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**From the Experiences of  
Women Mathematicians:  
A Feminist Epistemology  
for Mathematics**

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE  
REQUIREMENTS FOR THE DEGREE OF DOCTOR OF PHILOSOPHY  
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# Abstract

In this thesis a feminist epistemology for mathematics is developed. The rhetorical space in which this can be achieved and questions about the gendered nature of mathematics, its practices and epistemology can be asked, is created by considering feminist epistemology, the gender, mathematics and education research literature, the feminist science debates, the philosophy and sociology of mathematics and the experiences of women mathematicians,

Eight women research mathematicians were interviewed about their experiences in mathematics communities, the knowing styles they used in their work and the legitimating practices of acknowledgement and validation prevalent in these communities.

This feminist epistemology for mathematics addresses the questions of who knows, how we know and what we know. It includes a commitment to the inclusion of women as knowers, the asking of questions arising from women's experiences and the exposure of the feminine in mathematics and mathematical practices. It depends on a transformation of the binaries which have informed the definition of the subject of knowledge, the epistemological values of mathematics and the knowing practices of mathematics. The traditional Cartesian subject of knowledge is replaced by a subject who acts within a community of knowers and who is both rational *and* emotional, subjective *and* objective and who uses reason *and* intuition. Defining knowing in mathematics includes accounts of the social *and* of the defining values and commitments of mathematics. Reflexive processes that account for intuition, creativity, incompleteness, and the social relations and processes in the mathematical community are included, as are the traditional mathematical values of logic, rigour, objectivity and abstraction. These traditional values are identified as having been defined within a social context. Mathematical objects are formed as part of a framework, a language, a conceptualisation of the abstractions made from the regularities of reality and which are in turn imposed upon that reality. They are formed out of the interaction of nature and culture and the changes each imposes upon the other. One is neither privileged over nor prior to the other.

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# Chapter 1

## Introduction

It is man's supreme intellectual achievement and the most original creation of the human spirit. Music may arouse or pacify the soul, painting may delight the eye, poetry may stir the emotions, philosophy may satisfy the mind, and engineering may improve the material life of man. But mathematics offers all these values (Kline, 1980:352).

When Kline first wrote these words he may well have intended his use of the word 'man' to be understood in the generic sense of all men and women. The reality is, however, that the values mathematics offers are not equally accessible to all. Women's participation in mathematical endeavours and in the pleasure to be found in mathematics are disproportionately lower than men's. My project is fuelled by my political commitment to increasing the number of women participating in mathematics, and in the sciences, engineering and technology. As mathematics acts as a critical filter for entry into these other disciplines participation in them is virtually impossible without some background in mathematics. Mathematics therefore, appears to be a good place to start to improve the situation. I will be arguing in this thesis that greater participation of women in mathematics would have an impact not only on women but also on the mathematics community and culture and the course of mathematics itself and would lead to positive benefits for mathematics and all mathematicians.

Research questions often stem from the personal experiences and interests of the researcher and the questions raised in this thesis are no exception. Prior to beginning this project I had sat in women's studies classes with women who, for a wide variety of reasons, stretching far beyond individual interest and aptitude, had little background in mathematics and science. They often described these disciplines as some kind of male torture from which they were lucky to have escaped. They made assumptions about women and science or

mathematics that seemed quite foreign to me. They assumed that women who were successful in the sciences and mathematics were in some way extraordinary. Such women must be extraordinarily intelligent but if so it was at the expense of the rich emotional life they assumed they had themselves. In relating their experiences and self-understandings to the binary rational/emotional they had firmly ensconced themselves on the 'emotional' side. Whereas I sat there with my first degree in mathematics, asking myself whether I was missing something and whether I had failed again in the 'real feminist' stakes because I did not conceive of the rational and emotional as opposites. In reflecting on this, I realised that women - living, loving, birth-giving, breastfeeding, menstruating, pre and post-menopausal - mathematicians occupy a particularly contradictory position on the rational/emotional divide. The experiences of women mathematicians could be a good site within which to examine the interplay of the rational and emotional. This led to my interest in exploring the issues they face and the experiences they have. How do they experience and understand their position? How do they achieve success in mathematics when so few women do? How does their presence affect the social worlds of mathematics and the practices and developments in mathematical knowledge?

## **Gender and mathematics in education**

In a subsequent class I had the opportunity to develop this interest further when I searched the literature on gender and mathematics. This literature includes some historical accounts of great women mathematicians of the past and extensive research on gender and mathematics in education. Very little feminist analysis has been done on the relationships between women and mathematics or the experiences of women mathematicians, outside of the education literature. As I read a little voice kept asking "What about the women and girls who *do* mathematics?" Their voices are seldom heard in these debates.

The focus of research on gender and mathematics in education has been on establishing differences, particularly in achievement but also in participation. In establishing these differences male students are characterised as the norm against which female students are compared and very often described as lacking. Emphasis is then placed on finding large numbers of causes and explanations for the differences which focus on girls and their supposed deficiencies. The number of reasons suggested is disproportionate to the size of the 'problem'. While many writers describe their work as being about 'gender', this term has become a euphemism for 'girls and/or women' and the experiences of males and their relationships to mathematics are seldom problematised.

The question of differences in achievement between females and males is not as straightforward as many researchers in the field claim. A closer examination of the research carried out in the past calls the conclusions drawn from this research into question. Differences in achievement between males and females were not as well founded as has usually been concluded. I argue that researchers were predisposed to find these differences because of the cultural milieu in which such questions and answers were raised. If mathematics is seen as a pure form of reason and women are associated with the emotions then questioning women's ability in mathematics is likely to appear to be a question worth asking. This association also predisposes the researcher to find such differences. It is now well established that females do at least as well as their male counterparts through to the post-graduate level although the participation rates of female students continues to be a problem. An extended review of this gender and mathematics in education literature and discussion of the issues raised is undertaken in Chapter 4.

Researchers in this field are now looking at some of the issues I have raised here. They are reflecting on the ways in which girls are constructed as the problem in these debates (Willis, 1995). Burton (1995) and Damarin (1995b) are focusing on epistemological questions about the nature of mathematics and the links between our understandings of what mathematics is and masculinity.

This association of mathematics with masculinity affects the participation of women and the suppression of the feminine in mathematics. These epistemological questions are central to my thesis.

A principal question I address in this thesis is whether mathematics would be different if more women were involved. This question implies differences in mathematical knowledge and practices. In order to establish the possibility of such differences I establish that mathematics has been influenced by its male gendered history. Traditional epistemology of mathematics is based on values such as objectivity which are defined by hierarchical dualisms which reflect the privileging of the masculine over the feminine. This gendered epistemology together with gendered practices in mathematics not only affects the course of mathematical developments but also influences who is included and excluded in the group, mathematicians.

### **Gender, the masculine and feminine**

My use of the theoretical concept, gender, in this thesis requires clarification. Feminist theory has been careful to distinguish between the concepts of sex and gender (Humm, 1995:106). Sex refers to the biological and anatomical differences between male and female whereas gender refers to the emotional and psychological attributes and the behaviours which are expected to coincide with biological maleness and femaleness in a given culture (Tuttle, 1986:123). We may be born into a particular sex but we become our gender. The gender of an individual may not always coincide with their sex (Tuttle, 1986:123).

Both of these concepts, sex and gender, have been further developed and problematised by feminist theorists. The immutable nature of 'sex' itself has been contested and the argument made that it is also culturally constructed (Butler, 1990:7). Even the concept of there being two sexes is increasingly contested. Gender is not constituted coherently and consistently in different contexts. What attributes and behaviours we attribute to gender vary across time, race, class, ethnicity and sexuality (Butler, 1990:3).

For my purposes in this thesis, I am taking a relational view of gender in which gender is a shifting and contextual phenomenon and not a substantive or immutable concept. It is “a relative point of convergence among culturally and historically specific sets of relations” (Butler, 1990:10). This allows for a set of attributes and behaviours to be associated with a particular gender but not in such an immutable way that members of other genders cannot display them. When a group such as women mathematicians take on attributes such as reason and abstraction which are commonly associated with men they present a challenge to our definitions of gender appropriate behaviour.

My decision to focus on gender to the exclusion of other differences reflects the development of theoretical work in mathematics at this time. Considering the possibilities of mathematics being influenced by social and cultural factors is a radical move in itself before any consideration is given to the possible consequences of gender. There is little theoretical groundwork on which to build an even more nuanced analysis. My decision also reflects the population of women mathematicians<sup>1</sup> which very sadly does not include Maori or Pacific Island women<sup>2</sup>. Excellent work in the area of ethno-mathematics concentrates on different issues than those of interest to me here. The emphasis in that literature is on the mathematics that has been developed in other cultures. It does not discuss the possibility of change in the dominant forms of mathematics as practised in the West which might occur as a result of including mathematicians from a more diverse range of ethnicities.

<sup>1</sup> I have defined ‘women mathematicians’ for my research to be those women who work in mathematical research. I have not included teachers or statisticians or those who use mathematics as a tool in their work.

<sup>2</sup> Maori are the indigenous people of New Zealand and people from the various Pacific Island nations make up the biggest minority group in New Zealand. Both groups are disproportionately under represented in higher education and the professions.

In my thesis I distinguish between men/women, male/female *and* the masculine and feminine. When referring to men/women, or males/females, I am referring to actual people. The ‘masculine’ refers to those attributes commonly associated with masculinity, for example reason; objectivity; abstraction; and the mind; which may not be referentially tied to actual people. In the same way the feminine is associated with particular attributes such as emotion; intuition; caring; and the body; independently of actual people. Thus to say that the ‘feminine’ is suppressed in mathematics is to say that those attributes associated with the feminine are suppressed. This does not necessarily imply the suppression of actual individual women.

### **Rhetorical spaces**

The view of mathematics as value free, abstract, rational, and objective which Ernest (1991:3) describes as the “dominant epistemological perspective of mathematics” leaves little room for asking the kinds of questions which interest me. This view implies that mathematics is above and beyond the influence of culture. If this were so the question of whether mathematics might be different if more women did it would not make sense. I will go on to argue that this is not an accurate picture of mathematics, but here I am clarifying Code’s (1995) concepts of ‘rhetorical space’ and ‘choral support’ which I use throughout my work. According to Code’s definition a rhetorical space is a location in which some things can be said, and some questions can be discussed, in the expectation that they will be seriously considered. The questions themselves ‘make sense’ in that location. ‘Choral support’ refers to the acknowledgement by others participating at that location that the matters raised are worthy of discussion.

Rhetorical spaces, ... , are fictive but not fanciful or fixed locations, whose (tacit, rarely spoken) territorial imperatives structure and limit the kinds of utterances that can be voiced within them with a reasonable expectation of uptake and ‘choral support’: an expectation of being heard, understood, taken seriously. They are the sites where the very possibility of an utterance counting as ‘true-or false’ or of a discussion yielding insight is made manifest (Code, 1995: ix-x).

Traditional epistemology of mathematics has not provided the rhetorical space to ask my questions about mathematics. In my thesis I establish that such space can be found or established in the gender and mathematics education debates, the feminist science debates, feminist epistemologies, the philosophy and sociology of mathematics, and the experiences of women mathematicians. By situating the debate within the rhetorical space created in these contexts the question, 'would mathematics be different if more women did it?' can be raised and addressed in the expectation of finding 'choral support'.

### **Feminist science debates**

The work that feminist theorists have done in analysing the intersection of gender and science is relevant to my work in mathematics because of the similarities between mathematics and science. These similarities include the low participation rates of women; the lack of attention paid to questions of interest to women; the nature and underlying values of the two disciplines; and their high status in society.

The questions raised in the gender, mathematics and education research have also been addressed in relation to science education. Questions have been asked about differences in achievement and participation and explanations for these differences suggested, but the discussion has also been wider than the education issues in science.

Questions have also been asked about the number of women working in particular areas of science and their experiences in these areas have been analysed. These investigations lead to the questioning of the intertwining of masculinity and science and the gendering of scientific practices and knowledge. Just as with mathematics, a model of science as being a discourse of objectivity and truth, above and beyond the claims of history and culture, does not provide the rhetorical space within which such questions could be asked. The questioning of the gendered nature of science and scientific practices has to be set within the context of social studies of science if 'choral support' for the discussion is to be found.

