be cooler first.'
Tara writes under the worksheet title of 'fair test': 'Putting same amount of water, and timing from the same time.' She concludes in the report: 'Yes, it was what we expected. The water in foam would cool down fast.'
Darrien sits at his desk, watching lazily as Kevin cleans up. Suddenly he springs to life and copies down the information Kevin has carefully gathered.
Tara slaps at Shannon, and Shannon slaps her in retaliation. There is recognition simultaneously around the room that the period is almost ended and frantic packing of either equipment or bags takes place. As the girls wait for Mrs. Stubalm's exit command, Tara twists Shannon's arm once more.

The Effect of an Open investigation on Tara's and Darrien's Scientific Literacy

Having presented the first vignette of Tale Two, focusing on Tara and Darrien, I move on to addressing the research question by interpreting this tale using the three-metaphor interpretive framework. What are the effects of this more open investigation in Science on Tara's and Darrien's scientific literacy?

The metaphor of *students-as-scientists* is demonstrated when students generate their *own claims* to know, and attempt to *persuade* others about these claims. It was exemplified by Mrs. Stubalm's admonition that the girls' experiment must be conducted and reported in a way that should 'convince people it is right'. In terms of the above metaphor, this will often require students to work together to generate empirical evidence that they can call upon to help build persuasive arguments. This task seemed to be well suited for students to work as scientists: although it was closed in terms of problem choice (students had to choose one of only two options), it was more open in terms of method (although, of course, limited by the available materials) and seemed to be open in terms of possible solutions. Whilst this was not as open an experiment as that presented in Vignette Three, which featured students involved in experimentation with parachutes, it was the most open investigation that I observed in Mrs. Stubalm's class. First, I will consider the effect of this more open experimental task on Tara, before considering effects on Darrien.

Tara and Shannon as Scientists

Unlike Shelly in Vignette Three, who was compelled to work individually, the students in 'Cooling Off' worked in pairs, as was their custom. If we view this vignette through the three-metaphor lens, there is a picture of Tara and Shannon beginning to work as scientists, designing and conducting an experiment on the cooling of water. This vignette, as pointed out in Chapter Four, is atypical, in that it is the only lesson that I observed where students seemed to be given the opportunity to engage in a more open-ended experiment in Mrs. Stubalm's class. The atypical nature of this vignette highlights the lack of opportunity students had to work in this manner.

Tara and Shannon initiated and designed their own experiment with their own criteria for validating knowledge claims, thereby actively participating as scientists. The girls' hypothesis was: 'The material around the water affects how fast it cools down'. This hypothesis required, at least in their understanding, water to cool completely: 'We'll stop at room temperature.' This criterion of *completeness of cooling* meant that it was virtually impossible for them to satisfactorily conduct repeat trials within the time constraints provided. Therefore, they chose (volitionally or unthinkingly) completeness of cooling to be more relevant in their experiment than repeat trials. This has at least one potential advantage for their experimental knowledge claims: they would not have to infer information about water cooling to room temperature from experiments which were halted above room temperature. For example, I, as participant-observer, encouraged Tara and Shannon to record temperatures for a ten-minute period, after which time the water temperature would still be well above room temperature. If they had done this they would have needed to extrapolate their data to room temperature, resulting in additional complication and requiring inferences or assumptions to be made. In their original design, Tara's and Shannon's experimental data would *directly* address their hypothesis with a minimum of additional inferences. Was *completeness of cooling* a more persuasive experimental criterion in their minds than the ubiquitous repeat-three-times criterion that had been built into many of their previous teacher-directed experiments? If they discussed the completeness of cooling criterion in a class forum, would it have had persuasive value, or would it have been discredited by other class members? I asked the girls if they considered their completeness of cooling criterion to be better than the repeat-trials criterion:

> John: Do you still think that may be a better way than doing it three or four times?
>
> Tara: Yep. I think we should do it that way, and then let someone argue about their points, and then say "you do it"... I'd argue my point. (interview, 17/5/99)

Even well afterwards, Tara seemed to believe the completeness of cooling criterion had persuasive power.

Intervention by the researcher and the teacher

Whilst Tara and Shannon may have felt that the design of their experiment was sufficient, Vignette Four suggests (ignorant) dissatisfaction of the design by myself and then by Mrs. Stubalm. The girls were happily engaged in conducting the experiment that they designed, until our interventions. These interventions are significant because they seemed to compel Tara and Shannon to move away from using their own criteria for conducting a convincing experiment, and thus mark a departure from the girls working as scientists. Tara did not have the opportunity to 'argue her point' about the viability of the *completeness of cooling* criterion. There is little leeway given to Tara and Shannon to encourage their role as scientists. Indeed, the vignette portrays a low regard for the girls' ideas: 'It seemed to me like the girls had it all wrong... Mrs. Stubalm came, and ... suggested to them that my idea was probably more appropriate'. The counsel Mrs. Stubalm and I gave them was corrective in nature, yet disguised as suggestions. However, these suggestions were not ideas that Tara and Shannon owned, but caused them to modify their actions merely to fit in with what we said, without really understanding why. If the girls had been able to keep to their original plan would they have learned more about experimentation, such as the need to consider time constraints, or would they have been able to make their experimental evidence more rigorous?

Tara and Shannon's response to the intervention

Whatever my, or Mrs. Stubalm's, intentions, the actual outcome of the girls' planning, plus our intervention, was that: 'The girls only take one time reading at 70 degrees for each container, sullenly pack up and sit down'. From a classroom-science perspective, this is a very restricted, unconvincing experiment, and unsatisfactory, given Mrs. Stubalm's statement to the girls: 'That's what science is all about. How could you convince people you are right'. Nor was it a satisfactory outcome for the girls, who could think of only one benefit of the experiment:

John: So when you stopped early at seventy [degrees], how did that make you feel about the experiment?

Tara: (Shrugs her shoulders)

John: Did you think your results told you anything?

Tara: I don't know. I guess. We didn't get it right down to room temperature, so... it saved time (laughing) (interview, 17/5/1999).

So, Tara saw the technique modified by teacher and researcher as more efficient (see Chapter Four), if nothing else. The opportunity for them to design their own experiment about factors that affect the cooling of water turned into a prescription of what they should do. This prescription, by its authoritarian nature, stole away the opportunity for Tara and Shannon to work, as they had begun to, as scientists. Tara and Shannon chose to stop experimenting rather than follow our suggestions. If they could not work as scientists, they wouldn't work empirically at all. Why did the girls shut down so severely? Was it just stubbornness? Was Tara disappointed that a rare opportunity they were enjoying had slipped from their grasp? I asked the girls if there had been other situations when they were told they could do one thing, yet were compelled to do another:

John: Did you have any other experiences in Science like that?

Tara: Yeah

John: Any particular ones?

Tara: No. I just know there were other ones (interview with Tara and Shannon, 17/5/99).

Tara's perception that this was not an isolated event, but rather the interruption of students' own planning which occurred from time to time, may have contributed to her suddenness in ceasing to experiment. I asked Tara:

John: How did you feel about that; I came along in the story and tried to persuade you to change? How did you feel about your class teacher telling you to design this experiment, and then me, and then her, coming and telling you to change it?

Tara: Well, she said that we had to do it our way, and then she said we had to do this...I don't know... why don't you just get the whole thing down? (interview, 17/5/99)

Tara felt that it would be better for her teacher to have been honest at the beginning, by stating that students had to write down a particular experimental method, instead of saying they had the opportunity to conduct an experiment of their own design. So, the girls resigned symbolically from working as scientists by packing up the equipment after taking only one reading of the thermometer. I observed no further opportunities during the year for them to engage in open investigations. By the end of the lesson depicted in Vignette Four, Tara and Shannon had no inspiration to design their own experiment and produce knowledge claims. Rather, they seemed to leave the laboratory with negative impressions of what it meant to work as scientists in Science.

Tara wrote in her report that, 'Yes, it was what we expected. The water in foam would cool down fast.' Not only was this not a persuasive report of their experimental design, but Tara did not produce results that confirmed the classroom-science notion of foam slowing the cooling of water. She therefore missed out working as a scientist, and did not access the classroom-science knowledge of the day. I consider further Tara's dissatisfaction in the discussion after Vignette Six, in which students are provided with two completely closed experiments.

Darrien's Engagement in the Open-Investigation

Many students in the lesson depicted in Vignette Four simply followed Mrs. Stubalm's 'suggested' experimental design. That was true of Kevin and Darrien in their implementation of the experiment. Darrien, however, chose not to participate in the experiment that his co-worker was immersed in. Kevin said at one stage of the experiment: 'In eight minutes it went down to 68 degrees.

Incredible... In ten seconds we do another time reading.' Darrien had participated already in the preliminary classroom discussion, written a prediction for the outcome of their experiment, had a co-worker highly interested in the experiment, and yet showed little interest in being involved in the experiment. Darrien withdrew, despite Kevin's enthusiasm.

There are some comparisons and contrasts to be made between Darrien and Tara. In contrast to Tara, Darrien did not appear to put much personal effort into the experimental work. He merely sat near Kevin, allowed him to do all the work, and ultimately recorded a minimum amount of information. At the end of the lesson, it appeared that Darrien had recorded the information that Mrs. Stubalm expected, namely that foam cups cause water to cool more slowly than plastic, and so could be said to have worked as a recruit, albeit reluctantly. He did this without the disappointment felt by Tara, who was compelled to restructure her original experiment. He did it without the 'error' of Tara, who found an answer in opposition to the classroom-science answer.

Summary

Questions that are raised so far include: 'Why was Darrien so willing to be uninvolved while his work partner was active and motivated to conduct the experiment?', 'Did the change from open to closed investigation have a large impact on Tara's scientific literacy?' As I noted in Chapter Seven, Shelly was provided with an open investigation, which she utilised to work as a scientist. However, there was no intervention to stop Shelly. Maybe Shelly's use of a host of classroom-science notions protected her work as scientist, and made it more acceptable to the teacher and more persuasive. Tara, on the other hand, seems to have utilised more commonsense notions, less in line with classroom science. However, she was not given the opportunity to persuade her audience about the efficacy of her approach. This suggests that a student with the appropriate classroom rhetoric may be allowed to pursue his/her line of experimentation, whereas a student without this rhetoric may be compelled to change his or her direction. This is another instance of an access issue, because Tara was prevented from engaging with the freedom that Shelly enjoyed.

In Chapter Seven, Jimmy found himself excluded from working in the open-ended parachute experiment. Did Tara respond in a similar way to Jimmy when given a closed experiment? Did she use its structure and safety to work as a scientist by pursuing questions that fell outside of the classroom-science knowledge being developed? If Tara's access to the science experience she had anticipated was denied her, maybe Darrien too found himself shut out from the type of experience he expected. Or, possibly, Darrien shut himself out from science experiences that did not motivate him. I proceed in the next chapter to consider the effects of non-Science subjects on Tara's and Darrien's scientific literacy.

Chapter Nine

Tara and Darrien in Non-Science Subjects

Tara and Darrien are engaged in English, Mathematics and Social Studies classes in the vignette that follows. Situations in non-Science subjects are included for their value in enriching understandings of these students' scientific literacy.

Vignette Five: English Kingdoms, Maths Calculators and Social Aliens

The quietness of the room seems to envelop the students. Tara sits with one girl between herself and Shannon. Each individual is working on a map of an imaginary kingdom with a brief to design the kingdom's shield and motto. Tara is focused on her work, and looks happy in this somber yet creative environment. I almost try to hold my breath, wanting to remain as unobtrusive in this unfamiliar setting as possible. Although these students are getting used to seeing me appear in different non-Science lessons, they often ask me why I am there. In this classroom, only Tara, Shannon and Darrien know for sure.

Darrien, sitting towards the back, politely breaks into the silence: 'Miss, on the map, do we have a legend?'

Ms. Harsham replies: 'A key? That would be helpful.'

Darrien has a heading written on his rough-work paper: 'The Kingdom of People.' His motto states: 'Have fun and enjoy life.'

Tara has written: 'Miss Harsham's Monastery', next to a drawing of a building on the good copy of her detailed map. Many other buildings are labeled too. When she realizes I am looking at her map, she asks: 'Sir, can I put you on the map?'

'OK,' I consent happily, wanting to see how she will represent me. In the weeks that I have been focusing on Tara, I have developed, in my mind, a metaphor of 'learning as fighting' to make sense of her behavior in Science.

She draws a little building, and writes below it: 'Mr. Willison's porta-loo.'

Is she still annoyed at me for flushing her Science experiment down the proverbial sewer? Or is she looking for a fight?

****

'I'm looking for the student who finishes first. They will get ...'
'Lollies???', anticipates a chorus of voices.
'...a MAPLE award', finishes Mr. Dunlop, somewhat agitated by the interjection.
Tara sits alone. She works on the Mathematics handout sheet, which asks a cryptic question: 'How small is this?' It also includes about 40 mathematical questions and a join-the-dots diagram. Each correct answer to a mathematical question leads students to information that will allow them to join two dots. Once all the dots are joined, a picture or message should appear in front of their eyes. One of the girls behind Tara manages to grab the last available calculator, and begins to punch numbers in. Tara, without calculator, glances behind, looking for answers to write down, from time to time. However, the girls do not cooperate with her and so she begins paper-and-pencil calculations on some of the mathematical questions by herself.
Darrien, Kevin and another boy are sitting at a set of four single student desks that are grouped so they face each other. They are working on the flip-side of the class worksheet, which asks the question: 'What tree has fingers and thumbs?'
I walk up to this group and find that Kevin has already written 'Palm trees' as an answer, and yet has done less than half of the mathematics questions. I ask him how he knew the answer. He says he just figured it out.
Darrien is working through the mathematical questions, and is using the answers to join the appropriate dots. He finishes joining dots, but unfortunately he adds in lines unintended by the designer so that the two words produced look like they are in capital font with a running-writing style. Darrien has a lot of trouble reading what the answer is. Finally he gives up, saying: 'Who cares!' When I look at his work, I realise he had every mathematical question correct. How ironic that he felt like a failure and gave up. My attempts to persuade him that all was OK fail.

Their third group member struggles to read upside down Darrien's cryptic writing and, suddenly, realizing what it spells, calls out excitedly: 'Palm trees.'

Tara chats with the girls behind, and has completed only a quarter of the answers. 'I've only done the easy ones', she informs me when I come to her, 'but I'm waiting for the calculator.' The girls behind are still not sharing with her their answers or equipment.