Harding (1991) argues that the asymmetrical gender relations in society are carried into science through the association of science with masculine identity; the division of labour by gender occurring within and outside science; and through gender symbolism. The symbolic work of gender through the use of metaphors and gendered binaries extends into science and reinforces within science the hierarchical nature of these gendered dichotomies. I add to this list the dominance of gendered practices, particularly in communication and networking practices and the privileging of particular knowing styles. In extending the feminist science debates to mathematics I argue that asymmetrical gender relations are carried into mathematics in similar ways.

Mathematics and science are similar in that the values of objectivity and rationality are central to both. The formalised symbolic language of mathematics epitomises these values and its use in other sciences reinforces their claims to the status attributed to reason and objectivity. These values are themselves associated with masculinity. Harding (1991:117) argues not only that their use has developed from androcentric interests but they also serve to legitimise the pervasiveness of gendered interests.

The norms themselves have been constructed primarily to produce answers to the kinds of questions an androcentric society has about nature and social life, and to prevent scrutiny of the way beliefs that are nearly or completely culture-wide in fact cannot be eliminated from the results of research by these norms.

It is more difficult to see how gendered metaphors enter mathematics than science because of mathematics' reliance on this formalised symbolic language but drawing on the work of Keller (1985; 1992), who analyses the use of such metaphors in science, provides some inroads into such an analysis of mathematics. The notion of purity as in 'pure' mathematics also has gendered connotations which I will explore further in Chapter 6.

Although there are differences between mathematics and science, in that mathematics is predominantly but not exclusively analytical and science is predominantly but not exclusively empirical, feminist analysis of the gendering of

science provides an important rhetorical space from which to examine similar questions in mathematics.

### **Mathematics: philosophy and sociology**

It is not only feminist analyses that support the asking of my questions about mathematics. Recent developments in both the philosophy and sociology of mathematics are also useful to my project. Historically, mathematics has strong links with philosophy. Philosophical debates about the nature of mathematics, its foundations and its relationship to 'truth' have raged long and furiously over the centuries. Some of the philosophers participating have claimed that mathematics is a creation of pure mind above and beyond the exigencies of temporal life and subjectivity. If this were so then there would be no space to ask how gender influences the course of mathematics and how the gendered subjectivities of mathematicians are intertwined in their mathematics. But philosophical accounts of mathematics that have been derived from such assumptions about the nature of mathematics have been found to be inadequate to explain mathematics, its developments and practices (Goodman, 1986; Kline, 1980). Hersh expresses the necessity of developing philosophical accounts that are true to the reality of mathematical experience. This experience tells us that mathematical truth is fallible and corrigible (Hersh, 1986).

Mathematics is not indubitable truth but is another form of human knowledge arrived at through social activities and processes and is thus affected by the kinds of people who participate in its making. Standards for mathematical proof and rigour are established through processes of contestation and acknowledgement amongst mathematicians. The composition of the group, mathematicians, therefore affects and partly determines the standards accepted.

Mathematics is however more than an arbitrary collection of conjectures, proofs and theorems as accepted by the group mathematicians. Its success in describing the universe demonstrates this. This interrelationship between mathematics and the physical world and the way in which the physical world can be the source of new axioms, objects and theorems points to the quasi empirical nature of mathematics

(Putnam, 1986:63). This aspect of mathematics also needs to be taken into account in explanations of the nature of mathematical knowledge. It also indicates a point of connection between my analysis of the gendering of mathematics and the feminist science debates as these debates establish how gender is implicated in empirical processes.

In developing philosophies of mathematics that take the social context of mathematics into account the boundary between philosophy and sociology is eroded. There are, however, very few sociological accounts of mathematics and the social relations and cultural contexts within which mathematics is undertaken. Restivo's work (1993; 1992; 1991; 1990; 1988; 1983) which I have drawn on in my analysis is a noticeable exception.

In the social worlds of mathematics, each mathematician is involved in negotiations over what problems are worthy of attention, what methods are appropriate and what solutions are acceptable (Restivo, 1993:266). Restivo (1993:249) argues that mathematics is practised within networks involving relationships of domination and subordination and "[n]ew social circumstances and arrangements will give rise to new conceptions and forms of mathematics" (Restivo, 1993:276). It follows that feminist interventions in mathematics are likely to lead to changes in mathematics itself although this is not an argument Restivo makes himself.

I take up the beginnings made by Restivo and develop an analysis of the gendered nature of the social relations and practices in mathematics. The composition of the group creating mathematics can and does influence the standards of truth which are accepted. Controlling access to 'adequate education' clearly controls who can speak and be heard in this group. The concept of pure mathematics and the consequences of this concept for women are an aspect of this analysis.

The philosophy and sociology of mathematics seldom engage directly with questions about gender<sup>3</sup> but as the social is taken into account in this theorising the

<sup>3</sup> Ernest's work (1995; 1994a; 1994b; 1991) is an exception.

foundations for the rhetorical space in which such questions can be addressed are laid. The experiences of women mathematicians can illuminate the gendered nature of processes and practices within mathematical communities to which members of the dominant groups in these communities are oblivious.

### **The experiences of women mathematicians**

The women mathematicians interviewed for this project related experiences of working in mathematical communities that illustrate the gendered nature of some practices in mathematics and the stories told about what mathematics is and how it is done. The feminist theoretical concept of the public/private is useful in analysing the stories these women tell about their mathematics and their experiences in mathematical communities. The face of mathematics we see and experience in public is quite different from the private worlds of mathematics. In the public view such as that seen in mathematics classrooms in schools, mathematics is presented as certain, logical, deductive and rigid. But in the private worlds of mathematics, to which these women have gained access, the creative, intuitive and tentative aspects of mathematics can be found and enjoyed. For these women mathematicians, there are contradictions and pleasures in their experiences. There are contradictions between dominant discourses of femininity and of mathematics; between the communication, networking and processes of acknowledgement that these women preferred and those most commonly practised and valued amongst other mathematicians; and between preferences for connected rather than separate knowing styles. But there are pleasures to be found too in the combination of abstraction, reason, and logic, and the creative, intuitive and exploratory aspects of mathematics.

While my research has been successful in gaining new insights into the challenges faced by women mathematicians it is more difficult to draw conclusions about the question of whether women might do mathematics differently. The women's responses to this question were necessarily speculative because none of the women had had the opportunity to work closely on mathematical research with other women mathematicians.

## Methodology

In undertaking this project I have a commitment to feminist methodologies. This does not entail a commitment to particular methods but a commitment to a high standard of preparation, a reciprocal relationship with the participants, and a commitment to a 'strong' form of objectivity. Rather than looking only for the commonalities that would confirm my original thoughts I was looking for the contradictions, the inconsistencies *and* the commonalities within an individual participant's account, between participants, and between the participants understanding of their experiences and my theoretical understandings. I conducted in-depth, semi-structured interviews with the participants. They are all 'creative mathematicians' in the sense that they work with mathematics in such a way as to make a contribution to that body of knowledge. I defined the discipline loosely enough to include pure, applied, engineering and operations research branches of mathematics but not statistics. I maintained a tight definition of 'creative mathematician' because I had a primary interest in whether women might influence the course of mathematics itself in different ways from the traditional mainstream.

As part of my commitment to feminist methodologies I have attempted to retain as strong a sense of the individual women's voices as possible. To achieve this I have at times quoted at length from individual participants rather than including only the briefest most relevant excerpts. Throughout this thesis I have tried to avoid the use of dense theoretical language where possible to make my account and analysis more accessible to the women mathematicians who shared parts of their lives and experiences with me.

### Feminist epistemologies

I began this project with an interest in the dilemma identified here by Hekman (1990:31). Because men are identified with rationality and women with emotion, women face a contradiction between femininity and rationality.

Men, who are identified as the 'natural' occupants of the sphere of rationality, are contrasted to women whose sphere is that of emotion and feeling, the irrational. This dichotomy leaves women two unacceptable options: either they can talk like women and be 'feminine'

but irrational or they can talk like men and be rational but 'unfeminine' (Hekman, 1990:31).

Women mathematicians would seem to be in a particularly precarious position in relation to this dilemma. They are within the most rational of disciplines yet they are feminine and they are constantly positioned as 'women' in relation to individual men and masculine practices of knowledge in mathematics.

Hekman (1990:37) argues that dichotomies like reason/emotion either have to be accepted or rejected.

[E]ither the dichotomy itself is flawed and thus cannot be an accurate description of either the masculine or the feminine (the postmodern move) or it is accurate and describes masculine and feminine nature (the modern move).

I argue that these dichotomies themselves require deconstruction. They are not an accurate description of either women's capabilities or lived experiences nor of men's emotional lives and commitments. They only receive 'choral support' within a context of women's oppression. These dichotomies have never deserved the certainty they attained but they continue to authorise complex social situations in which some groups are privileged over others. The association with some values and practices based on these dichotomies legitimises knowledge claims based on them. The dichotomies become part of the perpetuation of women's oppression and exclusion from certain forms of knowledge making.

Indeed, feminists have shown that this dichotomy between masculine abstraction and feminine contextuality has been the central means of excluding women from the sphere of rationality and maintaining their inferiority (Hekman, 1990:16).

My starting assumption, which is confirmed in both the empirical and analytical aspects of this thesis, is that there is nothing intrinsically or essentially oxymoronic about women being producers of mathematical knowledge. It is only the denial of opportunity and the discursive construction of these subjectivities as oxymoronic that supports the belief and practices that this should be so. Women who do mathematics are just that, women who do

mathematics. They are exceptional only because we define them to be so. Women are rational *and* emotional and so are men. Women do not have to give up something 'feminine' to think in mathematical ways and to enjoy and take pleasure in doing so. They do not do mathematics at the expense of having a rich and satisfying emotional life.

Lorraine Code (1991:47) provides support for this argument: "Emotion and intellect are mutually constitutive and sustaining, rather than oppositional forces in the construction of knowledge." The 'positive' sides of the dichotomies have been a caricature used "to affirm a certainty that was never rightfully theirs" (Code, 1995:53). In rejecting essentialist claims about femininity that associate the feminine with the emotional, Code (1991:53) points out that equally essentialist claims are made about masculinity. I take this rejection further by arguing that reason and emotion are neither opposites nor mutually exclusive. While the status of 'knower' has been reserved for those who can give the appearance of having risen above their emotions to the heady heights of reason, these knowers remain emotional beings. Some emotions are legitimated and others are not in these caricatures. As long as emotional expressions are kept private they are acceptable and do not appear to be implicated in knowledge making.

In the individualist tradition, emotions are private matters, associated with particular, whimsical (= unruly) aspects of subjectivity. Rational agents are passively subject to emotions, which should be suppressed in deliberation and ratiocination. Only the products of these latter processes are deemed appropriate to place before the public eye, to become the bases of the policies and actions of authoritative public figures. People may *care* about the everyday affairs of practical life and about their personal associations. But these are private concerns that theoretical reason has to leave behind to attain universally valid, public knowledge (Code, 1991:243-244).

This depiction of the relationship between the two poles of the dichotomies disguises both the ways in which mathematics is practised and the emotional commitments of mathematicians.

Feminist epistemologists take issue with the position of the knower in traditional epistemology. For the traditionalists, knowledge is produced by undifferentiated individuals who are supposed to be able to take up an Archimedean point removed from their emotional commitments and outside their historical and social location, and from this point discover true knowledge (Jaggar, 1983:357). This notion of the knower is predicated upon hierarchical dichotomies such as reason/emotion; mind/body; objective/subjective. Feminist critics of this epistemological position argue that these dualisms reflect a fundamental dualism male/female which associates women with the right hand side of these dichotomies resulting in their exclusion from positions as knowers of truth. If it is assumed that women cannot rise above their own subjective experiences; the emotional; the private; the body; and attain objectivity, they will seldom be granted the status of 'knower'.

One response to this exclusion is to valorise the feminine side of the dichotomies and to value women as knowers with a distinct style as contextual knowers and to valorise the knowledge arrived at by this style. This is not the position I am taking. I argue for a deconstruction of the definition of objectivity defined in opposition to subjectivity.

Along with Harding (1993b), I claim that the traditional conception of objectivity is not strong enough to eliminate culture wide beliefs. What has been claimed to be objective is tainted by the emotional commitments associated with masculinity. The processes by which subjectivity is constructed and reconstructed are incompatible with a concept of objectivity which is based on an assumption of the possibility of stepping outside one's subjectivity. My position should not be confused with a relativist stance however. I am supporting Harding's notion of strong objectivity in which the knower locates themselves on the same critical plane as that which they desire to know. Part of the knowledge seeking process involves asking how our prior commitments influence and restrict our ability to conceptualise this problem and to accept possible explanations for this phenomena. I am not arguing for the rejection of reductionism and linearity in favour of contextual and holistic

approaches. It is the privileging of some approaches at the expense of others and the power relations involved in this privileging that are the issues for me.

Feminist epistemologists set a broader agenda for epistemology than traditionalists have considered because they are concerned with asking the question ‘who can know’. Efforts in traditional epistemology to “determine necessary and sufficient conditions for the possibility of knowledge and for cognitive practice” have had a silencing effect on much knowledge created by and about women. Feminist epistemologists are therefore interested in examining “*practices* of knowledge construction to produce critical retellings of what historically and materially ‘situated’ knowers actually do” (Code, 1995:176). They look at “how knowledge is produced in specific disciplines and areas of inquiry; how hypotheses are circulated and evidence selected; how conclusions are drawn and enacted; how disciplinary power structures work” (Code, 1995:176). My project is an example of this feminist approach to the epistemology of mathematics. I am interested not only in what can be known in mathematics and how, but also in who can be a ‘knower’. Leone Burton (1995) also takes a feminist approach to the epistemology of mathematics and insists on the importance of the knower in the knowing of mathematics. I will discuss her work in Chapter 9 when I present my own epistemology.

### **A feminist epistemology for mathematics**

By exploring the possibilities opened up in the gender and mathematics in education research, the feminist science debates, the philosophy and sociology of mathematics, the experiences of women mathematicians, and the possibilities of feminist epistemologies, the rhetorical space for asking whether mathematics might be different if more women did it, can be found. Although the ‘choral support’ for such arguments may be uneven and highly contested there remains sufficient room for exploring the possibilities of a feminist epistemology for mathematics.

Such an epistemology requires more than the valorisation of the feminine and an increase in the number of women mathematicians. A broadening of the

questions addressed in epistemological projects to include an examination of who can achieve the status of knower; the practices validated in creating and acknowledging new developments in mathematical knowledge and a transformation of the fundamental values of epistemology and mathematics are required.

The next steps cannot merely be the addition of some notes about women's subjugated knowledge to the existing corpus of received knowledge, or the integration of women on equal terms into received epistemological theories. They must transform the terms of the discourse, challenge the structures of the epistemological project (Code, 1991:324).

# Chapter 2

## Feminist Epistemology

### Introduction

Feminists have good reasons to be interested in questions about knowledge and how we arrive at it. In addition to the realisation that women have been oppressed within and excluded from knowledge and its creation, feminists have an interest in establishing grounds for truth claims for feminist research and knowledge. Of course feminists also share in a curiosity about the questions addressed in traditional epistemology, that is questions about knowledge, its significance, its creation and its certainty.

In this chapter I am going to discuss feminist critiques of mainstream epistemologies and the development of feminist epistemology that takes account of who the subject of knowledge is and how this knower creates knowledge. This development is based on a reconceptualising of the values that inform traditional mainstream epistemology and radical feminist theories of women's knowing, and a reconceptualising of the subject of knowledge. In this epistemology knowledge is not solely the result of the activities of an individual rational subject but is developed within social processes.

### History

Traditional mainstream epistemology was developed out of a different set of historical conditions to answer different questions about knowledge than those in which we are currently interested. Formerly the basis of reality had been seen as depending on the caprices of Providence. A changing relationship between the Church, king and individuals which was associated with the rise of science lead to questions about the nature of truth and the foundations for knowledge. The realisation that the earth revolved around the sun was an example of the threat to the kind of faith upon which knowledge had traditionally been built.

Reason was the weapon used by scientists to counter arguments based on faith. It was thought that, through reason, laws governing the universe would be discernible. Western philosophical traditions then moved from discussions about the nature of God and reality to questions about knowledge and truth (Grant, 1993:95). When God was accepted as the source of truth, this truth was interpreted by the priesthood and accepted on faith, but scientific discoveries represented a challenge to faith-based knowledge. The basis or foundations of knowledge shifted to the laws of nature as discerned by scientists through the application of reason. The basis of truth itself was challenged (Hekman, 1990:11-12). What constitutes the foundations of knowledge and reason has been the topic of philosophical discussion ever since.

Bordo (1988:628) argues that it is no accident that in another period of social upheaval different philosophical questions are being asked. She argues that these different questions “followed close on the heels of the public emergence, in the 1960s and 1970s, of those groups marginalized by the dominant metaphysics.” Like the challenges to knowledge occurring in the Enlightenment as a result of developments in scientific knowledge, what has since become mainstream epistemology is being challenged by new developments in knowledge creation. These include the failure of foundationalist schools in mathematics (discussed further in Chapter 6) and new developments in physics and other scientific disciplines.

### **Definitions of epistemology**

Traditional epistemology has been concerned with establishing necessary and sufficient conditions for knowledge: for justifying knowledge claims and for refuting scepticism (Code, 1991:266 & 315). Epistemology has been an inquiry more concerned with whether knowledge was possible than with identifying the conditions necessary for producing knowledge. No data or empirically based speculations about the manner in which knowers come to have knowledge have been included (Duran, 1991:3). The conditions that have been of concern are the conditions necessary to establish truth, not the conditions necessary for a

knower, a person or persons, to ‘know’<sup>1</sup>. Epistemologists have “sought ways of establishing a relation of correspondence between knowledge and ‘reality’ and/or ways of establishing the coherence of particular knowledge claims within systems of already-established truths” (Code, 1991:1). They have been concerned with the ‘truth’ and ‘certainty’ of knowledge claims and that this truth is established by conformity to “a permanent, objective, ahistorical, and circumstantially neutral framework or set of standards” (Code, 1991:2). Epistemology’s central concern has been with establishing a set of standards against which knowledge claims could be judged.

Traditional epistemologies can be broadly grouped into three categories: rationalist, empiricist and naturalist. For a rationalist the most knowable things are those that are purely conceptual and which are investigated by a pure mind unsullied by sense perception and the domain of the physical. A hierarchy of knowledges is established in which the most knowable are those things that can be rendered mathematically. Mathematics achieves this high status on the rationalists agenda because it is claimed that mathematical objects are eternal, undeniably real, and immune from the vagaries of sense perception, a view that will be challenged in Chapter 6. The degree to which knowledges can achieve this abstract mathematical status determines their place in the hierarchy of knowledges. This hierarchy is played out in the status hierarchies of the various branches of knowledge with the highest status going to the most abstract such as mathematics and physics and lower status attributed to the biological and psychological sciences. ‘Rationalist’ knowledge is assumed to be timeless and intersubjectively valid, although it is acknowledged that not all individuals will have the same ability to know well (Cole, 1993:73-76).

Empiricist epistemologies are based on the ontological presupposition of an objective reality that can be observed, recorded and understood. The starting

<sup>1</sup> I have used this punctuation to signal that ‘knowing’ and ‘reality’ are under consideration but for ease of reading I will not continue this practice throughout the chapter.

points are actual entities in the physical world which are carefully observed by sufficiently open-minded knowers who will produce knowledge based on their observations. The sciences are built up as knowledges through the aggregation and organisation of data. The potential for individual bias and prejudice to distort the results is held in check by the possibility of other observers confirming the original observations (Cole, 1993:76-77). New directions in the philosophy of mathematics have led to the development of quasi-empirical strands in the epistemology of mathematics which again I will discuss in Chapter 6.

In the naturalised view of epistemology many philosophical questions about knowledge become scientific or psychological questions as knowledge is thought to be the representation of our interactions with a biologically structured world. This knowledge is constructed in terms determined by our own human biology. The epistemologist is then faced with the task of explaining how this construction occurs (Cole, 1993:78).

All of these epistemological stances have been developed in an adversarial relationship to one another. Each school of thought is attempting to explain all knowledge and to protect their explanation from the weaknesses pointed out by adherents to the other schools of thought. They are not supposing that a rationalist epistemology could explain some aspects of knowledge and that an empiricist approach could explain other kinds of knowledge. These approaches have developed out of a commitment to a notion of the possibility of a single unified truth.

In their attempts to establish unassailable foundations for knowledge claims and universal and abstract conditions for knowledge (Code, 1991:122) epistemologists have tended to reduce knowledge to “propositional ‘simples’ whose truth can be demonstrated by establishing relations of correspondence to reality, or coherence within a system of known truths” (Code, 1991:6). From ‘S knows that p’ propositions epistemologists have hoped to build up to other

kinds of knowledge (Code, 1991:163) but they are rarely concerned with how people 'know' in their everyday lives (Code, 1991:111).

“Mainstream epistemologists are no longer unanimous in constructing the ‘epistemological project’ as an attempt to discover the universal and abstract conditions of knowledge, as a quest for unassailable foundations, or as a knockdown refutation of skepticism” (Code, 1991:122). Some challenge the validity of epistemology itself, some are engaged in evaluations and reevaluations of relativism, interpretation, and pragmatism. Others have moved away from the knower as a solitary individual to knowledge as a communal, social activity (Code, 1991:122-123).

### **Feminist challenges to the definition of epistemology**

The scope of epistemology has traditionally been narrowly confined to establishing certainty and refuting sceptics. Certainty has been established through the founding of epistemology on the values of objectivity and reason where these have been constructed within binary oppositions such as objectivity/subjectivity and reason/emotion. For the purposes of feminists these values have been too narrowly defined and feminist work in epistemology has been concerned to expand the scope of these investigations.

Feminist epistemologists begin from different assumptions arising out of a different set of historical circumstances and conditions than those which spawned traditional epistemology. They assume that we can and do have knowledge. Their task is not to refute the challenges of the sceptics but to expand the circle of knowers and stretch the confines of what we know and accept as knowledge. Feminists, like other people marginalised by traditional epistemology, have little to lose by discarding a search for certainty as the certainty of traditional epistemology was never shared by them and their knowledges. I will argue in Chapter 6 that mathematics was never as certain as traditionalists claim either.

Although raising different concerns for epistemology we cannot totally discard it. As Cain (1993:73) argues:

[W]e are not and can never be beyond epistemology. All social theories, including feminist accounts of social life, entail some theory of knowledge, and some theory of how we come to know social life. All feminists are concerned with how knowledge which is helpful to women can best be produced and with what such knowledge should be like. These are epistemological questions.

The responses of feminist epistemologists do not come from nowhere. There is no point outside or unaffected by traditional discourses from which feminism can start afresh.

[F]eminism is not external to traditional philosophy, but actually made possible by traditional categories and concepts. For feminism there can be no definitive break with the philosophical past. And this is not because of some peculiarity or weakness of feminist theory, but because of the way in which a critical theory is conceptually related to the position it opposes (Witt, 1996:227).

It is from within the gaps and lacunae and challenges of and to current discourses that feminism has been able to push the boundaries, to develop discourses counter to the hegemonic and dominant ones. The question: “whose knowledge are we talking about?” is central to feminist epistemological enquiry (Code, 1991:114).

Some might argue for the abandonment of epistemology as it “is precisely a discourse about all of the things one is criticizing” (Grant, 1993:100). Grant argues that because what feminists want to do diverges so far from epistemology as we have come to know it, epistemology does not seem a good place to start. But I reject this argument for several reasons. It is not at all unusual for feminists to take a concept, theory, definition, or discourse and rework it to suit feminist purposes. Telling feminists they cannot do something ‘because that is not how it is done here’ is a challenge which provides enough of a starting point in itself.

Another counter to the opinion that what feminists are attempting cannot be called epistemology occurs in the revelations of the “tacit underpinnings” (Code, 1991:12) of this view. It is based on binary thinking in which there is a tacit assumption that either you have objectivity, reason and value-free inquiry or you have subjective, emotional opinion and prejudice. These two positions do not exhaust all the possibilities. We can reclaim epistemology, expand its scope and the regions of its concern and still call it epistemology. Who is to say that we cannot? Nor are we alone in doing so. As I have said, other marginalised knowers, such as indigenous peoples, are making similar claims for their own “subjugated knowledges” (Foucault, 1980:81-2).