One of them says to me: 'I know- it's going to be a giraffe. That one's going to be Palm tree.'

'How do you know?', I ask

'We've done it before', they laugh.

'Me too', throws in Tara.

Tara finally captures a calculator and quickly finishes most of the mathematical questions.

Mr. Dunlop approaches Tara to gauge the class work temperature and says: 'Tara, how are you going?'

'I've done this, but not this.' He congratulates her for her efforts.

****

Ms. Sparkee informs the students that today they will begin work on an essay worth 30 percent.

Darrien whispers to a nearby boy: 'I want to get an A.'

'We'll set up headings from page 48. So turn there', Ms. Sparkee directs the class. 'Now, the hardest part is going through and taking notes in point form.'

The class begins to discuss what words fit in to a note-taking structure that had been handed out. Tara draws a picture of a shell on a blank sheet of paper.

Mrs. Sparkee asks: 'What does inundation mean?'

Darrien Responds: 'Ummm..... when it rains?'

As the class discussion ensues, Tara's picture clarifies into an alien with an interesting hair-do.

Mrs. Sparkee writes: 'Agriculture of Ancient Egypt', on the board.

Most students write. Darrien looks at a full-page cartoon of water safety somewhere in the back of the text. Tara starts to fill in some words in the note-taking structure, then flicks back to the alien, which develops breasts and a body. She spends another half-a-minute on the structured overview, then erases the alien's cheek bones, and adds some extra features.

Darrien keeps up with the task of copying ideas from the board, sometimes gazing at the roof when he's finished.

Ms. Sparkee asks: 'Why did they work on the pyramids?'

Darrien replies: 'They got paid?'

'Not really.'

Darrien suggests: 'They'd get food'.

Tara, drawing under cover, chips in: 'They've got nothing else to do.'

Ms. Sparkee declares: 'Why? Because it's raining.'

Tara adds: 'When they've got nothing else to do, they work on the pyramids, and stuff like that', whilst adding to the alien.

After the class finishes filling in the information about the pyramids, they move onto food production.

'You plough your soil. What do you do next?', asks Ms. Sparkee.'

Darrien answers: 'Have a holiday.'

Ms. Sparkee reminds Darrien: 'No holidays.'

'You put your seeds in', someone suggests.

'And then?'

'Use goats to trample the seeds in', states Tara.

Ms. Sparkee pushes: 'What else was used to trample seeds in?'

'Donkeys', says Tara, as she puts the finishing touch on her alien.

The Impact of Non-Science Subjects on Tara

In interviews with Tara's teachers, several expressed the idea of her being a model worker, or a gauge as to how the class should be working. However, in

Mathematics, Tara seemed to waste time and be off-task often, and in Social Studies she squeezed her work between episodes of drawing an alien. She did the work, she caused no trouble, she seemed to be everything the teachers wanted, but she did not appear to be extended in her education, challenged, or stimulated intellectually. She seemed to function as a recruit of these subjects, and completed only the required work, although she seemed to have the potential to engage with more challenging work. I now consider the possible effect of each subject on Tara's scientific literacy.

English

Tara was able to operate in a highly creative manner in English. But what is the difference between the nature of this creativity and that shown in Vignette Four, where she used imagination and knowledge to design an experiment on cooling rate? In English, creativity was safe, as previously noted with Shelly. Creativity was not wrong, as long as it was congruent with the framing of the lesson. In Vignette Four, Tara's creativity in Science was quickly assessed and found to be inadequate. Tara was not developing arguments or knowledge claims in English, but rather was using her creativity in a fictional context. Ms. Harsham seemed to have strict, clear guidelines that the students were careful to remain within. This can be contrasted with Vignette Four, where it was difficult for Tara to know if she had stayed within the guidelines when creatively designing the experiment. It was revealed to her that she had not stayed within the (implicit) guidelines, and that she was working in a manner inappropriate to my, and Mrs. Stubalm's, intentions. Science seemed to demand correct answers and procedures, and to stifle creativity, whereas English provided a platform from which to build creatively. The effect of this in Science could be to mediate against the creativity needed for students to work effectively as scientists.

What was the impact of English on scientific literacy? If Tara compared her creativity in the Science of Vignette Four, and the English of Vignette Five, she may have felt that, somehow, her creativity 'failed' her in Science, but was rewarded in English. In creatively designing Science experiments, 'you don't know if you're right' (see Vignette Six), but in creative English activities, you can't be wrong. This could have the effect of Tara seeing creativity as being inappropriate in Science, but well suited to English. Her motivation to explore the natural world in a purposeful, rigorous and creative manner, that is, to work as a scientist, could be replaced by the safer creativity of expression in a more artistic way. Tara declared in interview (24/9/98) that Art was her favorite subject. In English this creativity was on-task and rewarded. Tara liked to be 'not inferior' to others (see Chapter Ten), and creativity in English seemed to be more satisfying to her than in Science as it may have given her a competitive edge. The room for creativity in English and not in Science possibly suggested to Tara that there was something deficient about Science, and that it was better just to work at a safer or more comfortable level than that of scientist.

Mathematics

Tara, Darrien, and Kevin participated in the same kind of curricular tasks in the Mathematics class. These tasks seemed to have as their basis that students appropriate and practice classroom-mathematics. However, each student's response to this task was very different. Tara's work in Mathematics was highly regarded by Mr. Dunlop, who stated (interview, 1/11/98) that he often used Tara as a guide to how the class should be working. Tara calculated in her head some of the questions, but waited till she had a scientific tool, the calculator, to finish most of them. Here, Tara seemed to appropriate classroom-mathematics knowledge and so participated as a successful recruit, especially when using a calculator and answering questions correctly. How did this Mathematics lesson affect Tara's scientific literacy? She seemed to be satisfying only the basic requirements of the lesson, which reinforced the idea that it is comfortable to perform as recruit. It would seem that she did the minimum work required, was not extended, and yet was rewarded with teacher praise as successful.

Social Studies

Social Studies classroom-knowledge was forthcoming in Vignette Five, and indeed methods of accessing that knowledge were being discussed by Ms. Sparkee and the class. Tara not only kept up with all the copying requirements, but also actively participated by contributing to the class discourse. Yet, at frequent intervals, she drew her alien. This activity suggests that she was 'cruising' in her thinking, and not extended in her academic performance. The Social Science classroom knowledge was presented as uncontroversial, unproblematic, and as needing only to be written down. Tara was one of the top students in the class, and achieved 'A' grades throughout the year.

When I asked Tara what was the most interesting subject, she stated 'Social, with the things we're doing now, that's really interesting' (interview, 1/11/98). Tara's interest in Social Studies was expressed during my two visits to that classroom by her significant contributions to the classroom dialogue. Maybe it was because of her interest in the topic that she could easily draw the alien, keep up with the work, and contribute suggestions. Was 'interest', for her, commensurate with information that is readily available and with good marks? Or was it a place of safety, where intellectual grappling did not have to take place? Tara did enjoy grappling with concepts, but when it became confusing, counter-intuitive or contrary to practical experience, it became unsatisfying and frustrating. Social Studies knowledge seemed logical and understandable, and stood out in sharp contrast to Science knowledge (see Chapter Ten), again reinforcing the safety of working as a recruit.

As with Shelly and Jimmy, English seemed to provide Tara with a safer place for exercising creative expression than did Science. Moreover, Mathematics and

Social Studies seemed to reinforce the idea that it was safer and more rewarded to act as recruit.

Darrien in Non-Science Subjects

In all three subjects depicted in Vignette Five, Darrien engaged in work that was required of him. In Social Studies, he contributed to the classroom discourse and copied down the required notes. In English he creatively constructed his 'Kingdom Map'. And in Mathematics he answered correctly all the questions. He could be considered to be acting as recruit in each subject.

Social Studies

Darrien participated willingly in the Social Studies lesson, suggesting appropriate answers such as 'when it rains?' and 'they got paid.' He also threw in the occasional joke answer, such as 'have a holiday'. Yet, there were occasions when he had finished his writing and waited idly for the next input from Mrs. Sparkee, evidenced by him reading cartoons, or staring out of the window. She commented:

> I get the impression that Darrien is quite- he's definitely a B student- he's quite bright. And he processes things fairly quickly to the point where he gets distracted because he's already got the point of what I'm talking about, and I'm still trying to teach the point again to some other kids in the class (interview, 10/11/98).

Ms. Sparkee not only perceived Darrien as bright, but found his work effort matched his ability, and so Darrien was rewarded, as recruit, with a 'B' grade. I asked Darrien about his attitude to Social Studies:

John: Do you like Social Studies?

Darrien: No. Because it's too much work.

John: Oh, right. Is that, you are made to [work]?

Darrien: Yeah, we're made to.

John: Well, how's that different from, say, Science?

Darrien: Um- well we muck around a lot more in there. Teacher doesn't see you.

John: So you reckon Ms. Sparkee will force you to do more work? And so now that you've done a lot more work in Social Studies than in Science, which one do you think you've benefited from?

Darrien: Social Studies.

Kevin: Social Studies.

John: So, is that a good thing, or doesn't it matter?... Good?

Darrien: Mmm.

John: So you're proud about that?

Darrien: Only about the mark, but not about the work.

John: What mark did you get?

Darrien: I think I'll get an A or a B (interview, 20/11/98).

Indeed, in Vignette Five he whispered to his neighbour, 'I'll get an A'. His attitude in Social Studies may have been, to a large extent, determined by Ms. Sparkee's way of dealing with the students:

But he does settle down and do some serious work as well...Sixty-six-and-a-half, so he got a B. And last time, sixty-four-and-a-half, so I boosted him up to a B. So, yeah, he's doing all the work. Mind you, I always get all the work. Because, otherwise, they are in for detention, so...he actually got an A for his unit test, which is really good, because most of these kids, it's all a plus if they are just copying down and putting in something. With the test, it's all multiple choice and some paragraphs, and things like that (interview, 10/11/98).

Darrien's success as a recruit of classroom Social Studies seemed to be facilitated, at least in part, by his response to Ms. Sparkee's discipline. However, when Darrien's on-task work, good grades and teacher comments in Social Studies are contrasted with times of staring at the roof and gazing at comics, one must question how challenged he was as a recruit of this subject.

Mathematics

Darrien successfully answered the mathematics questions in Vignette Five, yet he gave up in despair on the exercise. This is because he was unable to convert the correct mathematics answers into correctly joining the dots that ultimately provided 'the answer' to the cryptic question. Kevin deduced the answer by reflecting on the question itself: 'What type of plants have fingers and thumbs?' He used the scientific tool of a creative inference, as well as some general knowledge, to produce the correct answer. Darrien did not gain access to a calculator, very much ensuring he was engaged in computations in his head, which he did correctly. Yet, his correct mathematical answers didn't help him interpret the written answer that resulted from joining the dots. A simple misunderstanding of the instructions caused him to give up in despair. This failure to find the correct answer, even after doing the mathematics correctly, may have been an ongoing issue for Darrien. He said that he was an 'average' mathematics student but he hated the subject (interview, 20/11/98). Negative experiences such as this may have started a decline in his attitude to mathematics. The idea of a mathematically able, yet underperforming, Darrien was also stated by Mr. Dunlop:

> His test grades- both tests- this one he just did was appalling.... And I would class Darrien as being one of the most able kids in the class. I think that he may even like mathematics 'cause perhaps he sees the reasoning and he understands the logic behind some of the stuff that we do, and he may even see patterns. So I don't think Darrien sees Mathematics as being futile. He can understand it when he wants to (interview, 1/11/98).

Why did Darrien end up as an unsuccessful recruit in mathematics, even when he was considered to be not only quite able, but a student who liked mathematics? It is salient to compare the work of Tara, Darrien and Kevin in the Mathematics lesson. Who was demonstrating mathematical literacy? Kevin, the imaginative reflector, Darrien the mental-mathematician, or Tara, the user of scientific equipment? All had the answer, but Darrien, who was really wrestling with the mathematics, and learning from the experience, didn't realize he had it in front of him. If they were assessed, who would succeed in the assessment? Tara was utilized by her teacher to determine where the class should be up to, however, she seemed to be the most off-task of these three students. Her teacher believed her to be on-task, because of the way she kept up with the work. Darrien, even if on-task, may never quite have done what it takes to be a successful recruit of Mathematics.

English

It could be said merely that Darrien was quiet and happy, apparently engaged as recruit in English. However, the motto he wrote down for his 'Kingdom Map' seemed to make a lot of sense about the way Darrien acted, not only in English, Social Studies and Mathematics, but also in Science.

Darrien's motto: Have fun and enjoy life

A significant revelation of Darrien's self-image occurred during the English lesson depicted in Vignette Five, where Darrien had written a motto for his imaginary Kingdom. I asked he and Kevin about how this motto fitted Darrien's life:

John: You know in your kingdom thing in English, you wrote something like 'enjoy life and have fun'.

Darrien: Yep.

John: So, is that your motto?

Darrien: Yep.

John: When you go into Science or Mathematics or whatever, is that what you try to do most?

Darrien: Have fun?

John: Yeah.

Darrien: Yeah.

John: So, when you're actually doing work, say in Social or English, you know when you really do the work you're supposed to do, what makes you do that instead of just mucking around?

Darrien: Otherwise you'll get detention.

Kevin: Or scab duty.

John: So, that's less fun?

Kevin: Yep (interview, 20/11/98).

If Darrien saw himself as a fun-loving student, then possibly he would maximise fun in each situation. Having maximum fun in English and Social Studies seems to have constituted doing the work prescribed by the teacher, because the enforced consequences of not working were bad enough to scare Darrien. Of course, it may not have been merely the punishment of 'detention' but also the prospect of a clash of strong personalities, such as with Mrs. Harsham, that was intimidating to Darrien. In addition, Darrien stated that he liked the grade success he achieved in Social Studies. The 'have fun and enjoy life' motto was further corroborated by Darrien's teachers. First, his Social Studies teacher said:

> Darrien's quite bright. And he doesn't- he's not even a ratbag. He actually likes learning. He likes learning for learning's sake. You don't have to get on his back.... and he's really got a very good sense of humor. And even 'life is fun' is true (interview with Ms. Sparkee, 10/11/98).