Code (1991:314) argues that there could not be a feminist epistemology that retained allegiance to the pivotal ideas around which epistemology has defined itself - ideals of objectivity, impartiality, and universality - because these ideas are androcentrically derived. My discussion here leads on to a debate about this androcentricity. However, saying that there could not be a feminist epistemology based on these values is not the same as saying there could not be a feminist epistemology or epistemologies. Traditional epistemology draws its boundaries tightly in ways that can and do serve to suppress and deny status to women’s constructions of knowledge (Code, 1991:158). What is being called for is a “remapping of the epistemic terrain” to include “analyses of the availability of knowledge, of knowledge-acquisition processes, or - above all - of the political considerations that are implicated in knowing anything more interesting than the fact that the cup is on the table, now” (Code, 1991:266). Duran (1991:10-11) argues that the “structuring of the epistemic rules so that to do epistemology is to work only in a certain manner - a manner that produces self-confirming evidence” is part of the androcentricity of epistemology.

Epistemology is a political project for feminists. Who confers the status of knowledge and how this is done and how we define knowledge itself, determines who can know and whose knowledge counts. To say feminist epistemology is political is equivalent to saying traditional mainstream

epistemology is political. The difference is that in the knowledge/power conundrum of traditional epistemology the political nature of the puzzle was disguised.

### **Questions for a feminist epistemology**

In developing my own position on feminist epistemology I want to consider the questions raised by both Braidotti et al (1994:34) and Harding (1987:3).

Who can be a knower?

What are the processes that determine and legitimate the practice and act of knowing?

What kinds of things can be known?

Implicit in these questions are the considerations that Code (1991:158) raised that illuminate the connections with the politics of knowledge. This involves examining how a knower can establish credibility and status as an expert; whose observations and experiences count as evidence; how and by whom the political agendas for knowledge making are drawn up; what kinds of things we want to know about; and who decides and what responsibilities do knowers have to other potential knowers and to the objects of their knowledge. All of these questions point to the social character of knowledge. Just as Longino (1990) writes of science as social knowledge, I will be arguing in this thesis for an epistemology for mathematics that is based on mathematics as a social knowledge developed in communities by groups of people whose knowledge claims are interrogated and acknowledged by other members of those social groups. The relations between knowledges and 'reality' and coherence between particular knowledge claims, which are concerns of traditional epistemologies, retain their relevance in this feminist epistemological approach. I will expand on this analysis in Chapters 6 and 9.

A significant difference inherent in these questions is a nonadversarial approach. While traditionally epistemologists were committed to a rationalist or an empiricist epistemology for instance, feminist epistemology, while

assuming that knowledge is possible and exists, does not depend on a unitary, unified position for explaining and justifying all knowledge claims (Harding, 1987:3). Different strategies will be convincing to different audiences (Harding, 1987:186) and for different kinds of knowledge. Nor is it merely an eclectic collection of bits and pieces gathered up from mainstream epistemologies, it contains its own coherencies. This argument too will be expanded in Chapter 9.

### **Critiques of mainstream epistemology**

In critiquing traditional epistemology I will focus on three areas. The first is the narrow range of concerns and the definition of knowledge which traditional epistemology addresses. The second are the binaries upon which such knowledge is based and the third is the particular conception of the self as the 'knower' of the knowledge. These are all relevant to the possibilities of feminist epistemology.

Epistemologists have been attempting to provide absolute foundations for and in support of the truth claims of science. The scientific method of the natural sciences is taken to be the paradigm for all knowledge. But scientific and mathematical knowledge represent only a very small proportion of what we think we 'know'.

The model of knowledge embodied in the scientific method of the natural sciences is not the only paradigm of knowledge (Hekman, 1990:4).

The knowledge needed to enable people to negotiate the everyday world and to cope with the decisions, problems and puzzles they encounter daily covers a broader expanse than that of the natural sciences and mathematics (Code, 1991:3). Knowing other people is an example of another kind of knowledge. So too are the hermeneutic methods of the humanities and social sciences. Traditional epistemology also obscures the extent to which "people are dependent, at a fundamental level, on other people - parents, teachers, friends, reporters, authorities, and experts - for what they, often rightly, claim to know" (Code, 1991:131). Individuals do not independently rediscover everything for

themselves. Some contemporary philosophers of science go so far as to conclude that the natural sciences are also fundamentally hermeneutic (Hekman, 1990:4).

Although much feminist epistemological work has been concerned with forms of knowledge other than the 'scientific' this is not so relevant to my project as I am, of course, primarily concerned with mathematics. But in giving paradigmatic status to scientific and mathematical knowledge the assumption is made that other forms of knowledge would be improved, that is would have more certain foundations and would therefore be closer to the 'truth' if they adhered more closely to the methods and values of science. I am raising the possibility here of mathematics (and science) learning from the values and methods of other kinds of knowledge, for example, hermeneutic approaches might be useful to 'knowing' in mathematics.

Code (1991:118) explains how in the context of the binary oppositions of traditional epistemology, 'feminine' and 'masculine' in their early philosophical origins refer to:

a meta-physical principle that separates an entire aggregate of characteristics attributable to entities in the world, both animate and inanimate, into positive, masculine qualities and negative, feminine ones. In the Pythagorean table of opposites, *maleness*, like limit, light, good, and square, are associated with determinate form; *femaleness*, unlimited, dark, bad, oblong, with (inferior) formlessness.

The opposition male/female is fundamental to these binaries which define the values and associated practices of reason, objectivity and abstraction (Hekman, 1990:39). The opposition is hierarchical with the left hand side favoured over the right in this depiction. In this way the dominance and higher status of things male both informs and is reinforced by these other binaries and their place in establishing what we can 'know' and who can be a 'knower'.

In this discussion I am particularly concerned with how these hierarchical dualisms limit our understanding of knowledge acquisition, of what counts as knowledge and who can be knowers. I will begin with a consideration of the

rational and emotional and then include a brief introduction to discussion of the relationship between the subject and object of knowledge and objectivity and subjectivity as these themes will be discussed at greater length in Chapters 3 and 5.

### **Reason and emotion**

As mathematics is often held up to be the epitome of rational thought and the place of women in mathematics has been marginal and tenuous, the rational/emotional binary is particularly germane to my project. The alignment of reason with masculinity is more than a matter of mere symbolism as the use of reason designates what it is to be a good knower and determines what counts as knowledge. This filters through into popular conceptions of what knowledge is, who knowers are, and whose knowledge claims are authoritative. Women cannot merely claim the right to positions as rational knowers when the very concept of reason is based on “hegemonic ideals of masculinity” (Code, 1991:119).

Reason incorporates attributes valued as masculine and is defined in terms of them by suppressing traits that are devalued because of their associations with ‘the feminine’. Those who can know are those who can transcend obscurity and chaos, those who can rise above emotion, perspective and human interest or at least can appear to or are assumed to have done so. This dichotomy stems from “Western philosophy’s historical obsession with ‘pure’ thought [in] its search for ultimate or foundational categories with which to order the world.” This search assumes “a hierarchical, oppositional construction of reality” (Bordo, 1988:622-3).

There is a connection between the reason/emotion dichotomy and the fact/value distinction which stems from the belief that value judgements are emotional and not verifiable (Code, 1991:46). As emotions are thought to ‘clutter up’ reason, both emotion and value judgements must be prevented from cluttering up knowledge construction (Code, 1991:242). There can supposedly be no certainty if emotion and values are involved. This view is

based on assumptions about emotions as being “ineluctably whimsical and unstable, erratic, idiosyncratic, and irrational” with “uncontrolled hysteria” as “the paradigmatic emotion” (Code, 1991:47). The split between reason and emotion

connects with the fact/value distinction, deriving its force, in part, from a belief that value judgements are purely emotive, hence neither verifiable nor falsifiable. They must therefore be prevented from contributing to the construction of knowledge. ... Emotion invariably clutters and impedes the essential project of reason: the attainment of certainty in knowledge (Code, 1991:47).

The public/private dichotomy reinforces these binaries as the emotions are considered to be private whimsical and unruly matters. Rational agents have to deliberately suppress the emotions to which they are passively subjected (Code, 1991:243).

Only those with highly developed reasoning capacities and a firm grasp of universal, theoretical principles meet the prerequisites for entry into the public domain. Hence women, who are supposedly more preoccupied with particularity and the practical, should naturally occupy themselves with private matters. In the private domain women can have experience but it is only subjective experience. Men can ‘know’ based on their experience because they have ‘objective’ experience (Code, 1991:244). Men’s experience takes place in public and supposedly can be observed or repeated by other rational knowers and can be assumed to be informed by theory (Code, 1991:245). Women’s experience can easily be dismissed as subjective when it is confined to the private and is consequently unobservable except of course by other women and children.

This discursive construction of the knower as a rational male individual engaged in his quest for knowledge and certainty in the public arena presents a number of points from which feminist epistemologists take up their critiques, all of which stem from the binary splits through which reason has been established. The binary male/female which is fundamental to the other binaries in action here is based on an essentialising of both masculinity and femininity. This

alignment of masculinity with rationality effaces differences between men. It is not all men that can claim to have this unequivocal rationality but rather a small group of powerful white men with class privilege.

Even these men cannot claim to be 'untainted' by emotion. The binary split between reason and emotion is clearly not such a clean break as its adherents would wish, when the practices of real knowers are given even the most cursory consideration. As Code indicates here emotions have an important place in the construction of knowledge:

The idea that it is *reasonable* to feel emotions in certain circumstances, and that when someone does not *feel* concern, joy, sorrow, or pleasure under some conditions, then her or his close associates may be puzzled or worried, bears no weight. Yet emotions such as curiosity, interest, amazement - all of which make sense in certain circumstances - are necessary to the construction of knowledge: without them, many inquiries would never have been undertaken or sustained. Indeed investigations are often prompted by rage, frustration, political necessity, enthusiasm, or despair (Code, 1991:47).

No account is taken of the shared and public nature of emotions such as patriotism and loyalty (Code, 1991:243). These emotions do not fit the individualist nature of the rational subject. Their role in inspiring and constraining knowledge projects is suppressed. Patriotism may inspire people to work harder or to undertake research leading to the development of new weaponry such as has occurred in times of war. Loyalty may constrain the asking of questions that could present leaders or traditional beliefs in a negative light.

While the argument of traditional epistemology is that emotions should be suppressed in the pursuit of knowledge, in practice, the pursuit of knowledge is driven by emotions such as those mentioned here. Without them the pursuit would be very difficult to sustain. "Even if such an inquiry is sustained throughout by such affective motivation, its results can stand up to viable criteria of objectivity. Emotion and intellect are mutually constitutive and sustaining, rather than oppositional forces in the construction of knowledge" (Code, 1991:47).

This reason/emotion split is connected to the individualist conception of the reasoner as individual acting alone. The pursuit of knowledge in this description/prescription is portrayed as an individual pursuit which rarely if ever occurs in practice. Instead the pursuit of knowledge can be shown to be a social activity based on reason as a social construct determined by a standard of acceptability arrived at by a community of knowers interacting at particular historical moments. While these communities have traditionally excluded women from participation, the presence of women (without intending to imply any essential qualities to women as knowers), presents a threat to these social conceptions of the values that are claimed to constitute knowledge.

Like Code (1991), I am arguing that the gender of the knower is epistemologically significant because the values upon which knowledge claims have been based have traditionally excluded or suppressed any qualities associated with the feminine. The inclusion of women does not necessarily mean that these values will now be included but that attempts to suppress their presence or deny their place in knowledge production will be made so difficult as to become virtually impossible. The inclusion of women as knowers has the potential to break the knowledge/experience split in two major ways. The first is that the presence of women means that knowledge is more likely to be able to begin from women's experiences, from the questions which arise from women's lives. The concerns of women that have been suppressed into the realm of the private can now be brought forward for public scrutiny by both men and women as knowers and producers of knowledge. The second is that women's knowledge, the subjugated knowledges of women, traditionally denied or suppressed as either 'old wives tales' or subjective experience, can be clearly seen to represent knowledge about the world. This knowledge can and does meet the criteria of traditional knowledge claims when the public gaze is turned upon it (Code, 1991:68). Women will not bring emotions which have been absent up until now, to knowledge projects. They *will* make it difficult to deny the pivotal role of these formerly suppressed emotions.