Ms. Harsham, Darrien's English teacher, said regarding the motto Darrien used on his 'kingdom map':

> Yes, it does fit: cheeky, jokes, relaxed in class, lots of eye contact, asks questions, leaves his desk and comes up, doesn't say he hates English, is positive. If he's reprimanded- yesterday he had to come back- he didn't fly off the handle. He knows when he's done the wrong thing (interview, 10/11/98).

Without mentioning Darrien's Kingdom Motto, I asked Mr. Dunlop, Darrien's Mathematics teacher, what he thought would be a fitting motto for Darrien:

> If I put myself in Darrien's shoes there's the motto, 'work hard and play hard'. Certainly he doesn't work hard... he doesn't come to the lesson to work. He actually- if he does work hard then he works hard at avoiding doing what's necessary. Work's not a motto. I like Darrien. I try and like most of the children. I find him interesting and I find he has got a sense of humour, and a higher intelligence than the average intelligence of that group. And he understands when you're joking and when you're not... If he's motivated and he wants to, he can do it. It's finding when he wants to do it, which is not often.... Yeah. He wants to have fun. He wants things to be- not even fun whilst learning- I don't think he would be too worried if he learned nothing in Mathematics. Maybe I've got it wrong. But some of the kids after a few lessons may say, 'Well, I'm learning something.' But he's a bit more

> demotivated. Perhaps as long as Darrien's having fun with his mates, he's not at all concerned about his education (interview, 1/11/98).

Mr. Dunlop seemed to have captured some paradoxical elements of Darrien's character: work hard…to avoid work; higher intelligence… and not worried if he learned nothing; if he wants to he can do it… which is not often. Of the non-Science teachers, it was only Mr. Dunlop that deplored Darrien's lack of application, especially as he perceived Darrien's potential as one of the most able students in the class. Yet, each teacher agreed that Darrien's motto of 'have fun and enjoy life' was well suited to him. All seemed to see a clever student with great potential.

The simplest explanation for Darrien's application in English and Social Studies, is that he responded to the discipline and character of the teachers of these subjects by doing as they asked. Would Darrien's potential ability, that his Maths teacher felt he possessed, have been partly realised if the teacher had higher expectations and enforced punishments? Probably not, as Mr. Dunlop expressed (interview, 1/11/98) that, as he began to increase sanctions against Darrien's lack of work, so Darrien's negativity had increased.

Another possibility is that English and Social Studies did not pose a threat to Darrien as they did not challenge him academically. In the English Vignette, Darrein was merely drawing a map of an imaginary kingdom and, in Social Studies, Darrien gazed around the room and out the window whilst waiting for the next step. However, in the Mathematics lesson of Vignette Five, Darrien seemed to apply himself, without a calculator, to get the right answers to the mathematics. Yet, he was confounded in the solution to the cryptic clue, not by his mathematics, but by a few wrongly drawn lines. As noted previously, maybe he had a few too many experiences like this when his maths ability did not seem to help him get the right answer. Possibly, failure as a mathematics recruit was self-perpetuating. He was observed utilising maths concepts in Science on numerous occasions (field notes, 1998), even when this was not specifically asked for by Mrs. Stubalm. Yet, Darrien's first 20 minutes of any Science or Mathematics lesson tended to be characterised by reading magazines, chatting, humming, doodling and wrestling (field notes, 1998). It is as if the first rule of 'have fun and enjoy life', for Darrien, meant that he should reduce to a minimum the time spent doing school tasks. This then leaves time for fun.

Darrien's Underperformance in Science and Mathematics

Darrien was presented in Vignette Four (a more open science investigation) as involved initially in the class discussion and writing predictions, and also at the end in recording Kevin's results. In between, he did very little, leaving the work to Kevin. Darrien's failure in terms of grades, and frequent reluctance to engage in tasks, were similar in Science and Mathematics. Mr. Dunlop, Darrien's Mathematics teacher said:

> I'd find it interesting to find what outcomes were hypothesised about Darrien, because Darrien is an interesting student; frustrating, interesting, he's different... quite a special student (interview, 1/11/98).

Darrien's Science teacher also found Darrien difficult to understand:

> I'm currently in two minds. I'm not sure if he is actually pretty bright once he is motivated, or if he does things as a means to an end. Is he working to his fullest, to, I suppose if he's working as fast, to the greatest capacity he can be? Or whether he's just doing it: "Mrs. Stubalm said get it done. I want to get it finished, I want to get home, and I'll get it done as quickly as possible." I don't know whether he gains any connection by doing it (interview with Mrs. Stubalm, 3/7/98).

It would seem that Darrien was very much like a conscript at school when forced to work as recruit. This manifested in Social Studies and English as consistent participation, good marks and teacher acclaim, because, in these subjects, Darrien seemed to suggest he had little option but to do the work. However, in subjects such as Mathematics and Social studies, he did not seem to be affected by this type of pressure, and completed work only when it was absolutely necessary.

Summary

It would seem that Darrien's non-Science teachers believed he was quite capable of completing in a satisfactory manner the work set in their classes. His English and Social Studies teachers managed to extract that kind of work from him. Seemingly, however, without the fear of significant punishment in Science and Mathematics, he slumped to completing a bare minimum of work. Darrien's actions appeared to be in keeping with someone recruited against his will, conscripted into classroom-knowledge. That was actually very close to the case, as his mother informed me that she had 'pulled him out' of his previous high school and made him repeat Year 8 at the smaller Righschool (interview, 5/5/98). Possibly Darrien, feeling conscripted by Righschool, would only 'march' if the 'sergeants' barked at him.

Salient in the non-science lessons for Tara was: the dialectic tension between participation and working off-task in Social Studies; her avoidance of mathematical work, in contrast to her use as the class 'thermometer' in Mathematics; and her freedom of expression in English. Taken together, these subjects seemed to suggest the comfort and security of working as recruit. In Mathematics and in Social Science, Tara seemed to be capable of much more, yet did not achieve it, and was not extended. In the next Chapter I present how Tara dealt with a challenging situation that arose from a closed investigation. I suggest that the lack of challenge in some non-Science subjects, coupled with her grade success, had an impact on her scientific literacy. Likewise, the apparently safe creativity of English continues to be contrasted with the creativity possible in Science.

Figure 4.

Righschool students involved in a closed investigation into the expansion of solids. When students heated the metal ring, the metal ball, which did not fit through prior to heating, was able to pass through.

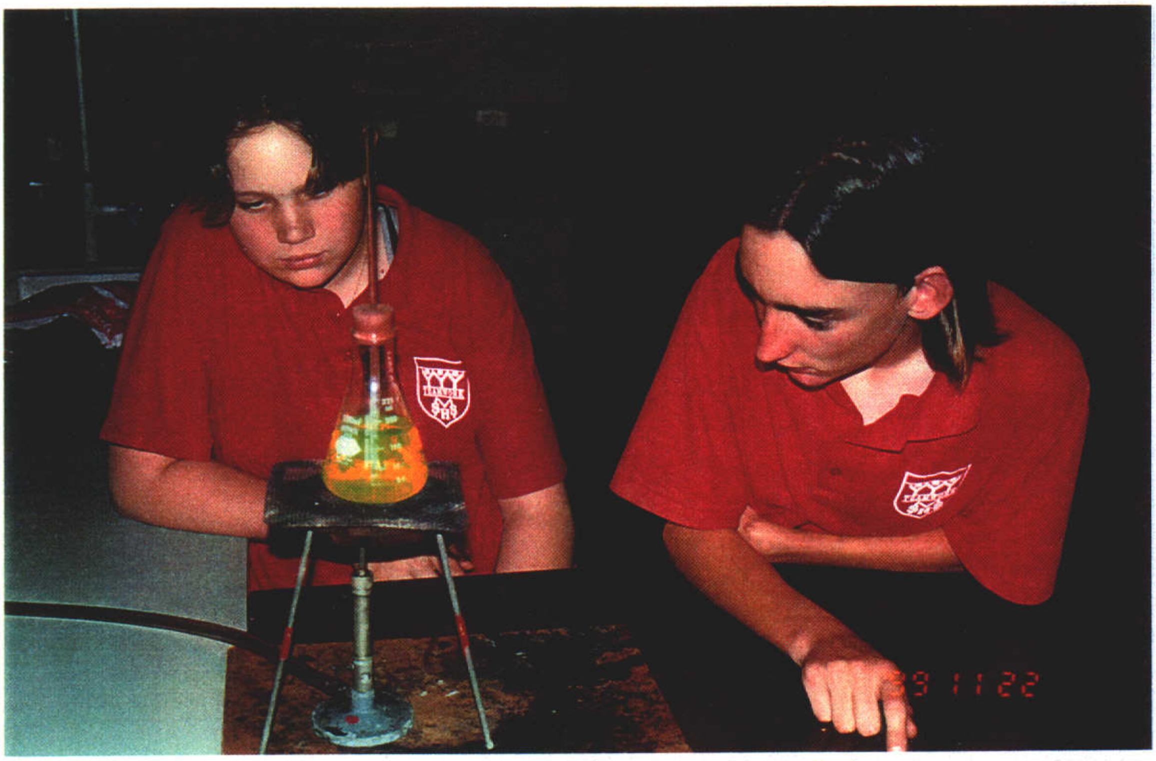


Figure 5.

Righschool students involved in a closed investigation into the expansion of liquids. As students heated the green-stained water in the flask, the water rose up the glass tube, supposedly showing that liquids expand when heated.

Chapter Ten

Tara and Darrien in a Closed Science Investigation

This chapter presents the third and final vignette of Tale Two. This vignette is typical of many Science lessons in that it represents a situation of a closed investigation, an event that occurred frequently in Mrs. Stubalm's class. The vignette focuses on the effects of typical Science tasks on Tara's and Darrien's scientific literacy. The three-metaphor framework is utilised to interpret the vignette, and the significant implications from Chapters Eight, Nine and Ten are considered together.

Vignette Six: Science is Stupid

As I stroll towards the back of the Science classroom, Mrs. Stubalm is already talking to the class. I hope to be unobtrusive, yet want to acknowledge the occasional smile of greeting from the students. Tara is, as usual, sitting next to Shannon. They turn around to chat to me, but I quickly persuade them to look to the front. It is the final lesson of the day, and I hope that the class will carry out an experiment, partly because this usually turns out to be more relevant for my research, but mainly because it is more interesting listening to the students try to make sense of phenomena. By the time I sit behind the girls, on the experimental bench that runs along the rear wall, Mrs. Stubalm is already asking the class a recollection question: 'What happens to a gas when we heat it?'

'Expands', exclaims one of the boys.

Tara calls out: 'Matures'.

I wonder to myself why Tara uses a word like that.

'This afternoon we are doing another experiment, and I want you to predict what will happen', declares Mrs. Stubalm. The class is obviously pleased, and I smile to myself.

Mrs. Stubalm asks: 'What do you think will happen if we heat the liquid?'

'Bubble', someone calls out.

'Yes…,' hesitates Mrs. Stubalm, seeming somewhat disappointed at the answer, '…and a solid?'

'Expand', says one of the boys near the front.

'Yes. A very good word', commends Mrs. Stubalm. The boy throws his chest out.

'Metal burns and shrinks when you heat it', adds Darrien.

Mrs. Stubalm seems to avoid his statement, and immediately asks the students to start writing their predictions in their exercise book.

After a short while, the students are instructed to gather a text book, and refer to a specific page. On it, a diagram depicts a metal ring of slightly smaller inside diameter than the outside diameter of an accompanying metal ball.

Mrs. Stubalm explains: 'What you're trying to do is put the ball through the hoop. You need to be careful, because you could burn yourself. Decide what to heat, the ball or the ring. You have to push it through the ring.'

She then explains about an investigation involving heating liquid in a flask, and asks students to write down predictions for this experiment.

Darrien calls out: 'Miss, what do we predict?'

Mrs. Stubalm, with patient agitation says: 'About what will happen to a solid and liquid when we heat it.'

Tara collects the equipment and sits down next to Shannon at their lab bench. They light the Bunsen, and start heating the ring. Soon Tara lowers the ball through the hole in the ring, and says: 'We did it!' She looks very satisfied at their success.

Shannon also takes a turn at using the apparatus, and after she finishes, she hangs the still-warm, carbon-coated laboratory tongs from her nose for a joke. 'Ow!' she screams. Tara rushes up to look, and we all laugh at her barely scorched, yet blackened, nose. Shannon recovers some composure, and she and Tara start heating a flask containing water stained with flouroscene. A vertical glass tube passing through the middle of a rubber bung had been positioned so that its lower end is immersed in the water. The green-stained water begins to rise up the tube.

'Hey, look sir, it's going up,' Tara comments to me as I look on.

'Why?' I ask

'Air pressure. The air bubbles expand and the liquid has to go somewhere, so it goes up.'

As I look I see the thousands of tiny bubbles rising to the surface of the coloured water inside the flask. I feel a little dismayed, since the experiment is supposed to show expansion of liquid, not increased pressure due to gas release. Yet Tara's explanation strikes me as having a better fit with what seems to be occurring in the flask.

Tara turns off her Bunsen. As the flask cools down, she exclaims to me: 'Hey, look, there are bubbles coming back.'

'Why is that? I ask, at the risk of sounding repetitive.

'Maybe the air is trying to get back into the water.'

'But look where it is going', I respond, trying to help her see the air is rising through the water, and disappearing as it reaches the air space above.

'So it must be less air in there', she infers.

'Yeah', I agree.

Darrien and Kevin are using the gas outlet next to the girls. Darrien asks: 'Why did the skeleton cross the road?'

Kevin doesn't know.

'Cause he had no butts,' chortles Darrien

'That's not even funny,' complains Kevin.

Suddenly Mrs. Stubalm calls out: 'OK everyone, pack your equipment away.' The girls quickly pack up, and sit with the text open, and quietly do nothing.

'Quickly sitting down, facing the front,' says Mrs. Stubalm. 'We want to keep moving... Write down what equipment to use for the liquid experiment'

One of the boys asks: 'Can you use the book?'

Mrs. Stubalm responds pleasantly: 'Of course you can. Very few things in life you can't use a book.' To the class she says: 'Once that's done, you need to come up with a procedure. It's actually in the book, so you can copy it out. It'll save you thinking of one yourself.'

Tara asks: 'Miss, where's the procedure?'

'All the dots,' she says, indicating some bullet points on a page.

Tara sits, copying.

'Tell me what happened to your liquid and solid', asks Mrs. Stubalm.

I return to Tara and ask her: 'What was your prediction?'

'Metal would burn and shrink...and that's what happened. It shrinks to let the ball through.' I'm caught by surprise, as this answer seems totally inappropriate. Shannon rescues me.

'No it doesn't. It expands.'

'No, the ring *shrinks.*'

'It *expands*'.

'It *shrinks*, because the ring becomes thinner and thinner, until the ball gets through', explains Tara, getting extremely frustrated with Shannon's thinking.

Shannon is also annoyed with Tara, and retaliates: 'The hole has to get bigger to let the ball through, so the metal must *expand.*'

Tara's explanation has me puzzled, too. They call in Mrs. Stubalm, but the conversation goes round in similar circles.

Returning to the front, Mrs. Stubalm asks the class: 'What happens to the solid when it's heated?'

'Expands,' someone calls out.

Mrs. Stubalm nods confirmation.

Shannon whispers to Tara: 'I *told* you.'

Tara sits quietly, looking annoyed. I return to her to try to understand her point, and she continues her explanation: 'I mean it shrinks outwards. Like, the metal inside shrinks towards the outside.'

'You're saying the actual metal bit gets smaller?' I probe.

Tara nods.

'What actually happens is the metal expands and moves out,' I explain.

'I told you!' triumphs Shannon again.

Tara grows even more frustrated that I, too, do not understand her. She presses on: 'The outside expands to give the inside room to shrink... see, I said Science is stupid, 'cause you don't know if you're right.'

I wonder at the meaning of her strange explanation. I want to find out more from Tara, but the class discussion intervenes.

'What happened when you heated the ball?' asks Mrs. Stubalm.

'When you heated the ball, it was bigger so it didn't fit well into the ring,' replied someone at the front.

Tara browses through the text with an air of disinterest.

'So it *expands,*' exclaims Mrs. Stubalm.

Tara nonchalantly turns another page.

Mrs. Stubalm asks the class: 'What happens to the liquid?'

Tara tunes into the question and suddenly calls out: 'It went up, then it went down.' The class discussion continues with the theme of substances expanding when heated, and Tara does not mention the observations she revealed to me about bubbles in the solution. When Mrs. Stubalm dismisses the class Tara leaves with a peaceful expression on her face.

Interpretation of Tara's Involvement in Vignette Six

What is the effect of this more closed experiment on Tara's scientific literacy? The 'open' investigation of Vignette Four closed sadly for Tara, and seemed to disenchant her. Does the closed investigation of Vignette Six provide more encouragement to Tara, because Mrs. Stubalm clearly specified that students were to follow her predetermined steps? In other words, there was no promise of students being able to design their own experiment, and so no potential existed for this promise to be revoked.

I noted in Chapter Seven that Jimmy could be understood as working as a scientist in a closed experiment, but a more open experiment did not involve him. Darrien already displayed little participation in an activity that was presented as being more open than closed. Was he, like Jimmy, more likely to be motivated to take part in a closed experiment?

Recall that working as judge is exemplified in Tara's comment in the sixth vignette, 'I said Science is stupid, cause you don't know if you're right.' In this statement, *she evaluated the knowledge claims* of the classroom-science being developed at the time. This statement by Tara flowed out of her interaction with Shannon, Mrs. Stubalm and myself, regarding the heating of the metal ring in Vignette Six.

Tara's Conception of the Metal Ring

An interview I conducted several weeks after the event portrayed in Vignette Six provided some insight into why Tara conceived of metals shrinking when heated (see figure 4, p. 175). When I asked her to explain, she summarized with great clarity what she believed happened:

> Well, the size of the actual ring didn't change shape, but the inside went outwards, but the outside stayed virtually the same distance around the outside, so the ball fell through. And she [Shannon] said that it expanded around the outside (interview, 7/9/98).

Although Tara went quiet after her disagreements over the expansion concept, and did not push her knowledge claims during the whole class discussion, weeks later she continued to believe in the more *logical* value of her 'shrinking' concept. This is suggested in the same interview:

> Tara: Yeah, but mine, I knew I could win.
> John: What, you think the logic of your argument was satisfactory?
> Tara: I actually thought about mine before I actually went out and yelled it out (interview, 7/9/98).

Tara had an alternative way of inferring about the observations of this experiment, and she ended up in conflict over her shrinking concept. Tara struggled to get others to see her point, and became increasingly frustrated as each person, in turn, did not understand her:

John: Did everyone else's thinking - that was different from yours- like how did you feel about it?

Tara: Like, everyone who wasn't listening to me? Made me angry, 'cause they weren't listening to me, and made me yell even louder, and say my point (interview, 5/5/99).

Some possible elements that influenced Tara's conceptions are: Darrien's prediction that metals shrink when heated; her experience in other Science lessons with metals burning, for example, when she heated magnesium; and Tara's prior 'real-world' experience with metals being heated, such as watching her dad weld.

John: Had you seen any metals heated that did shrink before?
Tara: Yeah... when my dad was welding.
John: What did you see then?
Tara: I don't know... just... I don't know...I wasn't supposed to look, but I did anyway... It went in that way a little bit, into it (interview, 7/9/98).

Whatever the reason for believing metals shrink when heated, Tara seemed to have a thoughtful concept, consistent with her prior knowledge regarding why the ball passed through the ring, in accordance with Duit's statement that 'most students' conceptual frameworks are not just 'fuzzy ideas' but often form surprisingly coherent frameworks that guide and determine learning considerably... Student's conceptual frameworks guide observations (1991, p. 71).

There are at least three factors that may have affected Tara's understanding about heating metals.

Three Factors that Affected Tara's Conceptualisation

If we conceive of Tara as judge, weighing the evidence, why did the scales tip away from the classroom-science concept of metals expanding when heated? Why did this closed experiment cause her to pass her judgment of Science as 'stupid'? At least three significant factors may have impinged on her adjudication. First, the class was engaged in a *chemistry unit* at the time of Vignette Five. A few weeks earlier they had been considering chemical changes. However, during the consecutive weeks from which were taken Vignettes Four and Six, the class was involved with concepts of physical changes. Darrien's and Tara's prediction that metals should burn and shrink when heated was perfectly fitting for the context of chemical change. However, the classroom-science knowledge that Mrs. Stubalm was addressing was not concerned with the effects of heating on the chemical nature of metals, but rather their physical properties, and specifically that of volume. The earlier class context may have provided the conceptual lens through which Tara viewed the heating of the ring, that is, a 'chemical' lens rather than a 'physical' lens.

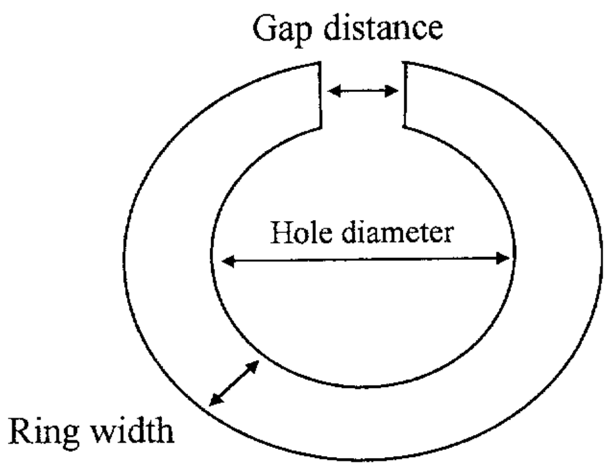
This relates to the second factor of decontextualised questions in Science. Mrs. Stubalm asked 'What do you think will happen if we heat...a solid?'. The wording of the question is vague in terms of subject and tense. 'A solid' is a very vague term, stripped of context. If that solid was magnesium, then Tara's prediction would be correct, unless it was heated in a vacuum, or in an inert gas. If the question was specific, such as, 'what do you think will happen to *this* ball and ring when heated?', it would be far less open to ambiguity. Furthermore, the question could be reworded in at least two tenses: 'what happens to solids *whilst* they are being heated?', that is, present tense; and 'what happens to solids *after* they are heated?', a case of past tense. This second rewording is relevant to Tara's observation of her dad welding, where, after heating, the metal 'went in', that is, the welding rod contracted to a small seam when her dad had finished. It is possible that Tara interpreted the question in the past tense, whereas Mrs. Stubalm intended the meaning of the present tense, a meaning seemingly taken up by Shannon and others. It is possible that, in effect, two students, sitting side by side, were answering the same string of words, while perceiving quite different questions.

The third factor regards the insufficiency of observations made by Tara. Tara took the option of heating only the ring, and found that the ball fell through it. However, she did not measure the outside or inside diameter of the ring whilst it was hot, nor was she, or any other student, encouraged to do such a measurement. No surprises there, as this would be a hazard to safety. However, without such a measurement, it is not possible to say whether Tara's idea, that the outside diameter remains the same and the inside 'shrinks towards it', is true or false. In addition to the above factors, there is also a significant issue of common-sense knowledge that seemed to impinge on Tara's thinking.

Expansion of metals

It is commonly taught that the expansion *joints* between railway lines *shrink* when the rails get hotter, because the rails expand and so increase their length. A metal ring is a three-dimensional object which expands in every direction when heated. The width of the ring becomes larger as the metal expands inwards *and* outwards, so the hole due to the width dimension expansion would be smaller. However, since the length dimension of the metal (in this case the circumference) also expands, the whole ring expands, causing the hole to be larger. It seems that the expansion of the hole due to length expansion was, in the situation depicted in Vignette Six, greater than its shrinkage due to width expansion. This idea is clearer if we have a metal ring with a gap in its diameter (see Figure 6). If such a ring is heated, the hole diameter will become smaller *because* the metal is expanding in the dimension of the ring width, and because the circumference expansion has no effect on the hole size until the gap is completely closed. To say we know that metals expand when heated because the hole in the ring becomes larger may seem, to Tara, to be like saying that a hole in the ground gets larger when dirt is added to it.

Figure 6.
Three dimensions that change during the heating of a metal ring with a gap in its diameter.



When a conventional Year 8 Science experiment ring is heated the hole does indeed get bigger. However, because Tara seemed to use a schema of 'when metals expand, holes in them shrink' she was at conflict with the logic of the classroom-science. Because the hole was bigger when Tara heated the ring, her schema led her to conclude that the metal shrank.

Her own logic did not seem to be faulty; she seemed to have very good reasons for believing her own explanation. However, the effect of the experiment was that Tara became isolated from the classroom discourse and the ideas being presented. This is not so much the fault of anyone, but rather there needs to be greater awareness of alternative logical positions which might be counter-intuitive to those who hold a conventional viewpoint.

Who Did Tara Believe Was Right?

In the final interview with Tara, she had some interesting comments about who was right about the metal ring:

> Tara: (To Shannon, indignantly) You were right! What are you complaining about?
>
> John: In what way was she right?
>
> Tara: Well, um, I don't know.
>
> John: Well, when did you decide she was right?
>
> Tara: When everyone else agreed with her (interview 7/5/99).

At first glance, it seems as though Tara was saying that the overall consensus persuaded her that the ring *did* expand when heated. This seems to me to be a foreshadowing of a concept that *right* is not about what makes sense, but about what is popular. If 'everyone else agreed' with Tara there would be no pressure and strain on her. However, they did not agree, and she was quiet in the ensuing class discussion about the metal ball and ring. For Tara, it was as if it was more important to have the type of rightness that was popular, rather than the type that comes from sense-making. I asked Tara when she changed her mind about Shannon being right and she stated that she had not done so, but rather:

> Tara: It just made me want say my point even stronger.
>
> John: So why do you think you don't feel so strongly now?
>
> Tara: It [my emotions] is [as strong]. Exactly the same.
>
> John: Don't you, in reality, agree with Shannon now?
>
> Tara: Not really... I agreed with her to an extent and then I just, like, agreed with myself (interview 7/5/99).

Here is evidence of conflict in Tara's thinking. She seemed to agree with herself, because she felt her position was the only one that made sense. She seemed to agree with Shannon 'to an extent' because Shannon was on the side of the popular vote. I suggest that the conflict between what seemed right to Tara and what popular accord deemed to be right had a large impact on her scientific literacy, as we shall see below.

Tara's 'Wrong' Observations

The above conflict emerged again in Tara's involvement in the whole-class discussion about the experiment of heating the liquid. Mrs. Stubalm utilised the experiment to confirm that liquids expand when heated. However, Tara made the 'wrong' observations; she noted the evolution of bubbles, and inferred that the water level in the tube rose because of increased gas pressure. This does seem a more complete and satisfactory inference than the classroom dialogue regarding the *expansion of liquid* idea. It could be said that Mrs. Stubalm's intention for the experiment was to develop the 'wrong' classroom-science knowledge, because observation evidence better supported the inference of expansion due to gas pressure. Tara didn't seem to pass a judgment on the idea of liquids expanding, and her inaction suggests that, by this point in the lesson, she had resigned from judging the classroom science of that lesson. I infer this because Tara actually contributed to the classroom dialogue about expanding liquids by providing a carefully screened observation statement that confirmed the day's classroom knowledge, although she disagreed with it (a point developed below). Her external agreement belied an unwillingness to work any longer as judge. It was here that, to Tara, being *right* seemed to mean providing the *popular* answer for the class forum, although she believed it was an incorrect, or at most, partial answer.

This suggests that, on occasions, students who are making thorough observations can construe 'wrongly' the experiment, and thus fail to appropriate classroom-science knowledge. If they are somewhat like Tara, the outcome may be heightened frustration and either surrender or diminished academic success in terms of grades. Tara appeared to choose to surrender, to suppress thoughts that deviate from the class norm, even when she had in her intellectual possession powerful alternative evidence. If she had, for example, stated 'Miss, the liquid went up the tube, because of increased pressure. The pressure was due to the bubbles of gas released when heating', then other students who, possibly dismissing a similar observation, would recall having noticed the bubbles, and felt like agreeing with Tara's explanation. If mentioned, this could have brought into potential disrepute the classroom-science concept of the expansion of liquids due to heating. Tara could then have argued also against the expansion of metals and, having regained some credibility, won support for that idea. However, at the time she could have used the bubbles evidence, she not only did not, but also chose to give selectively only that part of her observations that was in keeping with the emerging classroom-science view. Instead of challenging what she believed to be wrong, her earlier treatment led her to feel that it would be better, safer, less effort and more rewarding, in the school sense, to confirm it.

Which Classroom-Science Knowledge?