In this thesis I will be arguing that mathematics itself, one of the highest pinnacles of rational thought (Tymoczko, 1985:260), is implicated in the intertwining of the rational and the emotional, of the individual and the social. The binary oppositions “reveal themselves not as polarities but as two confused elements that inhabit each other” (Hekman, 1990:171). The descriptions of traditional epistemology have not been accurate portrayals of most knowledge claims when they have only taken account of the privileged side of the binaries. This is not to say that knowledge can be equated with the emotional and any attempts at rationality can be discarded as misguided. If knowledge claims are only to be guided by the emotional we may well find ourselves in an even worse position than that which reason devoid of emotion can land us in. The pursuit of knowledge has often entailed the discarding of ideas and commitments which were once held dear but if we were to cling to the emotional at the expense of the rational, we might be very reluctant to discard commitments we have strong feelings about. A lurch from the emotional to the rational and vice versa is not what is called for. It is the rational informed by the emotional, the emotional informed by the rational, the intertwining and unravelling of these comminglings, that has the potential to shed light on our knowledge claims and to propel our ‘knowledge’ of knowledge and its making forward.

The binary rational/intuitive also loses its ideological force when the practices of mathematicians are examined more closely. As I will be discussing this more fully in Chapters 6,7,8 and 9, I will confine myself here to a brief signal of what is to come. Mathematicians often ‘know’ that something is true before they have proved it or undertaken the deductive steps necessary to justify their claim. ‘It is intuitively obvious’ is a very common statement in mathematical communities. What this means is more difficult to establish but it does signal the importance of intuition in mathematical knowing. Because we have accepted a binary between reason and intuition based on our desire for a certainty which intuition does not seem to offer us, we have disguised the ways in which reason and intuition are intertwined and mutually inform each other.

Intuition, like irrationality, has been defined as a uniquely feminine quality, the opposite of the masculine quality of rationality. To appeal to intuition as opposed to reason thus entails not a displacement of the gender-based dichotomy, but an attempt to move from one side of the hierarchy to its opposite, to privilege the previously disprivileged side. The advocacy of intuition involves reifying the distinction between reason and emotion, rationality and irrationality that is central to Enlightenment epistemology. What is needed is not a reliance on intuition to the exclusion of reason but a means of breaking down the distinction between the two modes of thought (Hekman, 1990:132-133).

In critiquing the dichotomies upon which traditional epistemology is based, I have focused on the binary reason/emotion. In other chapters of this thesis I will focus on other binaries such as objective/subjective and subject/object. In the next section I will discuss the nature of the subject of knowledge.

### **Subjectivity, objectivity and the knowing subject**

This section is concerned with theories of the subject of knowledge and the relationship between that subject and the object of knowledge. Questions about these are central to any epistemology. In traditional epistemology the nature of the subject of knowledge appears at first glance to be quite clear and straightforward. Knowledge is discovered by an individual acting within the bounds of the ideals of reason and objectivity. The object of knowledge in turn is assumed to be separate and distinct from that knower.

The Cartesian subject acts independently and autonomously in his quest for knowledge. He pursues knowledge by “reason alone, unassisted by the senses” (Code, 1991:5). He can be assumed to be male as his very definition is based on the exclusion or suppression of those ideals traditionally associated with the female. He is autonomous, independent, and rational. The empiricist subject has much in common with his Cartesian brother except that his knowledge is the result of careful and thorough observation, by a sufficiently open-minded potential knower. Primacy is given to his individual sense perceptions (Cole, 1993:76). Despite the differences between these two positions, the assumption

remains that either knower can take up an Archimedean point outside the contingencies of his social and cultural locations.

Conceptions of selves as atomistic creatures whose experiences are unmediated by structural influences, as neutral inquirers in pursuit of the Truth, have legitimated epistemologies that wear the mask of political and perspectival neutrality, while perpetuating the Enlightenment illusion that it is possible to produce a single authoritative representation of the objective nature of the 'real' world. Transparent, 'natural' selves claim to speak them 'from nowhere', in voices cleansed of ambiguity. ... [T]hey marginalize people whose experiences do not conform, and smooth over the specificities that must be visible in any 'faithful account of the real world' (Code, 1991:258).

Women are excluded from becoming knowers because supposedly they are "unable to abstract from their particular situation and thus are unable to make the conceptual leap to the Archimedean point that is the necessary precondition of scientific thought" (Hekman, 1990:107). Women can be knowers "but only if they renounce the 'feminine' values that excluded them from this realm in the first place" (Hekman, 1990:188).

The concept of the rational knower in traditional modernist epistemology rests on a contradiction that is usually carefully disguised. For the assumption is that people (in this case knowers) "are essentially and interchangeably *alike*" while assuming "at the same time that subjectivity and its manifestations in experiences are inherently idiosyncratic - that there is no commonality" (Code, 1991:67). Individual knowers are alike in that they will make the same observations from the same 'data' and draw the same logical deductions from the same 'premises and assumptions', but the experiences of any particular individual are supposedly idiosyncratic and serve to sully and muddle the purity and clarity of 'proper' knowledge. For of course the knower in these epistemological traditions is an ideal person. Knowers are not the embodied people who "know in their everyday lives" and "knowledge properly so-called transcends experience" (Code, 1991:111).

There is an assumption that the processes of the production of knowledge are irrelevant to that knowledge. The objects of knowledge are assumed to be

disconnected from the knower and unaffected by the processes of knowledge production and the knowers to be self-sufficient (Code, 1991:110). I develop this argument further in Chapters 3 and 5 so I will not repeat the arguments here other than to foreshadow the conclusion that “objectivity requires taking subjectivity into account” (Code, 1991:31).

To be a good knower in the epistemological position I am developing requires

*being* subjective and objective at the same time - subjective in taking account of the specificities of subjectivity, objective in drawing more general conclusions, showing how stories fit into broader schemes, while leaving conclusions open to modification and reinterpretation (Code, 1991:170).

### **Challenges to the notion of the rational subject**

I am interested in challenges to the notion of the rational subject that open up that notion to include women as knowers and to acknowledge the positions women have always occupied both as knowers of ‘women’s subjugated knowledges’ and of mainstream knowledges. ‘The rational subject’ is only a caricature which does not capture the experiences of any knowers, men or women. It is not an actual person, but a normative and prescriptive definition that serves to protect the interests of the status quo and to exclude ‘others’, the bearers of difference. This is played out in the lack of acknowledgement the knowledge of these ‘others’ has received. This is important for, as I shall address later, acknowledgement is an essential aspect of the process of knowledge creation and ‘knowing’.

Two strands in the critiques of the notion of ‘the rational subject’ that are useful to feminist critiques and reconstructions are: the displacement of “a dichotomy between the constituting Cartesian subject who possesses agency and autonomy and the constituted subject that is wholly determined by social forces” (Hekman, 1990:72); and “the picture of a knower as a solitary truth seeker [which] is giving way to a conception of knowers as social beings and of knowledge seeking, as a communal, dialogic activity” (Code, 1991:123).

Postmodern challenges to the rational subject conceive of “subjectivity as multiple, conflicted, and contested, shaped by unconscious and partially conscious desires, encoded in language, and constituted by a complex of shifting socio-political, class, race, and gender relations - of subjectivity constantly positioning and repositioning itself in meaning-creative activities” (Code, 1991:258). This postmodern conception of the subject as multiple and contradictory subjectivities created through discourses is illuminating and useful for feminist theory in that it enables feminists to theorise the subject without becoming trapped in essentialist, ahistorical and universalist conceptions of a female subjectivity. This is particularly relevant to the subjects in my research as women mathematicians occupy an apparently contradictory position. They are both women with the attendant assumptions of emotionality and embodiedness, and mathematicians with mathematics’ associated devils of rationality and the ‘mind’. However there is a weakness in postmodern positions when they “deny the subject’s ability to reflect on the social discourse and challenge its determinations” (Alcoff, 1994:104). Such a denial precludes the possibility of feminist political action for change if it is to be based on any notion of ‘women’. “We are left with a feminism that can be only deconstructive and, thus nominalist” (Alcoff, 1994:106). It also denies the possibility of a subject of ‘feminist epistemology’. Alcoff (1994:107) points out that “[b]y designating individual particularities such as subjective experience as a social construct, post-structuralism’s negation of the authority of the subject coincides nicely with the classical liberal’s view that human particularities are irrelevant.” For the liberal there is an essential human core so that ‘underneath we are all the same’ and for the postmodernist we are all the same in having no underlying core. Feminists need to develop a third course, a theory of the subject that “avoids both essentialism and nominalism” (Alcoff, 1994:107).

### **A feminist subject of knowledge**

The subject of a feminist epistemology is situated within a constantly shifting context that includes a network of relationships with others, the objective economic conditions, cultural and political institutions and ideologies (Code,

1991:179). Her identity as a woman is the product of her own interpretation and reconstruction of her history as mediated through the cultural discursive context to which she has access (Alcoff, 1994:117). She can and does engage in processes of reflexive practice in which she thinks about, criticises and changes discourse, resulting in the reconstruction of her subjectivity (Alcoff, 1994:110). As a woman she can take up a position within a changing historical context (Alcoff, 1994:117) but the choice of what she makes of this position and how she can alter the context are limited by the range of contexts available to her. The inner self she can constitute through these locations, contexts, reflections and practices, is neither simply fictive nor 'natural' (Flax, 1992:203). "Such a self is simultaneously embodied, gendered, social and unique. It is capable of telling stories and of conceiving and experiencing itself in all these ways" (Flax, 1992:203).

"I" is, therefore, not a unified subject, a fixed identity, or that solid mass covered with layers of superficialities one has gradually to peel off before one can see its true face. "I" is, itself, *infinite layers* (Trinh Minh-ha, 1989: 94).

There is not a subject 'woman' with an inner self which is primeval, natural and free while her outer self is "buffeted and fragmented by external social pressures". A woman's subjectivity is constituted within the particular "positions she occupies, the prescriptions, ideologies, myths, and other cultural constraints" that occur at her time in history. These cannot be stripped away in the hope of finding a core, real self underneath. Her subjectivity *is* these accretions (Code, 1991:178). It is neither defined in relation to a single, undisputed norm of masculinity (Code, 1991:179) nor in relation to a single undisputed norm of femininity. Her subjectivity may in part be formed in resistance to dominant discourses of femininity and in part may involve positioning herself within discourses of masculinity. Her subjectivity is formed through habits, practices and discourses. Although these are fluid they can be articulated at specific moments and sites (Code, 1991:179).

This concept of the subject avoids some of the pitfalls that the rational subject of traditional epistemologies has for women as knowers. The rational knower is

gendered male because the values that define this subject are based on the suppression or denial of qualities associated with the feminine. For a woman to be a knower in this epistemological location, she has to renounce the feminine values (Hekman, 1990:188) that mark her as an outsider in this place. The feminist subjects outlined in the epistemological position I am proposing here still have to steer themselves through conflicting discourses of rationality and femininity but they retain the capacity to resist and deconstruct. They can escape the confines of the Enlightenment dualisms that construct reason and emotion, objectivity and subjectivity, as opposites, and represent themselves as both emotional and rational, as both subjective and objective.

The knowing subject as a social construct is consistent with social theories of knowledge. The commonly held belief that knowledge is “a product of the individual efforts of human knowers” hides the “complex of historical and other sociocultural factors” which produce the “conditions that make ‘individual’ achievement possible” and disguises the notion that “‘individuals’ themselves are socially constituted” (Code, 1991:11). Knowledge seeking is a communal, dialogic activity marked by interdependence and intersubjective critique (Code, 1991:123). “Communities that construct and acquire knowledge are not collections of independently knowing individuals” (Nelson, 1993:124) they “are multiple, historically contingent, and dynamic: they have fuzzy, often overlapping boundaries; they evolve, dissolve, and recombine” (Nelson, 1993:125). The knowing member of these communities cannot occupy a static Archimedean point outside such communities for these boundaries are moving and shifting and there is no still point to occupy.