It seems from the sixth vignette that the classroom-science knowledge taught in previous science lessons might not have been helpful if applied to the lesson at hand. Only student comments that favoured the classroom-science knowledge developed that day, about an expansion concept, were considered valid by Mrs. Stubalm and rewarded with praise. When Tara was applying knowledge, possibly from earlier class work on chemical change, it provided a context that hindered her accessing the classroom-science knowledge pertaining to expansion. The specific classroom-science knowledge presented in any one lesson, on occasions in Mrs. Stubalm's class, seemed to have more weight than any previous classroom-science knowledge. Students may have needed to be aware that on those occasions they should have accessed the classroom-science knowledge of the lesson at hand to be truly successful and rewarded as recruits. It was, therefore, a risky business for Tara, fraught with difficulty, to apply knowledge from other Science lessons to the science of the present lesson. She may act as judge, but her judgment seat is on thin ice if she cannot discern which classroom-science knowledge the teacher was concerned with developing.

Mrs. Stubalm mediated against student-as-judge in classroom dialogue. She commended some students for using scientific terms, and the concepts behind them, yet suggestions that did not fit with the day's classroom-science knowledge received only brief recognition or no comment at all. The suggestion by a student that liquids bubble when heated fitted perfectly with the class's previous observations of boiling water, and was a correct prediction for the second experiment of Vignette Six, heating the liquid in the corked flask. Yet, this prediction was not valued. The appearance of bubbles could be due to the lower solubility of oxygen in water associated with increasing temperature. It would be the bubbles, in this conception, that caused an increase in pressure, which in turn caused the liquid level to rise. However, this more sophisticated idea was not the day's classroom-science knowledge, and it seemed that Mrs. Stubalm's agenda of 'liquids expand when heated' excluded recognition or negotiation about any other concept.

During the class discussion that confirmed, rather than challenged, the expansion of heated metals, Tara was quiet and disengaged. It seemed that, after passing sentence on Science, she retired as judge and withdrew her interest. Tara as judge seemed to find Science too ostracizing, intimidating and 'stupid'. Apparently, she continued to hold her own ideas, and feel that science was not an appropriate way of knowing; it did not fit with experience or common sense. This outcome concurs with Solomon's (1987, p. 1042, cited in Bianchini, 1997) suggestion that the explanations students create can differ not only from those of scientists but also widen the divide between everyday and scientific ways of understanding the world. This would be true generally for the student-as-judge who creates alternative understandings to the classroom-science knowledge being developed but is given no recognition for the viability of these understandings. If such conceptualizing is dismissed automatically then there is a subtle inequity for students who have a propensity to act as judges. Furthermore, such socially ostracizing forces can convey to other students the needlessness of student-as-judge, and so may purge the communication of conceptions that compete with classroom-science knowledge. With no avenue for expression or challenge, alternative concepts may root more strongly in some students' minds. Tara's actions suggest that, ultimately, acting as judge has no merit. From her perspective, it might thus be better to find out what the teacher is thinking, and to 'go with the flow'. Acting as a judge was at best confusing for Tara, and at worst induced draining arguments and drew derision.

An implication from the above is that it may be prudent for the development of students' scientific literacy that, at least occasionally, they are encouraged, or at least permitted, to function as judges. This may help to reduce the tension between students' alternative explanations and the classroom-science explanation, because there would be an acknowledgement that classroom-science can come under scrutiny without danger to the scrutineers, and that there are possible alternate understandings of the same phenomena. Avenues for working legitimately as judge may allow students, such as Tara, to communicate in full their understandings, to not feel that science is stupid, but rather to be willing to hold in tension with their own notion the classroom-science notion. A richer scientific literacy would allow students to present their own notions about phenomena alongside the classroom-science notion. These notions can then be compared, contrasted and evaluated with others.

As discussed in Chapter Nine, the Mathematics and Social Studies vignettes speak of the safety of classroom knowledge for Tara, classes where uncontentious classroom knowledge provided security and predictability. The vignettes from Tale Two suggest implicitly that it was unnecessary for Tara to act as judge in her Science class; rather, it was far better to look out for the classroom-science knowledge presented in class.

In Science, Tara, working as judge, gathered all her intellectual resources: memory of past out-of-class experience; previous in-class experience; the observations of the experiment; and her powers of reasoning. She found that the evidence went against the classroom-science concept of metals and liquids expanding when heated. Tara did not seem to display a cognitive deficit, or even illogical thinking. Mrs. Stubalm did not fail to allow Tara to engage in activities that helped her to construct meaningful knowledge. However, it was Tara's reasoning abilities and background knowledge that clashed with the only outcome that seemed acceptable to the teacher. As judge, Tara condemned Science for its failure to accord with everyday experience and reasonable thinking. Her lament, 'you *never* know if you're right', suggests that Tara found inconsistency a hallmark of the logic that leads normally to classroom-science understandings. To her, understanding Science was a hit-and-miss affair. Tara's verdict, 'I *said* Science is stupid', implied that her previous judgment was reconfirmed.

Tara as Trivialised Recruit

The hallmarks of student-as-recruit are actions that suggest an *acceptance* of, and *appropriation of*, the knowledge presented in the classroom. I identified previously events where Tara worked as scientist and as judge. However, the event where Tara worked as recruit was signified by an omission, rather than by an explicit statement. When Tara stated to the class, in the sixth vignette, 'It went up, then it went down' she contributed to the developing classroom-science dialogue of 'liquids expand when heated'. It was an accurate, yet partial, observation from her experience with the experiment that she had conducted (see Figure 5, p. 182). What she did not state to the class, however, was the inference and observation she conveyed to me as she was conducting the experiment: 'Air pressure. The air bubbles expand and the liquid has to go somewhere, so it goes up' (Vignette Six). The omission of her observation about bubbles, and of her inference drawn from this, allowed Tara to enter back into the classroom dialogue, and for the classroom-science notion of 'expansion of matter when heated' to be constructed without blemish by the class. In her statement, or rather

her omission, there may be a world of comment on her view of classroom-science: 'I think this view of expansion is wrong and stupid. But I will pretend that I agree, and so need not at this point have conflict with Shannon, Mrs. Stubalm, Mr. Willison and the whole class. I can agree with everyone, and get good marks, but I don't believe it.' In terms of the discussion above, Tara chose the *popular* answer in preference to the answer she actually believed to be right. From his research in Mathematics classrooms, Bauersfeld (1988) concluded that students are sometimes willing to trade off academic success for social reasons. In Tara's case, she trades off contributing her actual understanding of phenomena for social and academic gains.

A disbelieving recruit

The outcome of the experiments depicted in Vignette Six might be worse than merely confining Tara to work as recruit in the science classroom. She seemed to see the value of maintaining agreement with classroom-science, whilst not believing its truth claims. This could breed an internal inconsistency in her character, where Science is 'pretend time'.

I have already identified possible factors that mediated against Tara as scientist and judge. Factors that possibly mediated against Tara as recruit were: the incomprehensibility or apparent contradictions of science; the boredom of acting as recruit, especially evident in Mathematics and Social Studies; and the fun of off-task activities such as drawing, chatting and playing with her friend. However, Tara was a successful student, according to her teachers, her class marks and her own comments. It seems that, despite boredom, Tara wanted to learn, or at least access classroom-science knowledge and the knowledge of other subject areas.

Tara's Perspective on Learning

Tara and Shannon commented about the way they learned:

Tara: I learn because...I don't know. She [Shannon] reckons that she's smarter than me.

Shannon: And it's true.

Tara: Shut up... But if I act... if I learn, then I... then she [Shannon] thinks I'm smarter than her, and she feels really... not superior (interview, 1/11/98).

Tara appeared to see learning as a way of gaining some superiority over others, or at least of not feeling inferior to them. Tara's apparent view of her own motivation to learn makes some sense of her actions in Science. As noted earlier, Vignettes Four and Six are typical in the way they depict Tara play fighting: I observed her physically play fighting or arguing with Shannon frequently in Science. However, this was not the case with my observations of other classes she attended, nor congruent with other teachers' comments on Tara. Why was a more contentious character typical in Science, but not elsewhere? One possibility is that, to Tara, Science promised initially an opportunity to present her own knowledge claims that she thought would be superior to those of other students. Other subjects seemed to present non-contentious, concretely presented information, however, Science was, in over 40 percent of lessons observed, based around experiments, and Mrs. Stubalm encouraged the students to think, predict and draw their own inferences. This seemingly more open status of knowledge may have encouraged Tara to conceive of, present and defend her knowledge claims, thereby providing her with a forum for feeling 'not inferior'.

However, as the year wore on, it may have become apparent to Tara that the knowledge outcomes of the classroom discussions were already predetermined, and much more closed that she had first thought. Being right (in the popular sense) and 'not being inferior' seemed to be important to her, and so, to gain that success, she seemed to have chosen to work as a recruit, accessing classroom-science concepts. Her simple omission of part of her observations seems like a symbolic point of surrender: at this point she appeared to be willing to reinforce the emerging classroom-science knowledge regarding the concept of expansion, although she not only disagreed with the general concept, but had made observations which seemed to throw into disrepute the idea of liquids expanding. If she had chosen to include in the whole-class discussion her 'bubbles' observation, it is possible that she may have discredited the notion of 'expansion when heated'. However, it seems that, for Tara, the risk of exposing the prevailing knowledge claim was too great, because arguments, tension and derision may have followed. As mentioned previously, it is possible that the comfort of working as recruit in other subjects, and in Science on some other occasions, came to her mind, convincing her that it was better to give up the argument.

When Mrs. Stubalm was provided with Vignette Six, she entitled it: 'You can't make them listen.' Perhaps the explanations that Tara produced regarding the shrinking metal seemed strange to Mrs. Stubalm, but this title suggests that 'I wish they would just listen to the explanation. Then it would make sense.' The teacher's idea for a title highlights the strength of teaching-related factors moving Tara towards acting as a recruit, and of 'listening' as a key to appropriating classroom-science knowledge.

Effects of Working as a Recruit Only

If a teacher has an expectation for students to appropriate only classroom-science, this may have some harmful effects. For Tara, success earlier in the term in coming to terms with classroom-science knowledge seemed to be undermined by incidents depicted in Vignettes Four and Six, and possibly by numerous others like them. Students such as Tara may actually progress from gaining classroom-science knowledge, to applying it to help the classroom community judge the adequacy of newly presented ideas. However, if, at the same time, previous knowledge is seemingly discredited in class, then to students it might seem better not to use it for this purpose. Instead it might seem safer simply to access, with little comment, classroom-science knowledge even though it does not seem to be credible.

In the final interview with Tara, I probed her contribution to the emerging classroom dialogue about liquids expanding when heated.

> John: ...so it seems as if you were presenting something that agreed with everyone else in class, but actually what you told me was you disagreed with that.
>
> Tara: Yeah, I know... I think I was tired of arguing at that point so I just agreed with everyone.
>
> John: What effect did that have in you? What did it make you feel about Science?
>
> Tara: I don't know. She said there was only one conclusion. There's gotta be others. What do you think scientists do all day? Sit on their bums, and go 'yeah, that's right. That'll do me'? (interview 7/5/99).

Tara seems to have had an appreciation for scientists at work, but experienced the classroom-science representation of science, as a static and unproblematic human endeavour, to be sadly lacking. Perhaps this experience inspired her satirical image of scientists accepting the first explanation that comes to mind, and then sitting around for the rest of the day. This would seem to epitomize Tara's emerging opinion about Science classes: find out what the teacher wants you to know, then 'sit on your bum' till the end of the lesson.

If Tara started in Science hoping to develop her own persuasive knowledge, she seemed to end by confirming, even though disagreeing with, classroom-science knowledge. If she started willing to be involved in science-in-the-making, and grappling with the development of concepts, she seemed to finish ready to access ready-made science (Latour, 1987). If she started as a scientist, she seemed to finish as a recruit.

Will Tara be an informed citizen on future scientific issues? From the dissatisfaction that Tara displayed, it would be easier for her to regard science with suspicion at best, and flagrant disregard at worst. Possibly, she would trust her common sense understandings more than the views of scientists and their reports. Indeed, she may become a powerful opponent of scientific presentations. Tara was moved to silence in school, maybe due to peer pressure, or the comforts associated with getting the correct answer. However, with those constraints removed, Tara may be boisterous in opposition, having experienced what seemed to her to be the unfair, incomprehensible and wrong force of scientific thinking. She may learn some of the language of science, but this might help her to argue against science in an informed and persuasive manner. Far from developing scientific literacy, or even merely failing at this task, Science and other subjects may have facilitated an educated opposition to science, and created a scientific anti-literate, prepared to debate against the scientists of the Twenty-first Century.

The apparent ending, with Tara as a successful, yet not fully-honest, recruit is a sad one, because it suggests a student answering only what they know the teacher wants to hear. It suggests Tara is a student who may well commit classroom-science knowledge to memory, call out correct answers in class, and answer test questions in a satisfactory way. And yet, at least for Science, she may be highly dubious about the worth of the information. She may write 'liquids and solids expand when heated' in her final test, and believe that to be a stupidity, totally contradicted by experiments conducted in class.

How much richer would be the experience if the teacher had been able, at times, to engage Tara as judge, and recognize and acknowledge the validity of her thinking? In such an environment, it would be much more likely for Tara to test the viability of her belief as depicted in her 'metals shrink when heated' concept. But as it stands, her arguments against the canonical knowledge are seemingly robust and less likely to change over time. Furthermore, a classroom that provides students more opportunity to act as scientists may enable them to understand why their own experimental designs make it difficult, at times, to provide persuasive knowledge claims. Given this opportunity, they may develop heightened appreciation of, and therefore willingly apply, standard classroom-science techniques when conducting scientific experiments of their own design, especially because they have come to understand the limitations of their own methods. Shelly participated as a scientist in this manner, which facilitated her understanding of scientific terminology, due to the benefits of practical application (see Chapter Twelve). It is also conceivable that opportunities to act as scientists may enable students to develop their own criteria for experimental design that do facilitate persuasive knowledge claims.

Interpretation of Darrien's Involvement in a Closed Investigation

As for Jimmy in Vignette Three, there is little to suggest that Darrien was engaged deeply in the closed investigation portrayed in Vignette Six. He contributed a little to the classroom discourse early on, told Kevin a joke during the experimental work, and did not contribute to the later whole-class discussions. Therefore, this vignette consolidates the idea of Darrien as a minimalist recruit, reluctant to do more than necessary. Perhaps, heating water and pouring it into a foam cup, or heating metal rings and passing metal balls through the hole, did not constitute fun to Darrien.

The three-metaphor framework helps provide understanding of why and in what manner Tara worked as a recruit, but suggests merely that Darrien worked occasionally as a recruit. The interpretation of Tale Two, using the three-metaphor framework, provides little understanding of Darrien's scientific literacy, except to say that, as a bright student, he was at risk of having an underdeveloped scientific literacy, particularly in terms of student-as-recruit. This is a shallow inference, especially when compared to the much richer interpretations of the tales of Shelly, Jimmy and Tara. This is a limitation of the three-metaphor framework: it does not necessarily provide insight into why students choose a particular way of interacting with learning tasks.

In answering the research question, 'What are the effects of learning tasks on Darrien's scientific literacy?', one possible answer is 'negligible', as the learning tasks did not motivate Darrien to participate in a way that fell within the bounds of any of the three metaphors. Another answer is that, like Tara and Jimmy in their different ways, Darrien too was alienated from science.

It seems that Darrien did not choose to channel his creativity into acting as a scientist, even when given the choice. And although he contributed frequently to classroom discourse, it involved him in providing only his perspective, rather than disagreeing with or judging others' knowledge claims. For example, in Vignette Six, in which Tara was entangled in the shrinking/expanding of metals dilemma, it was Darrien who, in the classroom preliminary discussion, said: 'Metal burns and shrinks when you heat it'. Yet he was not seen disputing the classroom knowledge that was generated consequently. In terms of working as recruit, Tara's agenda may have been to be 'not inferior', and Shelly's as accessing 'the introductory things'. But it seems that Darrien either passively accepted the ideas that were presented, or ignored them altogether.

The idea of Darrien as a conscript, discussed in Chapter Nine, does suggest that Darrien would sometimes work when he was threatened with sanctions, or otherwise forced to. If there was an opportunity not to proceed through the recruitment process, it seems likely that he would readily opt out, even if his work partner Kevin was involved deeply in an activity. Shelly's cartoon, from Vignette Two, presents the notion of two children conscripted into an alien labour-camp, and forced to participate in tasks that seemed as unrelated to their own lives as knitting jumpers for aliens. Shelly, in this cartoon, represented the children as empowered sufficiently to negotiate some tasty reward, where 'happy burgers' may represent 'happy grades'. Was the conscripted Darrien left eating the 'grass' of fail grades and disinterest, and so refused, wherever possible, to knit?

Darrien is interesting. His laziness, his industry to escape work, is impressive. The three-metaphor framework does not do real justice to making sense of his scientific literacy, for his actions seem bound up in his desire to have fun. Darrien never seemed to hesitate when contributing to classroom discourse. He did not seem to care if his answer was the answer being sought by the teacher, that is, he did not seem to wish to discern the day's classroom-science knowledge. I have said that there was no significant evidence of Darrien acting as scientist or judge, and that his on-task participation was in keeping with student-as-recruit. Yet, this interpretation does not seem to tell the whole story, as if Darrien's scientific literacy was rich and full, and my interpretation of it is meager.

Having said that, the three-metaphor interpretation does raise some important questions. Why did a creative student such as Darrien not function as a scientist, even when given the opportunity? Why did he display no qualities of student-as-judge, even though there is evidence that his understandings were not in accordance with classroom knowledge espoused in class? Why was he so unsuccessful as a recruit in Science, as determined by grades, yet was quite successful as a recruit of Social Studies, even when he seemed fascinated with some scientific ideas (interview with Kevin and Darrien, 25/10/98). Possibly the answer to all three questions is summed up by Kevin:

John: How have you found Science these last two terms?
Kevin: Boring (interview with Kevin and Darrien, 25/10/98).

Darrien's imagination, coupled with his communication skills, suggests that he potentially could function as scientist, given the opportunity and motivation. In view of Darrien's poor grades in science, it is a pity that he was not challenged to go further than avoiding participating as recruit. If he was given more scope to design experiments of his own choosing, or experiments that provided a relevant motivation, would Darrien have taken on the mantle of students-as-scientists? In doing so, would his scientific literacy as recruit have been stimulated and expanded?

Tara, in the same Science class, did not describe Science as boring. She often argued with people and grappled with understanding phenomena. She may have found Science frustrating and restrictive, but not boring. But Darrien seemed always to be trying to find his entertainment elsewhere.

Whereas I have depicted Tara as being corralled into working as a recruit, Darrien seemed to choose this role. It was the path of least resistance, where he could fool around for half the lesson, then write extremely quickly, finish his work, not get into trouble, and so maximise his fun. To stop and try to generate his own knowledge claims, or argue about the claims of classroom-science apparently would waste time that could otherwise be spent in fun interactions with friends. As recruit, Darrien did the minimum amount of work required to keep out of trouble.

Tara as recruit of classroom-science seemed to epitomize the opposite to scientific literacy. Her role as scientist was discontinued, as judge was frustrated, and as recruit was trivialized, as she contributed partial observation statements to help develop an emerging notion that she considered 'stupid'. At least Darrien's occasional work as a conscript seemed to allowed him to retain more integrity than Tara.

Assertions Based on Chapters Eight, Nine and Ten

Chapters Eight, Nine and Ten considered the effects of learning tasks on Tara's and Darrien's scientific literacy, utilizing the three-metaphor framework. Taking these chapters together, there are five major assertions based on my interpretation of the two students' engagement in both Science and non-Science classes. These assertions relate to the issue of equity of access, which emerged in the analysis of Shelly's and Jimmy's learning (Chapter Seven).

1. *In Science, unexpected change to the degree of openness of an experiment can interrupt the manner in which students are participating as scientists in the experiment.* Tara, who was working with Shannon on an experiment that was open in terms of method, stopped experimenting when she was not permitted to work as a scientist constructing her own knowledge claims from her own experimental design.

2. *If students are not given the opportunity to work as judges, then they can harbour silent criticisms of classroom-science.* Because 'metals expand when heated' was a concept developed unwaveringly in the classroom, it not only seemed to fail to convince Tara about its validity, but seemed to demean the value of classroom-science for her. For Tara, classroom-science that was presented as lacking uncertainty seemed also to lack credibility.

3. *Although opportunities may be given for students to work as scientists or as judges, factors associated with non-Science classes can work against students enacting these roles.* For example, a key factor noted particularly in the case of Tara was the frequent experience of working comfortably as recruit in non-Science subjects. If Science teachers want their students to act as judges and scientists, then factors external to Science that mediate against these ways of acting, might need to be taken into account.

4. *When teachers implicitly expect students to focus exclusively on a predetermined set of laboratory observations and inferences about a particular phenomenon, the ensuing discussion can disenfranchise students who have made other seemingly relevant observations and inferences.* For example, in Vignette Six, it seems that Mrs. Stubalm expected students to focus only on change in temperature and change in water level, whereas Tara also noted the evolution of bubbles. Subsequently, Tara may have 'tuned in' to Mrs. Stubalm's implicit expectation, as evidenced in Tara's contribution to the class discussion of observation statements aligned with the teacher's agenda of 'expansion of liquid due to temperature increase.' Tara, seemingly compelled to provide a limited answer rather than all of her observations, may have been disenfranchised by the nature of these perceived prescriptions. Teachers may need to appreciate that students sometimes make reasonable observations and inferences that are not in keeping with the classroom-science agenda of the day.

5. *Able yet unwilling students like Darrien may not develop scientific literacy in a manner that is readily observable in the classroom.* The issue of student motivation can be an important factor with such students.

Equipped with the seven assertions about Shelly and Jimmy (Chapter Seven), and the five assertions about Tara and Darrien (Chapter Ten), I synthesise these and relate them to the literature in Chapter Eleven.

Section Three
Assertions and Discussion

In this, the final section of the thesis, assertions significant to equity of access into scientific literacy are presented, in Chapter Eleven, and, in Chapter Twelve, I discuss possible implications of the research for educational researchers and teachers.

Chapter Eleven
Assertions

The interpretation of the tales using the three-metaphor framework (in Chapters Five to Ten) raises questions about the equity of access of students to scientific literacy. In this study, the portrayal of the complexity of interactions between each student and tasks provided in Science helps to explain how differential access to scientific literacy can occur. In this chapter I present ten major assertions from the research.

Ten Assertions Regarding Equity of Access to Student Scientific Literacy

There are ten major assertions, compiled from the assertions of Chapters Seven and Ten, that relate to equity of access to scientific literacy. I have grouped these assertions into three categories: ways of accessing scientific literacy; use of the three metaphors to facilitate scientific literacy; and the place of non-Science subjects in providing information about student scientific literacy.

Ways of Accessing Scientific Literacy

1. Multiple outcomes may result from a learning task

Learning tasks should not be expected necessarily to achieve identical predetermined outcomes for each individual in a class, because students may react very differently to the same learning task in the same classroom. In this study, tasks provided differing amounts and differing types of access for each of the four students I observed. For example, the open-ended task of the parachute investigation (Vignette Three) prompted Shelly to work as a scientist, but failed to engage Jimmy, possibly because he was required to work individually and/or without significant visual input. Moreover, the closed task of the teabag rocket facilitated Shelly as recruit but Jimmy as scientist.

A study of a teacher implementing a middle-school Life Science curriculum designed specifically to 'address issues of excellence, equity, and access in science education' (Bianchini, 1997, p. 1043) found that 'even under the best circumstances, then, where a powerful groupwork model is implemented by a practiced science teacher using carefully crafted group tasks, groupwork can still fail to provide all students access to meaningful science learning' (p. 1062). It seems, therefore, that growing research evidence is suggesting that, in school Science classes, there is likely to be differing amounts of access provided to students engaged in the same task. In effect, a classroom may contain simultaneously multiple 'sub-environments' where 'individuals and groups experienced different learning environments' (Richie, Tobin and Hook, 1995, p. 320).

Kelly, Chen and Crawford (1998, p. 36) found that 'by focusing on the discourse processes in the moment-to-moment interactions ... researchers can study the ways science gets talked, meant and portrayed to students' (p. 34). The 'same' activities, scrutinised in moment-to-moment interactions showed, in this present research, that science can mean different things to different students. Teachers who are aware of the possible range of effects of a learning activity may be able more readily to minimise detrimental effects on some students while maximising the experiences of students who are enjoying effects that are more favourable to their learning. A diversity of student responses should be considered by teachers, therefore, as healthy and something to tap into, rather than a problem. Not only might this inclusive attitude be liberating for some students, it would enable their teachers to build up 'a rich array of material and intellectual resources (including their own understanding of their students)' (Anderson, Holland & Palincsar, 1997).

2. Changes in perceived style of student participation may alienate some students

Abrupt changes in the manner in which students are expected to work as scientists may result in student disenchantment. For example, Tara and Shannon (in Vignette Four) began working as scientists, but were restrained subsequently by teacher and researcher expectations, to the extent that they ceased working as scientists and became sullen and disinterested. This outcome suggests that if students are given open investigations, then they should be permitted to choose freely the experimental method, how to implement it, and how to report their findings, even if they are not employing standard classroom-science practices.

This intervention was very similar to that described by Roth (1993) in an analysis of his discourse as a classroom teacher with his students who were involved in designing and conducting their own experiments. He found that the discourse with his students sometimes fitted into a 'triadic pattern' of teacher question/student response/teacher evaluation, and yet he had 'not been aware of the controlling nature' (p. 368) of his discourse. In this thesis research, my original question to Tara (see Vignette Four) was 'when do you think timing should start?' Because she and Shannon had already started timing, my intervention seemed to suggest that I had judged their experimental technique as incorrect. Utilising a *cognitive apprenticeship* metaphor, Roth suggested that the asymmetric nature of the teacher-student relationship during scaffolding (see Chapter Two) meant that 'only when students are ready to take more responsibility does a teacher relinquish control' (p. 368). However, the question arises of who should determine 'readiness', the teacher or the students? Their classroom teacher and I determined the two girls to be 'not ready', but perhaps they considered themselves to be very ready. In order to avoid such conflicts of power, I suggest that students be made aware by their teacher of the actual degree of control they are permitted to exercise in their role of students-as-scientists.

3. Not all students may participate in classroom activities

There are no guarantees of student engagement, but it may be useful for the learning of less motivated students for teachers to become increasingly aware about their areas of interest and motivational strategies that may be employed. Darrien often did not take part in learning tasks until pressured by threat of sanctions. Yet he was commonly viewed as being a student capable of quality work. Costa (1993, p. 663) asserted that:

> a focus on gender, ethnicity, and class hides the fact that poor performance on assessment tests and disengagement from science is not simply a matter of unequal access or room in the pipeline. Although white males are most likely to persist in science and choose science as a career, *all* students find science less fun as they progress through school. Many who originally express interest in science and technology "drop out" of the pipeline as they advance from high school to college (Berryman, 1983). Not simply a matter of a narrowing pipeline (i.e., pushing students out), students of all gender, race and class make the choice to disengage from science.

Darrien's choice to disengage frequently is an example of unidentified factors, which minimise the involvement of students from a range of backgrounds.

Hanrahan, (1999, p. 713) found that the use of journals in which positive dialogue was established between each (anonymous) student and the teacher is one possible '... answer to the problems of poor performance and alienation from schooling, particularly among boys [and] ... particularly when teachers felt obliged to deliver a predetermined curriculum regardless of its inappropriateness for the majority of their students.' Students like Darrien, who appear to courageously participate in classroom dialogue, may, surprisingly, have multiple concerns that they do not express. A responsive type of journal may provide an avenue for students to voice concerns about blockages to their participation or motivation.

4. Social settings may limit access to scientific literacy

The social setting of the classroom may limit students access to tasks designed to develop their scientific literacy. Jimmy appeared to be alienated when instructed to work alone, and he and Shelly seemed to be alienated when working in teacher-determined small groups. Waldrip and Giddings (1994) found a significant proportion of 'social learners' at Righschool and various other schools throughout the city it is in. Given the prevalence of this learning style, it may, therefore, be preferable that a diversity of social interactions is facilitated in class, including assessments that require collaborative interaction.

Utilising a *school-science-as-a-rite-of-passage* metaphor, Costa (1993) argued that students 'are actually alienated from science'(p. 653) because school science 'fails to clarify the purpose of transition rituals' (p. 651). Jimmy may not have understood the 'transition ritual' requiring him to work alone, or with students with whom he did not socialise normally, thereby producing feelings of alienation, which manifested as a lack of motivation.