In a feminist epistemology the gender of the knower is a marked category. The gender of the knower has epistemological significance but this is not the same as saying that a particular knower made a particular knowledge claim because of their gender. Gender is one of the subjective factors constitutive of received conceptions of knowledge and of what it means to be a knower. Asking whether maleness and femaleness are constitutive of knowledge seems to imply that gender is constant, obscuring its social construction (Code, 1991:12).

Seeing the subject as located within multiple discourses and practices including those of gender, enables us to analyse the constitutive role of gender in knowledge making without having to start with a fixed, static and ahistorical formulation of gender. This allows for multiple social influences on knowledge construction and the varied relations gendered subjects have, in the construction of knowledge.

As Code (1991:187) says, logically every kind of thinking is as open to women as to men but in practice many women in knowledge projects are thwarted by the denial of women's credibility as a result of the tenacity of essentialist concepts of 'women'. Women cannot simply shrug off the constraints contained in these discourses of the feminine and gain full authority and acknowledgement as competent knowers. There is no unconstrained place from which women can assert their *real* selves as the basis for competent knowing. Women are not trapped without recourse but it takes more than a simple decision to escape. Women who become mathematicians have made some steps towards pushing back the constraints of traditional discourses that bind women but their positions are not unproblematic as will be seen in Chapters 7 and 8. The notion of the subject outlined here provides a more useful position from which to begin to analyse the positions, experiences and knowledge-making of such mathematical women than does either the essentialised woman subject of radical feminism or the rational subject of traditional epistemology.

As knowledge is a social construction made within communities of knowers who serve to criticise and legitimate new claims to knowledge, acknowledgement by these other participants is essential to ensure a knowledge claim is accepted and that the knower is accorded the necessary status as knowledge maker. Traditional discourses of the feminine and masculine work to preclude the possibility of women knowers and their knowledge claims receiving this acknowledgement both when traditional 'women's knowledge' is considered and when women enter fields such as mathematics from which they have previously been excluded. There is "no more effective way of maintaining

structures of epistemic privilege and vulnerability than evincing a persistent distrust in someone's claims to cognitive authority" (Code, 1991:218).

In developing a feminist epistemology I am particularly interested in how gendered subjectivities impact on the construction of knowledge. In describing the subject of knowledge in this epistemological framework as 'she' I have been deliberately provocative rather than claiming that the subject must be female. This subject could be male or female. This is not to say that their gender is irrelevant as is claimed for the rational subject, but to emphasise that the subject is formed through discourses, practices, material conditions and relations to others, at particular historical moments. These forces will have different impacts, intersections and implications for different genders.<sup>2</sup> There are complexities of multiple subjectivities and diversities in the practices of knowledge making in which both women and men have varied relations to the dominant discourses which allow for differently gendered people to occupy different positions - differently (Code, 1991:156).

### **Feminist epistemologies**

I share the assumption of feminist epistemological projects that we can have and do have knowledge. In my particular case we can and do have mathematical knowledge. In developing a feminist epistemology I am not attempting to assuage the concerns of the sceptics that knowledge may not be possible at all, which has been the underlying concern of traditional foundationalist epistemologies. I am concerned to address the questions which I introduced earlier in the chapter. Braidotti et al (1994:34) identify them as the central questions of epistemology:

<sup>2</sup> The same could be said with regard to race, sexuality, and class but I am focusing on gender, not in ignorance of these other factors but in the interests of keeping my project manageable within the constraints of the thesis format. Nor do I wish to disregard the deconstruction of the notion of two genders, but it is beyond the scope of my project to take up these discussions here.

1) Who can be a 'knower', that is to say, what structures and mechanisms are at work in the empowerment of certain subjects of knowledge? 2) What are the processes that determine and legitimate the practice and act of knowing? And 3) what can be 'known', that is to say, what factors affect the establishment of adequate objects of knowledge?

Often calls for a feminist epistemology are based on an appeal to the uniqueness of women's experience or distinctive qualities associated with the feminine that are presumed to provide women with a privileged epistemological standpoint (Hekman, 1990:160). They may be based on appeals to distinctive 'women's ways of knowing' or 'maternal thinking' (Hekman, 1994:58). Such appeals valorise the disprivileged side of the binaries upon which traditional epistemology has been based. Contextual understanding is privileged over abstraction, intuition and emotion over reason, the subjective over the objective, a concern with the everyday concrete world over the technological and scientific (Hekman, 1990:16).

Although this approach has the advantage of establishing the position of women as knowers, the disadvantages outweigh the usefulness of this. These disadvantages stem from the continued commitment to the hierarchical dualisms that have informed mainstream epistemology although they have been reversed. "The privileging of the masculine is integral to that dichotomy; it cannot be conveniently detached. Only a frontal assault itself can remove the privileging implicit in it" (Hekman: 1990, 17).

The valorisation of the disprivileged side is problematic. The 'feminine' qualities associated with these binaries were cultivated in a history of oppression and exploitation and have become marks of powerlessness so there is a risk in endorsing these traits, of continuing women's oppression and exclusion. A tension remains between this risk and the desire to reclaim and revalue these qualities (Code, 1991:17). Women are represented in these binaries "as naturally less intelligent, more dependent, less objective, more irrational, less competent, more scatterbrained than men" (Code, 1991:18). The association of women with these qualities does not enhance women's status as

knowers. This approach also has conservative implications in this exaltation of traditional feminine values; it entails a universalism, essentialism and ahistorical definition of the feminine and it perpetuates the dichotomy that constitutes female inferiority (Hekman, 1990:41). Just as these binaries attribute essential qualities to femininity they attribute the inverse of those qualities to masculinity, thus essentialising and dehistoricising masculinity (Code, 1991:53).

Disassociating women from the traits associated with masculinity also has conservative and detrimental consequences for women as knowers. Repudiating objectivity and reason exclude women from the possibilities of being mathematicians and scientists, a position many such women would see as even less liberating than the status quo. It also repudiates the possibility of women's experience and the knowledge developed out of it, counting as objective and rational knowledge (Code, 1991:120). While there are problems and difficulties associated with the concepts of objectivity and reason, as will be discussed at length in this thesis, to completely repudiate and dissociate from them would with all probability, continue to confine women's experiences and knowledges to the margins and obscurity. "[T]aking on an epistemic identity explicitly structured by devalued female attributes - occupying a 'feminist standpoint' - risks perpetuating the traditional reasons for women's oppression; refusing to take on an identity risks having no platform for intervention, no rallying position from which to contest oppression" (Code, 1991:121).

Developing a feminist epistemology on the basis of these revalued feminine traits particularly when supported by the belief that a 'truer knowledge' will result from it "will inevitably lead to the establishment of a new orthodoxy to replace the old, a new orthodoxy that will produce its own truths and its own hierarchies" (Code, 1991:128). Privileging 'women's experience' risks displacing "the tyranny of the universal, theoretical, and impersonal expertise" with a new tyranny in which women's experience is critically unassailable (Code, 1991:256). It assumes that "there is some uniform experience common to all women" (Hawkesworth, 1989:45) and effectively suppresses "the multiplicity of cultural, social, and political intersections in which the concrete

array of ‘women’ are constructed” (Butler, 1990:14). If knowledge is based on the authentic experience of women defined by the privileging of the disprivileged side of the Enlightenment dualisms then the experiences of women who work as mathematicians for example, and the knowledge they create, implicated as it is in the values of reason and objectivity, would not meet the standards of authenticity. Their position as women mathematicians would be just as oxymoronic under this epistemology as it was under traditional epistemologies. The epistemology based on privileging the feminine has as its subject the same ‘stable, unified self’ as the rational subject except that this self is based on the negation of those attributes that are positively regarded in the mainstream epistemologies (Code, 1991:257). It assumes “a ‘natural’ self who speaks a truth free of all ambiguity” and that there is “one position in the world or one orientation toward the world that can eradicate all confusion, conflict, and contradiction” (Hawkesworth, 1989:45).

A *feminist* epistemology implies change in the circumstances of women and the particularly relevant area of change when epistemology is under consideration is change in the status of women as knowers and of the knowledge they create. The construction of a monolithic, comprehensive epistemological *theory* without taking account of the political-power issues implicated in a theory of knowledge (Code, 1991:315) will not satisfy the feminist political action that is a necessary aspect of a feminist epistemology. A theory of the subject that is not merely the flipside of the rational subject is a vital part of such a *feminist* epistemology.

### **Is a feminist epistemology possible?**

Hekman (1990:39) summarises the alternatives for a feminist response to epistemology as:

Feminists could accept the masculine definitions of rationality, objectivity and abstraction and attempt to open traditional epistemology up to women as knowers.

Feminists could accept the Enlightenment dichotomies and revalorise the feminine side of those dichotomies.

Feminists could abandon epistemology altogether and thus displace the dichotomies, and lose the gendered connotations and the search for one correct path to truth.

Grant (1993:100) supports the third position when she writes:

If feminism wants to talk about knowledge in a way that diverges from the Enlightenment understanding of it ... an epistemological grounding does not seem a good place to start. As Nietzsche recognized, critiques of truth, reality, objectivity, and reason must end in the abandonment of epistemology insofar as epistemology is precisely a discourse about all of the things one is criticizing.

This is not the position I will be taking. I am arguing for a fourth position where epistemology is redefined to support the purposes feminists have for it. We need epistemological stories that are more true to the actual practices and daily lives of knowers. In such stories the rational, objective and abstract lose their privileged and defining positions and are reconceptualised to include and be informed by the emotional, contextual and intuitive. In these new stories epistemology comes to have a wider meaning and definition than it has had traditionally because I am using it to answer different questions. I am beginning from the different assumption that we do have knowledge. The experiences of women as knowers and their exclusion from positions as 'knowers' are vital concerns. The sceptics being answered in this vision of epistemology are not those who doubt the possibility of knowledge but those who have traditionally been excluded from the inner circles of knowledge makers and whose knowledges have been discounted and ignored as subjective, emotional and concrete.

Discourses, even hegemonic discourses, are not closed systems. The silences and ambiguities of discourse provide the possibility of refashioning them, the discovery of other conceptualisations, the revision of accepted truths. These refashionings lead to ... the formulation of a feminist discourse that constitutes the feminine, the masculine and sexuality in a different way. In a postmodern era feminists cannot oppose the discourses of male domination by appealing to a metanarrative of universal justice and freedom. They can be opposed by formulating a feminist discourse that displaces and explodes the repressive discourses of patriarchal society (Hekman, 1990:187).

The possibility of *a* feminist epistemology seems both remote and suspect (Code, 1991:317) because of the risks of replicating the dangers of traditional epistemologies. But the tendency to think that we must have either ‘a’ or ‘b’, traditional epistemology or a feminist epistemology and that these two choices exhaust all the possibilities comes from the adversarial paradigm of knowledge construction (Code, 1991:321) which is itself a product of traditional epistemologies. Feminists “must transform the terms of the discourse” and “challenge the structures of the epistemological project” (Code, 1991:324).

### **Proposal for a feminist epistemology**

[E]pistemology itself needs to be redefined. There is no universal, perennial, account of how we know, just as there is no single account of methodology in science, or a single unchanging set of goals which natural and human sciences should pursue throughout history. Epistemology has to become a critical discipline, revealing the presuppositions of the way current debates are conducted in all kinds of discourse, unmasking bias, contradiction and irrationality, and doing this within overriding value-systems upon which local consensus may be negotiable (Hesse, 1994:458).

A redefinition of epistemology requires a redefinition of the subject. In the approach to epistemology I am advocating there is no position outside discourse, no Archimedean point from which a knowing subject can create knowledge safe from the risk of tainting by her personal subjectivity. The subject is located within multiple contradictory discourses, material conditions and relationships of power and politics. But these discourses and relationships are not closed systems and within them and the contradictions between them, knowing subjects can take up positions within which they can engage in critical reflection on the knowledge they are creating. These positions offer “partial perspective, limited location, situated knowledge: positions from which subjects can be answerable, accountable for what they learn how to see, for the knowledge they construct - not out of whole cloth, but out of the specific pieces they can claim to understand, carefully, responsibly” (Code, 1991:264).