5. Learning styles may determine access to scientific literacy

Students' individual learning styles may be an important factor that governs their interaction with learning tasks and, therefore, their access to scientific literacy. Jimmy seemed to demonstrate a low lexicographical literacy but a higher visual literacy, resulting in a learning style that enabled him to gain ready access to tasks in lessons that foregrounded the visual, but minimal access in lessons that highlighted language. It seems, therefore, that in the interest of achieving equity of access, written and oral forms of communication, such as explanations and teacher and student writing, should not be the only legitimate forms of classroom communication. Rather, other avenues of communication, such as visual modes, need to be made available.

Students with learning styles that are not well catered for in their science classroom may need to 'border cross' (Cobern & Aikenhead, 1988; Baker & Taylor, 1995), for example, by leaving their familiar and successful 'visual literacy' and crossing into lexicon-based literacy. Jimmy and Shelly were in the same Science class, and, one could argue, were therefore given the same opportunities to become increasingly scientifically literate. However, if the issue of preferential learning styles is considered, then the predominance of tasks which favoured the written word seemed to have resulted in inequity of access amongst these two students: Shelly was on her 'home turf', but Jimmy needed to border cross into a style of learning that did not suit him. This outcome might be of only small concern if, over time, a balance had been maintained between visually-orientated tasks and lexicographical tasks. In that case, equity of opportunity would be enhanced. However, in their Science class, text book, board-notes and oral-explanation constituted the prevailing forms of discourse.

The Role of the Three Metaphors in Facilitating Scientific Literacy

6. *Students may be frequently engaged as recruits of classroom-science*

In this study, in Science, students were observed engaging in tasks that facilitated most students working as recruits for the vast majority of the time (154 forty minute periods out of 160 observed). The hegemony of student-as-recruit may be a narrow and restrictive way of developing scientific literacy, which has negative ramifications:

> If, in their science lessons, pupils get the impression that language is a labelling system, they may come to believe that teachers and pupils can relate in the transmission mode.... Such pupils may never discern the interpretive voice of the scientist, and may become unused to using their own language interpretively, to figure out what's going on (Sutton, 1993 p. 1225).

On the other hand, teachers' use of multiple metaphors, made explicit to students in science classes, may help them provide a range of approaches to developing scientific literacy, which in turn may enhance students' motivation to learn. The provision of multiple tasks that facilitate the roles of student-as-recruit, student-as-judge and students-as-scientists may broaden students' scientific literacy in a way that might not occur otherwise.

Roth utilised the metaphor of *cognitive apprenticeship* to provide teachers with a framework for conceptualising new learning environments. He found, however:

> The use of metaphors for understanding teaching practice introduces some real dangers. Whilst the use of metaphors may be beneficial in facilitating changes in teacher classroom actions, there exists a real danger that teachers merely appropriate a discourse without changing their basic beliefs and with it their teaching behaviours once the metaphor has been legitimated as a desirable norm (1993, p. 369).

This is a warning that rhetoric, in this case in the form of individual metaphors, does not guarantee significant changes in practice. It is possible, however, that utilising a *set* of metaphors, such as the three-metaphor framework, may help to sharpen differences in the optimal learning situations of each role, and so help teachers to apply different kinds of discourse at different times. For example, if a teacher wants to facilitate student-as-recruit, then he or she may volitionally take on a discourse of expert addressing novices. If the teacher wants to facilitate students-as-scientists, then the dialogue may be more like that of a resource supplier to inventors. A multiplicity of roles may facilitate changing discourses and practice.

7. Scope for student-as-judge may be significant for learning in Science

If students' criticisms of classroom-science are not heeded, they may become alienated from science. For example, when Tara's judgement of the classroom-science was not given credence by her teacher, she seemed to withdraw from classroom discourse. Moreover, it seemed that afterwards Tara began to contribute to the discourse in a way that reinforced the legitimacy of classroom-science concepts, even though she did not believe in the truth of these concepts.

If the teacher encourages students to judge the classroom-science, for example, by identifying perceived deficiencies then fewer students may become alienated from science. Conversely, when alternative student understandings 'are *not* [italics added] treated as candidate challenges to accepted scientific knowledge but as erroneous and explained by external factors, the teacher suggests that science offers an unfailingly accurate and thorough description of the world as opposed to providing the means of participating in the scientific construction of reality' (Costa, 1993 p. 661). Such a non-inclusive approach might not seem helpful to a student who is struggling to make scientific sense of phenomena.

From the perspective of the three-metaphor framework, it seems that Tara's actions as judge were suppressed in an unthoughtful manner, and that this devaluation of her critical insights about classroom-science (represented in Chapters Eight and Ten) trivialised her scientific literacy. It is conceivable that, at least for some students, the role of judge is critical in the development of meaningful scientific literacy. Norman focused on this role in developing scientific literacy when he advocated that students should understand the '... reciprocal impact of science and the general culture on each other' (1998, p. 365). Tara, however, was left thinking that 'science' and 'general culture' clash, and that, perhaps, 'never the two shall meet'. This clash is explained, in part, by Solomon who contended that students socially construct context-dependant knowledge rather than overarching theories common to science. The explanations students create may not only differ from those of scientists, but also *widen the divide* between everyday and scientific ways of understanding the world (1987, cited in Bianchini, 1997, p. 1042). Explicitly validating the role of student-as-judge may help to narrow the divide. Costa (1993) argued that 'in school science, the goal of socialization is not well articulated, resulting in uncertain student and teacher understandings of roles and what *counts as knowledge* [italics added] in the classroom.' Utilising the metaphor of student-as-judge, along with the other two metaphors, may help teachers and students clarify what counts as knowledge, when it counts and why. However, if students are expected to utilize unquestioningly classroom-science discourse 'they may in fact learn an improper school literacy which is dysfunctional in terms of both scholastic success and critically addressing structures for daily life' (Hanrahan, Cooper & Russel, 1997).

Moreover, a '... major obstacle to a deep approach to learning in science classrooms may be the implicit messages to students that science is authoritarian-that is, that they should put aside their own ideas and feelings and accept unquestioningly whatever the teacher tells them, even when he does not make sense to them' (Hanrahan, 1999, p. 700). The present research suggests, however, that if a student such as Tara suppresses cynically her own ideas and feelings in favour of appearing to accept classroom-science notions, then a greater human tragedy occurs than if canonical ideas are simply rejected as meaningless.

8. *Students-as-scientists may formulate deeper understandings of classroom-science*

Utilising the students-as-scientists metaphor may help facilitate the learning of classroom-science concepts for some students. For example, when Shelly was given the scope to work as a scientist, she used many classroom-science notions. To help develop student-as-recruit it may be beneficial, therefore, for teachers to promote sometimes students-as-scientists, which could provide the opportunity for students to make deeper sense of scientific terms, tools and concepts by attempting to employ them (creatively) in more personally meaningful ways.

Bourdieu and Wacquant stated that 'historians and philosophers of science, and especially scientists themselves, have often observed that a good part of the craft of the scientist is acquired via modes of transmission that are thoroughly practical' (1992, p. 223). This implies that doing the work of a scientist is a significant factor in acquiring the 'craft' of a scientist. Vellom and Anderson asserted from their case study of a sixth-grade classroom that:

> Although we do not characterize what went on in our classrooms as an exact model of the ways that scientific communities work, we do believe that replicating significant features of scientific working groups in our classrooms serves students well as they learn what science is all about. It is our contention then, that the better we do at helping them to see their own ideas as valuable, the better we have done in giving them a dynamic picture of the scientific enterprise' (1999, p. 197).

Thus, by engaging students-as-scientists, teachers may be able to facilitate students' practical knowledge of the 'craft' of the scientist.

The Role of Non-Science Subjects in Providing Information About Student Scientific Literacy

9. *Non-Science subjects may inform understandings of student scientific literacy*

Other subjects may potentially inform researchers about the complex nature of student scientific literacy. For example, Jimmy's relatively high visual literacy demonstrated in English, and low lexicographical literacy, suggested in Italian, complemented and deepened the understanding portrayed in this thesis of his scientific literacy. Future possible research of broader scope could be conducted on the influence of non-Science subjects on student scientific literacy, thereby deepening science educators' understanding of the concept.

10. *Non-Science subjects may effect the nature of student participation in Science*

Non-Science subjects may suggest strongly to students the most appropriate way to participate as a learner within the broader culture of the school. If the majority of these subjects facilitate a student-as-recruit role, the comfort and safety of working within the confines of this role may restrain students from enacting other learning roles in Science. For example, one of the factors that persuaded Tara to discontinue working as judge in Science may have been the safety and success of working as recruit in Social Studies and Mathematics.

Moreover, the impact of general literacy developed in English classes, numeracy developed in Mathematics classes, research skills developed in Social Studies, and learning a foreign language such as Italian, whilst outside the scope of this study, may have a significant impact on student scientific literacy. For example, Kearsey and Turner (1999) found that bilingualism, in some contexts, aided student understanding of scientific language, because aspects of metalinguistic awareness can help in its interpretation.

Conclusion

Each of the above assertions addresses different aspects of equity of access to scientific literacy, and suggests that different students can be provided with or denied access for different reasons. It may be that, like Tara, their own logical thinking efforts conflict with classroom agendas and so limit their success. For some, like Jimmy, their preferred style of learning is minimally accounted for. For others, like Darrien, little is presented that motivates them to participate. However, some, like Shelly, can adapt to numerous agendas and gain access. With these assertions from the research, I move on to the final discussion about student scientific literacy in Chapter Twelve.

Chapter Twelve
Discussion

Inconsistency of definitions of scientific literacy, incompleteness of in-depth portraits of student scientific literacy and inequity of access to scientific literacy were major reasons for engaging in the research presented in this thesis. The first reason was addressed by the development of a metaphorical framework for scientific literacy, the second by the production and interpretation of research vignettes, and the third by the assertions formulated from these interpretations. The vignettes, interpretations and assertions provide insight into why 'scientific literacy' may be so elusive, with many students being denied access to it. In this final chapter, I summarise the thesis and suggest possibilities for future research into scientific literacy, and ways to promote a more powerful and inclusive scientific literacy in the classroom.

Summary

In this thesis I have addressed the question: '*What are the effects of learning tasks in Science and in other subjects on student scientific literacy?*' In Chapter Two, I presented the rationale behind the participant observer research, which utilised extended involvement in Science classrooms, and, occasionally, tracking students into a variety of subject areas throughout their school day. I described the legitimation and representation of the research, the writing of the vignettes, and the evolution of the interpretive framework used to make sense of them. Before defining scientific literacy, I identified objectivism, personal constructivism and social constructivism as referents having the greatest impact on the variety of ways scientific literacy has been conceived. The emerging agenda for these competing viewpoints to complement, as opposed to conflict with, each other was a focal point of Chapter Three. Metaphor was promoted as providing a deeper and more encompassing level from which to address issues of difference, as it has potential for establishing a dialectical tension between each competing notion. Metaphor took the central role as the frame of reference for this thesis, and provided language to facilitate a pluralism of epistemologies.

Ascending from this epistemological level, still immersed in metaphor, I reached the level of concern, that of scientific literacy. I defined 'scientific literacy' in terms of the three-metaphor framework, consisting of student-as-recruit, student-as-judge and students-as-scientists, in order to investigate what the 'effects of tasks' could be. The viability of the three-metaphor framework 'to help consolidate and summarize the many definitions' (Agin, 1974, p. 405) in the literature was demonstrated, before proceeding to use it to interpret the two tales that focused on four students.

Each week of their Year 8 school life, Shelly, Jimmy, Tara and Darrien were timetabled to spend the equivalent of three-quarters of one school day in Science lessons. And they spent much of this time, in terms of the three-metaphor framework, as recruits of classroom-science. Factors that facilitated the adoption of a student-as-recruit role varied from student to student. Shelly was presented as a student who went to surprising lengths to appropriate classroom-science knowledge during closed investigations (Chapter Five). Tara, too, appropriated this knowledge, though only after a period of disenchantment with the value of the knowledge being presented. There is evidence to suggest that whilst Tara contributed to the emerging knowledge, she not only disagreed with it, but also considered it to be 'stupid' (Chapter Ten). Darrien worked as a recruit only as a last resort when sanctions may have been applied (Chapters Eight and Ten).

A variety of factors facilitated students-as-scientists in Science lessons. Shelly acted as scientist when she was presented with an open-ended experiment (Chapter Seven). Tara and Shannon showed signs of beginning to work as scientists, until the methods they were using were challenged and changed by authorities in the classroom (Chapter Eight). It may have been Shelly's familiarity and utilisation of classroom-science procedures that allowed her to work uninterruptedly on her research. Conversely, it may have been Tara's and Shannon's non-use of such norms that ultimately prompted the interruption in their work as scientists. Tara's disregard for classroom-science procedures in experimentation fits well with her view that such knowledge sometimes was lacking in logic. Jimmy utilised the structure and visual input of a closed investigation to function with Adrian, to some extent, as scientists (Chapter Five). Darrien is represented as not working in this way, regardless of the task provided.

Only Tara provided any sense of working as judge. She did so during a closed investigation in which she proved to have an alternative, well-considered concept that was contrary to the classroom-science knowledge being developed (Chapter Ten). When her alternative conceptions were misunderstood and then ignored, she seemed to abandon the role of judge. Shelly, whilst working as scientist, seemed to lack the skills associated with student-as-judge, a lack which may have contributed to her belief in the somewhat ludicrous results of a misapplied maths equation.

Chapters Six and Nine presented the four students in a variety of non-Science subjects. The English lessons provided deeper understanding about scientific literacy: the visual literacy theme emerging from Jimmy's class; the relaxed creativity of Shelly, compared to the tension of her creativity in Science; and Darrien's 'have fun and enjoy life' motto. Mathematics suggested the significance of social factors in both Shelly's and Jimmy's learning. Darrien was a paradox in Mathematics, seemingly capable of doing mathematics problems, yet he often worked at a minimal level and failed badly in tests. Tara operated at a level well within her abilities as a comfortable recruit of classroom-mathematics. This comfort was in strong contrast to her way of acting in Science, and may be one of the factors that convinced her that it was easier to surrender and act as a recruit of classroom-science. Social Studies and Italian were represented as requiring students to appropriate terms and knowledge primarily from text, and possibly salient for their effect on student learning roles in Science.

Next, the implications of the ten assertions of Chapter Eleven are discussed, first for educational research, and then for classroom application.