This notion of the located subject makes it appropriate to ask questions about ‘whose knowledge is it? and from whose subjectivity has it developed?’. These questions are vital for feminist epistemologists in their aim to accredit female knowers and women’s traditional, subjugated knowledges. Asking such questions does not imply a rejection of objectivity for subjectivity but enables the epistemologist to discern how objectivity and subjectivity together produce knowledge. “Knowledge is neither value-free nor value-neutral; the processes that produce it are themselves value-laden; and these values are open to evaluation.” The epistemologist herself, is located and has to find ways of analysing and shifting her positioning so as “to untangle the values at work” within her own positioning and the positioning of the subjects of the knowledge under consideration and to assess the implications of these positions and values. There is no external vantage point from which she can do this (Code, 1991:70).

In Sandra Harding’s feminist standpoint, she claims that “[w]omen’s experiences informed by feminist theory provide a potential grounding for more complete and less distorted knowledge claims than do men’s” (Harding, 1987:185). This is not the position I am taking. Discourses of gender are not the only discourses within which subjectivities are taken up and they have more relevance in some instances than others. There are situations where women’s experiences provide grounding for a less distorted knowledge than men’s *and vice versa*. In other situations gender may not be the most relevant factor at all. “It is also the case that physically male and female humans resemble each other in more ways than we differ. Our similarities are even more striking if we compare humans to, say, toads or trees” (Flax, 1987:51). While Flax here makes the point about our physical similarities there are other similarities in the discursive locations, material conditions and power relationships within which we position ourselves and are positioned.

My point is that gender makes a difference but is not the sole determinant of the knowing subject and her knowledge. “[I]t is unlikely that information about the gender of the knower could count among criteria of evidence or means of

justifying knowledge claims” nor that it would “have a legitimate bearing on the qualitative judgements that could be made about certain claims to know”. We cannot conclude that “if the knower is female, her knowledge is likely to be better grounded, if the knower is male, his knowledge will likely be more coherent” (Code, 1991:7). We do need to examine how claims to know are determined or influenced by the positioning of subjects within gendered discourses and asymmetrical relations of power between men and women.

Code (1991, 10) asks the questions:

Is there knowledge that is, quite simply, inaccessible to members of the female or male, sex? Are there kinds of knowledge that only men, or only women, can acquire?

We know that the answer has often been ‘yes’. This is not because of any essential nature of men or women, or an exclusive divide between them, but because asymmetrical power relations have denied women the opportunity to access certain kinds of knowledge and have denigrated the knowledge that women have traditionally developed thus excluding men from access to such knowledge. As Code (1991:131) says, much of what we think of as knowledge we come to as the result of information given to us by people we think have sufficient expertise to make their knowledge trustworthy. So it is not inconceivable that even that knowledge that arises from experiences that members of one sex may be denied for example the experience of breastfeeding, may be shared through interpretative means other than direct experience, for example writing, poetry, art or music. So my answer to the question is ‘no’, there are not kinds of knowledge that only men or only women can have, and particularly not mathematics.

This epistemological position does not entail a lurching from one side of the dichotomies which inform traditional epistemology to the other. In a redefined epistemological approach, the values defining epistemological success also need redefinition. “Many feminists are convinced that traits associated with essential femininity - responsibility, trust, and a finely tuned intuitive capacity, for example - are epistemically valuable” (Code, 1991:119-120) and it is my argument here that they are, but only in so much as they are redefined in

conjunction with a redefinition of the epistemological values of reason, abstraction and objectivity and the two sets are not constituted as opposites. We need to break down the divide between these polarities. “[K]nowledge is at once subjective and objective: subjective because it is marked, as product, by the processes of its construction by specifically located subjects; objective in that the constructive process is constrained by a reality that is recalcitrant to inattentive or whimsical structurings” (Code, 1991:255).

Knowledge claims are sometimes based on contextualist approaches and at others on reductionist approaches. It would be churlish to dismiss the wealth of scientific knowledge we have as a result of careful, patient, reductionist approaches even though historically this has often occurred at the expense of the knowledge gains that could have occurred from contextual approaches. The commitment in this epistemological stance I am proposing is not one approach over the other but critical reflection on the value of either and the ability of one to inform the other in particular instances of knowledge creation.

My contention like Code’s (1991:323), is not to eschew objectivity and accurate prediction but to balance such commitments against ecological and emancipatory projects so that sexism, insensitivity to other specificities, and human and environmental exploitation are controlled for consciously. In retaining a commitment to objectivity and subjectivity, rationality and intuition, I am maintaining a commitment to ‘getting it right’. The opposite of rational in this epistemological stance is not emotional, but irrational, that is, this stance allows for the possibility of getting it wrong and making mistakes and the practices of knowledge creation need to include mechanisms for identifying and correcting such mistakes. Reason informed by emotion still allows for the possibility of illogical and irrational arguments. Intuition is no more equivalent to truth than reason is. Many scientific and mathematical arguments that are now well established in our knowledge systems were originally thought to be counter-intuitive. The social processes of knowledge creation and the power dynamics operating within and around these processes, the public presentations

and seminars, the reviewing practices of journals, the subsection of new results to public scrutiny are a vital part of the correction process.

The subject in my epistemology is located within a “crisscrossing [of] sometimes mutually supportive and sometimes conflictual, discursive, dialogic relations which are lived not on a geographic analogue of a tabula rasa but in specific rhetorical locations - spatial, historical, racial, cultural, gendered” (Code, 1995:73). This subject does not create knowledge alone and independently. Just as the subject is created within locations and relationships so is knowledge. “The construction of knowledge is an intersubjective process, dependent for its achievement on communal standards of legitimation and implicated in the power and institutional structures of communities and social orders.” (Code, 1991:132). Knowledge is constructed in “an interactive dialogic community” (Longino, 1993:112) by individuals interacting with one another “in ways that modify their observations, theories and hypotheses and patterns of reasoning” (Longino, 1993:111).

From my epistemic position it is a vital aspect of the values of objectivity and rationality, emotionality, intuition and subjectivity, that the composition of the knowing communities is critically analysed in order to see how the community membership and its practices and power relations inform the knowledge created, refined and acknowledged. My political position of including the greatest possible diversity within those communities, will support more thorough critical practices, the acknowledgement of previously subjugated knowledge claims, the asking of different questions and therefore the production of better knowledge.

Mainstream epistemology has had a “near exclusive concentration on men’s experiences, masquerading as ‘human’ experiences, and counted as the sources of knowledge” (Code, 1991:60). My epistemological approach calls for the asking of questions that begin in women’s and men’s experiences. The experiences that are considered should include the experiences of both the marginal and powerful, but of course this entails a shift in existing power

relations. “Authoritative epistemic status” (Code, 1991:60) should be given to the knowledge that *women* (and all other marginalised groups) have traditionally constructed out of their designated areas of experience not because their experiences provide the basis for ‘better’ knowledge, which they sometimes will, but so that all knowledges can be exposed to the critical scrutiny and reflection espoused in this epistemology. As a result of this exposure knowledge claims can be acknowledged as such.

The relationship between the knower and the objects of knowledge is another central concern in this feminist epistemology. In mainstream epistemology the ability to manipulate, predict and control the objects of knowledge has been regarded as evidence that they are known (Code, 1991:140). But this is evidence of only one limited form of knowing. In this epistemology, understanding the objects of knowledge is the goal. Code (1991:152) likens the relationship between the knower and known to friendship. In a friendship, knowing the other person depends on developing empathy with that person. This gets around some of the problems associated with objectivist approaches but some will have difficulty envisaging a friendship with a mathematical object. This is not just because they may not have had very friendly feelings towards mathematics in their own learning experiences but because it is hard to imagine the mathematical object responding. In Chapters 6, 7, and 8 as a result of analysing the practices of mathematicians, this difficulty will be diminished somewhat. Mathematicians do develop considerable affection and feeling for the objects of their knowledge. They learn to anticipate the directions in which these objects will grow. They develop intuitions about their supposedly rational, logical objects of knowledge.

There is a danger though in this ‘friendly’ approach that it risks merging the subject and object and obscuring the extent to which the objects are separate from the researcher (Code, 1991:153). What I am calling for is a recognition that the objects of knowledge, whether they be people, chemicals or mathematical objects, are “located in many relations to one another, all of which are open to analysis and critique” (Code, 1991:164).

## Conclusions

In this chapter I have drawn on the work of feminist epistemologists to expand on the traditional scope of epistemology to reflect on the important questions of who can be a knower, what can be known and how do we know. My fundamental interest here is not whether knowledge is possible but how and what we come to know. While presenting an approach to feminist epistemology, it is not my intention to argue for 'a' feminist epistemology but to outline broad avenues within which more specific enquiries may proceed to answer some of the questions of interest to feminist and liberatory political projects. This thesis is concerned with one such inquiry.

This epistemology reconceptualises the values inherent in traditional epistemology and those in traditional notions of the feminine. I do not intend to promote a relativist stance or to promote a theoretical eclecticism but to develop a philosophical position that is more true to the social nature and practices of knowledge creation and the power and political relations within which knowledge is determined.

In the following chapters of my thesis I intend to use this theoretical base to relate this epistemic position to mathematics, the power relations within mathematics, the position of women as mathematical knowers and to provide a feminist approach to the epistemology of mathematics.

# Chapter 3

## Methodology

### Introduction

One avenue for addressing the questions of ‘whether mathematics might be different if more women were involved’ or ‘how mathematics is affected by its gendered history and traditions’ is through investigating the experiences of women mathematicians. In this chapter I present a methodological justification for such an investigation. I interviewed eight women who are involved in mathematical research in various locations and capacities. I was interested in how and why they became mathematicians, how they went about their work and their experiences in the culture of mathematics.

The mathematicians who participated in this project are women who work as creative mathematicians rather than women who may have a background in mathematics but are not mathematicians themselves. I restricted the definition of mathematician to include only those who are creative mathematicians and who undertake mathematical research and scholarship. They are creative mathematicians in that they develop new theorems, proofs or techniques; they rework, rewrite or make new connections in existing mathematical knowledge; or they use existing mathematics in new situations. This emphasis is necessitated by the focus of this thesis on the effects of the gendered location of the mathematician on mathematics itself.

In this chapter I discuss the methodological issues involved in my research and justify the qualitative approach I have taken. I present this justification within the context of the debates about feminist methodologies. The issues that I identify as of particular importance in this project include the nature of the relationship between the researcher and the research participants; objectivity and validity; the theoretical conceptualisation of ‘women’s experience’; and

data interpretation. I then move into a description of how I interpreted this methodology in the implementation of the research method.

### **Feminist methodologies**

Feminists have found much to criticise in traditional research methodologies and their claims to objectivity and validity. The selection of topics deemed worthy of investigation has reflected gender, class and race relations in society. Questions of importance to men rather than women have been selected for research and funding. Often the research design has been biased and the results claimed to reflect universal human experience when only men's experiences have been investigated and only male subjects have been interviewed. Sometimes women's experiences have been investigated by only asking men about them. The relationships between the researcher and the subjects and amongst the research team have been criticised for replicating existing social relationships of domination and oppression and for exploiting the subjects of the research. The information gained has been used against the interests of the informants. An illusion of objectivity, a theme which will be returned to again and again throughout this thesis, has been created and maintained. It is claimed that the researchers can and do stand aside from their own beliefs and prejudices and observe the objects of their research from a distance (Acker et al, 1991; Fonow and Cook, 1991; Harding, 1987; Jayratne and Stewart, 1991; Lather, 1991; Smith, 1979). This 'objectivity' will be critiqued at length in Chapter 5 but, just to reiterate, such research methods as have been used in the past have not been based on a concept of objectivity strong enough to eliminate values that are culture-wide or nearly culture-wide, or to eliminate values that are shared by the dominant groups in society (Harding, 1991).

The traditional notion of objectivity has been based on the premise that an individual can step outside their social and historical location and their emotions and opinions and find 'the truth'. Feminist critiques of this notion of objectivity have pointed out the coincidence of this approach, with the results of research based on this notion and the dominant values and emotional

responses of members of the dominant groups in society who also happen to be the people controlling research agendas and supervising research. While I do not want to base my research on a traditional notion of objectivity, that is, on the premise that the researcher can stand aside from the research and gaze dispassionately and unemotionally down onto the subjects below, nor do I want to find only what I set out to find. In rejecting traditional notions of objectivity I do not want to be reduced to a merely personal account of the experiences of women mathematicians. In critiquing one side of the dichotomy, objective/subjective, I do not wish to lurch from one side to the other. This is one reason why the work of Sandra Harding and Helen Longino is so attractive to me. They rework notions of objectivity rather than rejecting it out of hand (Harding, 1991; Longino, 1990).