Implications for Research

Research in Science Classes

Further research could now consider if the three-metaphor framework for scientific literacy can be effectively utilised in other educational situations by other researchers, and so determine its viability in a variety of contexts. Is this framework, constructed in one research context by one researcher, informative about the nature of scientific literacy generally, and in other specific situations? Could it be improved by modifying the nature or number of the metaphors, or is a metaphoric framework itself fundamentally unhelpful?

You will recall that the assertions of Chapter Eleven were divided into three sets. The first set, 'Ways of Accessing Scientific Literacy', contained five assertions:

1. Multiple outcomes may result from a learning task
2. Changes in perceived style of student participation may alienate some students
3. Not all students may participate in classroom activities
4. Social settings may limit access to scientific literacy
5. Learning styles may determine access to scientific literacy

These assertions fit in with existing literature and research directions, as discussed in Chapter Eleven, and do not suggest original future directions. However, the second set of assertions, 'the role of the three-metaphor framework in facilitating scientific literacy', is based on a novel understanding of scientific literacy that emerged from the research, and, whilst in keeping with the literature, provides some original direction for research:

6. Students may be frequently engaged as recruits of classroom-science
7. Scope for student-as-judge may be significant for learning in Science

8. Students-as-scientists may formulate deeper understandings of classroom-science

Further research can examine, in a variety of contexts, the three metaphors as a framework for scientific literacy. Research could investigate the efficacy of the three-metaphor framework by focusing on student perceptions: how useful is this framework for helping students forge a well-rounded scientific literacy? Another focus could be on teacher intentions, planning, and evaluation: Do teachers necessarily facilitate a larger proportion of students attaining scientific literacy, or attaining different types of scientific literacy when utilising the framework? Most productive initially, however, would be further research that utilised the three-metaphor framework as an a priori notion in classes with no intervention strategies, to find evidence and disconfirming evidence for the viability of the framework.

One helpful feature of the three-metaphor framework is that it attempts to embrace broad, even divergent notions, of what scientific literacy entails, a hall mark which makes it more difficult to reify a given metaphor. Roth (1993, warned that metaphors are open to 'multifarious interpretations', and suggested as part of the remedy that:

> through an ongoing process of reflection on action, enhanced by collaborative inquiry with peers and video-based data sources (Roschelle, et. al., 1992), metaphors and fine structures, such as specific forms of questioning, can be elaborated and made compatible. Such fine structures should not be developed in the form of lists of rules and prescriptions: In this form they would not be accessible to the teacher in action. Rather these specific discursive action patterns should use the demonstrated power of metaphors to convey complex information in complex ways (p.370).

Various types of research could elaborate the fine structures of the three metaphors.

In addition, if the three-metaphor framework (or an improved version of it) was widely adopted, it could have a large impact on research into scientific literacy because a variety of research methodologies could be reported in a common terminology that permits objectivism, personal constructivism and social constructivism to be held in dialectical tension. Wildemuth (1993) found that when she conducted an interpretive study in parallel with a positivist study that:

> each provided a different view of the same set of overt behaviors. The positivist study addressed such issues as how often the behaviors occurred and whether there were quantitative patterns in the occurrence of the searching behaviors. The interpretive study addressed such issues as why particular behaviours occurred, based on the view of the person engaging in the behavior (p. 465).

As explained in Chapter Three, there is an emerging agenda for researchers and teachers to hold different viewpoints in dialectical tension. A common terminology opens up the possibility to move from the realm of theoretical statements about scientific literacy to empirical studies. This research agenda could include qualitative and quantitative research approaches and, conceivably, accommodate conflicting evidence about students' scientific literacy. Of particular interest would be localised research on scientific literacy, such as action research, or participant observation, which could generate individual, fine-grained, credible (in the Guba & Lincoln, 1989, sense) data in a specific context, using the three metaphors as the interpretive framework. A meta-analysis of intrinsically non-generalisable case studies across many contexts could identify more general trends or patterns in student scientific literacy. This agenda could involve teachers as action researchers. Wildemuth's (1993, p. 466) conclusion was that 'interpretive research can be combined effectively with positivist research, in spite of the fact that the two approaches take very different views of the nature of reality and how one comes to know about or understand reality.'

Different approaches can ask and answer different, yet complementary research questions (Taylor, Fisher & Fraser, 1996).

Cases that cast doubt on the legitimacy of the three-metaphor framework need to be sought, and if found, considerations made about whether the metaphoric framework would need to be changed in a minor way or altered more radically. Moreover, the question of whether a metaphoric framework, in whatever shape, is able to provide rich understandings of student scientific literacy across numerous contexts needs to be addressed.

Research in Non Science Subjects

The third set of assertions in Chapter Eleven pertained to the informative value of non-Science subjects for understanding and influencing student scientific literacy:

9. Non-Science subjects may inform understandings of student scientific literacy
10. Non-Science subjects may effect the nature of student participation in Science

Further research, either utilising the three-metaphor framework, or otherwise, could probe further the value of non-Science subjects for informing researchers about the nature of scientific literacy: Is the scientific literacy of 12-to-18 year olds better understood in the context of Science classrooms only, or in the context of a variety of high school classes? In addition, the influence of participation patterns in these subjects on the roles students adopt in Science classes could be examined. The use of metaphors, perhaps somewhat parallel to the three-metaphor framework, to inform other forms of literacy, such as mathematical literacy and computer literacy may also prove to be a fruitful avenue for research.

Speculations for the Development of Scientific Literacy in the Classroom

If further research suggests that these three metaphors, or a modified set of metaphors, are needed to embrace all scientific literacy ideas, then teachers may begin to consider if the roles they suggest ought to be facilitated in science classes. A positive example of enacting multiple roles in the present research was Shelly, whose employment of classroom-science notions (in Chapter Seven) seemed to assist her role as scientist. It was suggested that by using creatively classroom-science notions, her role as scientist deepened the understandings she gained as a recruit. For a negative example, Tara's participation as judge competed with classroom-science knowledge (in Chapter Ten), and she ended up participating as a trivialised recruit.

If all three metaphors were to inform classroom practice, it may be possible for well-rounded scientific literacy to be developed by a variety of students. If Jimmy's more spontaneous adoption of a role as scientist had been recognised and valued, for example, by encouragement to convince the class about his truth claims by utilising written argument, then this may have helped his written literacy and thus assisted his role as a recruit.

Eisenhart, Finkle and Marion, (1996) advocated a scientific literacy which involves 'the ability to act (not merely to know).... Literate persons not only possess knowledge, but they use knowledge in varied contexts and for worthwhile purposes and in a socially responsible way' (p. 283). From my involvement in the research, I speculate that scientific literacy constitutes not only the *ability* to act, but also (as a precursor) that a person *has* acted scientifically. Much of the scientific literacy literature implicitly separates the practice of science and the literacy of science (see Chapter Four). It is possible that a person will rarely increase in scientific literacy, (e.g., understand a concept such as 'controlled variables'), without having carried out scientific acts related to empirical experiments that they have designed themselves. In other words, scientific literacy may be intimately wrapped up in the doing of experimental science. Bingle and Gaskell claimed that, for the general public, the meanings of scientific

'...evaluations are inaccessible to them unless they achieve the level of education and expertise of a professional scientist...' (1994, p. 197). Scientific literacy is a feature of citizens or students who are involved in the scientific process, not shut out from it. The term 'scientific literacy' may have become misleading to a large extent because it tends to direct science educators to pursue a literary or cognitive definition. However, it would seem that only a small percentage of Science students become scientifically literate without having acted in a scientific manner. So, for many, scientific illiteracy may be related to lack of opportunity to have participated in scientific acts that were meaningful to them.

In what ways can we make sense of the notion that students must be able to do science (i.e., act as scientists) as well as learn about science? Taken together, the experiences of Tara and Shelly suggest greater opportunities to work (uninterruptedly) as scientists could have incorporated rather than alienated Tara's creativity, and opened up further canonical understanding for Shelly. Facilitating student-as-judge may have legitimated and channelled positively otherwise destructive actions in Tara's experiences, and developed Shelly's application of classroom-science knowledge in a more critical manner. If students-as-scientists and student-as-judge are legitimated in classrooms they may not only reinforce students acting in the manner of recruit, but also vice versa.

What is the importance of these three metaphors for teaching? Primarily, they provide a conceptually accessible way for teachers to consider learning tasks: those intended by the classroom teacher, and those that students actually participate in. A teacher could choose to plan activities that may enhance the type of scientific literacy they see as suitable on a given day. A teacher could ask his or herself, 'How do I want students to participate in this lesson? Which metaphoric role is each student actually engaging in?'

A scientific literacy that construes student-as-recruit only is a reasonable and enduring concept, and is a good perspective to have if we prefer society to raise an elite of practising scientists out of a selection of the whole student body. Fensham (1988, p. 12) pointed out that there is 'a great deal of evidence, at least in many of the more industrialised countries, that the curriculum of science education... has been shaped to service subject maintenance and economic and political needs, rather than individual, social and cultural factors'. This is a view where a small proportion of the population is needed to be scientifically literate, and these people are, or become, by and large, the practising scientists. This mentality seems to be driven by a variety of powerful (political and economic) agendas with pervasive influence that will not easily be overcome (Hattam, 1994). Nevertheless, if an objective of Science Education is 'science for all', where more students are scientifically literate, we must consider the legitimacy of students working as recruits, as judges and as scientists. There is a need for Science teachers to be pedagogically tactful (Van Manen, 1991), a skill which can enable them to:

> make a well-justified professional judgement about which teaching-learning metaphors are most appropriate for a particular pedagogical purpose and context. This judgement requires a dialectical rationality: keeping one eye on the pragmatic requirements of the extant culture and the other (visionary) eye on possibilities for cultural transformation (Taylor, Gilmer & Tobin, 2001).

Possible Ways of Facilitating and Assessing the Impact of the Three Metaphors in the Science Classroom

In view of the outcomes of this research, it could be asked: 'how can teachers successfully set up learning tasks so that, on some occasions, they provide opportunities for students to work as recruits, on other occasions as judges, and on still other occasions as scientists? Tasks, such as the teabag rocket experiment (Vignette One) can be provided for students to work as recruits of classroom-science. However, questions such as those asked by Jimmy - 'Can we modify it?' - could be utilised to facilitate students-as-scientists during a subsequent lesson. Genuine questions doubting the suitability of the classroom-science explanation of why teabag rockets lift-off could become the basis for students functioning as judges. Tasks such as the experiment on parachutes that Shelly was involved in (Vignette Three) can promote much thinking, dialogue and opportunity for students to work as scientists in which they define their own problem, design their own experiment, and argue the validity of their results within realistic time and material constraints. There is also potential for the scope of persuading the classroom community and establishing a far more dynamic discourse (see Vellom & Anderson, 1999, for an excellent example of this). In addition, classroom-science concepts could be woven in at any time, or allowed to spontaneously arise from students' research.

An important consideration is that a school that decides to value all three aspects of scientific literacy needs to reflect this curriculum policy in its assessment. Some assessment may be conducted, using tests and exams, on classroom-science knowledge (in a manner that is possibly much the same as most assessment is conducted at present). Some may be determined by a student's work as judge, in which he or she has evaluated knowledge claims using viable inferences. This may be assessed, for example, by using student journals (Connelly & Clandinin, 1988) or collections of experiments accompanied by students' critical evaluations of them. Some appraisal of students-as-scientists may be made on the basis of experiments designed, reported and defended in class, utilising portfolios (Duschl & Gitomer, 1991; Paulson, Paulson & Meyer, 1991; Tobin & Tippins, 1993) that facilitate formative assessment of students throughout the whole school year.

Scientific Literacy: the Fuzzy Term that Focuses?

The stories of Shelly and Jimmy, Tara and Darrien could be taken to represent different ranges of operating within a dynamic spectrum of scientific literacy. Tara's range of scientific literacy included that of a deterred scientist, a frustrated judge and an unbelieving recruit of classroom-science. Shelly, on the other hand, functioned with success as recruit and as scientist. However, sometimes her work as scientist was seemingly illogical, and this was in accord with the lack of evidence of her participation as judge. Jimmy, too, provided evidence for operating as the first two, but not the third. However, his scientific literacy was often out of step with his teacher's plans, and he had less conventional paths for gaining access to learning experiences than did Shelly, and, therefore, his scientific literacy seemed to gather low recognition and low grades. Darrien demonstrated the smallest range of student experience according to the three-metaphor framework, working only as a recruit of Science. However, this seems to be more a limitation of the explanatory power of the three-metaphor framework than an indication of his scientific literacy.

If the experiences of Tara, Shelly, Darrien and Jimmy constituted restricted ranges within a wide spectrum of student scientific literacy, it is possible to imagine other student experiences falling either between or beyond these. I suspect that since 'scientific literacy rates' have invariably been measured as 'low' then that part of the spectrum where Tara, Darrien and Jimmy were located is more densely populated than Shelly's end. That is, more students might experience the types of frustrations, trivilisations, demotivations and restrictions that were typical of the three than of the one. Will students such as Tara continue to be disenfranchised by a narrow prescription of how they should act in the Science classroom? Will those such as Darrien continue to engage their creative powers in off-task, more-interesting matters? Will those such as Jimmy continue to be neglected because of their unrecognised or neglected preferred style of learning? Or will a greater proportion of students be enabled to embrace opportunities, as did Shelly, to develop their strengths, improve their weak areas and access a well-rounded scientific literacy? Will more students be given the kinds of access that is helpful to them to increase in scientific literacy?

The answers to these questions depend, in part, on the epistemological issues raised in Chapter Two. If a notion of learning theories competing with one another is prevalent, then conflicting understandings of how students learn will continue to not only divide science education theorists, but also restrict notions of scientific literacy and the experiences afforded to students in each classroom.

However, if the emerging view of the complementarity of objectivism, personal constructivism and social constructivism (amongst others) gains favour, it is possible that science educators at all levels, as well as science students, will benefit. For those who choose to use it, will the three dimensions of the metaphoric framework of student-as-recruit, student-as-judge and students-as-scientists, provide the needed explanatory power to help teachers and researchers conceive of scientific literacy in a more educationally helpful manner? And can this three-dimensional view promote, not a flat, prescriptive and divergent range of conceptions, but rather a full-bodied, dynamic and inclusive range that enables the fuzzy term of scientific literacy to focus otherwise conflicting energies on developing a scientifically literate generation in the Twenty-First Century?

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