I am not setting out on a quest to seek 'the truth' of the experiences of these women mathematicians but I still retain the hope that some accounts are better than others and I want mine to be a better one. Any researcher begins their work with some expectations about what they will find. The danger is that these expectations will be so dominant as to preclude the seeing/hearing of anything that does not fit those preconceptions. A better account will include an attempt to state as fully as possible those prior expectations and commitments and will include a challenge to them through the inclusion of data which is at odds with these prior assumptions. A better account then, embraces ambiguous and contradictory data rather than excluding the evidence that does not fit. It is not propelled by the need to come up with one 'true' account of complex human experiences.

There has been much debate within feminist circles in previous decades about the relative merits of quantitative versus qualitative methods. Quantitative methods have been criticised on a number of counts. Such methods are said to distort women's experience and silence women's own voices by translating an individual's experience into categories predefined by the researchers (Jayratne and Stewart, 1991:85). Lather (1991:62) describes this as pouring the data into containers. The argument is that a conceptual framework is imposed on the

data and only that which fits with the researchers' own conceptual frameworks is extracted (Jayratne and Stewart, 1991:90). Maria Mies (1991:67) continues to regard qualitative methods as more useful for what she terms "women's research" because these methods "do not break living connections in the way that quantitative methods do". She objects to what she calls "the fact that scientific research methods are instruments for the structuring of reality" and "that which is quantifiable qualifies as 'real'" (Mies, 1991:67). To me these arguments are indications of the necessity for better quality research design and method selection rather than a strong case for the argument that feminists should only be doing qualitative research. It is true that quantitative methods are used inappropriately to undertake tasks that qualitative research is best suited to do. If the researcher is intending to maintain "living connections" (Mies, 1991:67) and a "richly textured feeling" (Jayratne and Stewart, 1991:90) the choice of a quantitative research design may well be inappropriate. On the other hand the use of multivariate statistical analyses of large data sets can also provide contextual analyses (Jayratne and Stewart, 1991:93). It is also true that in a quantitative method, data will be poured into predefined categories. Whether this is a problem or not depends on the aims of the research and the prior commitments of the researchers. A feminist quantitative method would involve the selection of appropriate and meaningful categories that arise out of women's experiences and thus could be very useful in providing a wide overview.

Some feminists, such as Keller (1985) and Oakley (1981), have suggested that "the masculine values of autonomy, separation, distance and control are embodied in traditional quantitative research" (Jayratne and Stewart, 1991:89). This argument associates qualitative research with the myth of the existence of an essentialised feminine voice that can only be qualitative. Any conclusion that feminists should be doing only qualitative research places us back on what has become familiar territory and is central to this thesis. The quantitative is being associated with the masculine and qualitative with the feminine. Where does this leave the woman doing statistical research? The woman mathematician? Can she and her work be feminist?

Dichotomising 'quantitative' and 'qualitative' research methodologies is not helpful. These methods are both complementary and overlapping. Often a quantitative statistical analysis can present a broad picture that highlights the need for qualitative research to flesh out the intricacies and inconsistencies not captured within the statistics. Such qualitative research can, in turn, highlight the need for further quantitative work. This dialectic is well illustrated in the mathematics and gender literature which is discussed in Chapter 4. A quantitative method can highlight the rarity of women mathematicians and a qualitative method is needed to elucidate the experiences of these otherwise hidden and statistically insignificant women. There are also grey areas in which much debate could occur about whether a method is quantitative or qualitative particularly when a method is based on the coding of individual responses and the counting of their frequencies.

The feminist methodology debates have fortunately moved beyond such dichotomous arguments to a consideration of the most useful methods to answer a particular set of questions. This is summed up well by Jayratne and Stewart.

The emphasis here is on using methods which can best answer particular research questions, but always using them in ways which are consistent with broad feminist goals and ideology (Jayratne and Stewart, 91:1991).

In choosing a qualitative method I am not arguing for a preference of one kind of method over another. I am arguing that in my project, qualitative methods are necessary to address questions that quantitative methods are not capable of answering. Quantitative methods have established the presence/absence of women in mathematics but are not capable of shedding light on their subjective experiences or the construction of mathematical knowledge. I am choosing a qualitative method not because I believe it to be 'feminist' but because it allows me to find out what I want to know. In order to retain the "living connections" (Mies, 1991:67) and "richly textured feeling" (Jayratne and Stewart, 1991:90) mentioned above when quoting from the women interviewed I used larger

excerpts than strictly necessary to illustrate the point being made. This allows a sense of the individual women's voices to be communicated.

Describing a research methodology as feminist does not imply the choice of a particular method or methods for the research but does imply that feminist commitments will permeate and influence the processes (Taylor and Rupp, 1991:121). This will be played out in the choice of topics; the use of appropriate methods; the relationship between the researcher and the participants; the retention of the women's voices; the standards of objectivity adopted; and the uses to which the information will be put (Acker et al, 1991; Fonow and Cook, 1991; Harding, 1987; Jayratne and Stewart, 1991; Reinharz, 1992; Stanley, 1990; Stanley and Wise, 1990; Tomm, 1989). Feminist research involves a rejection of relations of domination, exploitation and oppression not only regarding human subjects but also animals and the physical environment. It involves a strong commitment to social change. This commitment to social change has often led to the use of action research methods in which effecting the desired change is an integral part of the research method. However there is now wide acceptance that this commitment to social change is also fulfilled in research based on other methods which aim to make women's experiences visible or to challenge misconceptions about women based on assumptions of women's inferiority. The feminist science debates point to the possibilities of a feminist commitment in any area of scientific research, even that not involving human or animal subjects. This will be discussed in greater detail in Chapter 5.

In the earlier debates about feminist methodology it was argued that the research was to be 'for women'. With subsequent theoretical work deconstructing the very notion of a unified concept of 'women', this criterion has become very tenuous. Recognising that women do not have a shared experience and that the category is intersected by interests of race, class, sexuality, religion and ablebodiedness, makes it very difficult to justify whether a particular research project is 'for women'. In claiming that research is 'for women' I have to ask which women is it for? Do women of all cultures, races, classes, sexualities, abilities and religions have a shared interest? Do the women

within these categories have a shared interest? Is the concept 'for women' defined in opposition to any other groups, for example men or children? I also need to ask who is deciding that the research is 'for women'. There is a danger that a group of privileged women who have access to the resources necessary to undertake research and who stand to gain financially or in personal recognition, are deciding what is in the best interests of a less privileged group. The less privileged group may well consider their best interests to be served in quite different ways.

Bearing in mind these critiques and the sentiment expressed by Acker et al (1991:41) that "[a]n emancipatory intent is no guarantee of an emancipatory outcome", I am still claiming that this research is 'for women'. I do this with the personal conviction that in this context what is good for women is also good for men and children. I am making this claim that my research is 'for women' because of the nature of the situation of women in mathematics. Quantitative analysis points to the serious imbalances in this situation. When the number of women doing creative mathematics in this country can be counted on one's fingers and toes then this is an indication that women are being denied opportunity and access. It also indicates that the development of mathematics is being retarded by the exclusion of some of those most capable of doing mathematics and by the loss of diversity of thought they could potentially bring to the discipline. I am not expecting to stir up revolutionary action or protest but there are stories to be told about these women that are worth hearing. Women mathematicians are not the oxymorons to which both the gender and mathematics literature and radical feminist discourse reduce them. Their stories serve to educate us further about the rich and diverse potential of women, of mathematics and of feminist theory.

It is difficult to know in what sense this research is 'for' the women who participated. While it could enable "people to change by encouraging self-reflection and a deeper understanding of their particular situations" (Lather, 1991:56), I do not wish to presume that these women would or should need to change. Change in those participating may be a positive consequence for them

but there is also the danger of the individual's sensitivity to gender issues in their personal situations being raised to an excruciating but paralysing threshold. In recognising that this project stems from needs and interests of mine not necessarily theirs, I retain some scepticism about the benefits for the women themselves and prefer to think that I asked for and those participating offered their thoughts and experiences as a gift; one which I value very highly. While I have some anecdotal evidence to suggest that at least some of the subjects were interested in and enthusiastic about the project, it has essentially stemmed from my own passions and interests and will hopefully lead to academic credit and publications for me.

I am optimistic that this research will have some positive implications for women more generally, for feminism and for mathematics. I hope it will be a contribution to dispelling the myth that women cannot do mathematics and that others may learn something helpful about mediating the binaries and working in such male dominated environments. I am also hopeful about dispelling some myths widely held by feminists coming from a radical feminist tradition. I am particularly interested in challenging essentialist beliefs about women as being emotional, intuitive, contextual and holistic thinkers and that these ways of thinking and knowing are antithetical to participation in mathematics and science. I believe it is important for more women to be involved with mathematics and to have confidence in their own mathematical abilities. This is not only because of the desirability of individuals being able to develop their human potential to the fullest but also for the benefits to mathematics. Excluding women from mathematics excludes them from huge areas of exciting, challenging scholarship. I believe that mathematics itself would benefit from the contributions of all people regardless of gender, race, class, sexuality, ability or religion. Not enough is known about the possible consequences of giving voice to "subjugated knowledges" (Foucault, 1980:81-2) in mathematics. However I am confident that mathematicians from a diversity of experiences and cultures will enhance and enrich the development of mathematical knowledge. I do not want to 'leave it to the boys' because this would be to the detriment of mathematics and exclude women from access to

the power derived from mathematics. Mathematics acts as a critical filter to many prestigious and well-paid professions and trades. It also serves to intimidate those who do not have access to it. Excluding women denies them access to employment opportunities and to the confidence and skills necessary to both use and challenge arguments presented mathematically. This will be discussed in Chapter 4.

### **Choice of method**

The choice of an appropriate method depends on the nature of the task and the theoretical perspective on which the research is based. In my case both of these indicate the need for a qualitative approach based on semi-structured interviews with women mathematicians. Almost all of the research on gender and mathematics has been quantitative in the sense of counting the relative numbers of males and females achieving or participating in particular aspects of mathematics and mathematics education. There has been very little published on the subjective meanings women and girls have given to mathematics and their relationships to mathematics. The quantitative research has been an important factor stimulating my interest in this topic by prompting me to ask about what lies behind the statistics. What about the women who do do mathematics? What about their experiences? How do they make sense of themselves and their positions as mathematicians? What subjective meanings does their mathematics have for them? How do they reconcile being women with their mathematical ability and interest? How does being women affect their mathematics? A quantitative method cannot answer these questions. They require going beyond and behind the numbers and seeking out the qualitative data that can give deeper meaning to the numbers. I speak to the very women the quantitative analysis hides - the women in that small statistical minority - the 'others' of the mathematics and gender literature.

My theoretical perspective(s) also determines the necessity for a qualitative, open-ended approach. By theorising the subject as being in a continuous process of construction within multiple and contradictory discourses I needed a

method that would allow evidence of change, contradiction and contestation to be included. This is dependent on a method that does not impose predetermined categories on the data in the same way that necessarily occurs in quantitative analyses. It is not the statistical trends that I am looking for but the nuances within the trends; the contradictions between such trends and the individual's experiences; and the meanings those individuals make of those experiences.

### **Negotiation and reciprocity**

The relationship between the researcher and the subject of the research is another fundamental consideration in feminist research. This relationship should not be based on exploitation or objectification. The subject is more than a mere object of curiosity. She is not just a potentially rich source of data to be mined for the sake of the project. It is important that her rights and feelings are protected by maintaining high ethical standards. To me this implies a relationship between researcher and subject that is based on reciprocity. It implies a process of sharing knowledge or expertise. The subject is the expert on her own life and experiences and the meanings she makes of them. The researcher while being an expert on her own personal life, hopefully also has some expertise on the topic of the research. In a project such as this where it is being driven by the researcher and not the needs of the subject and where the researcher is not a full member of the group under investigation, my life experiences were not of as much relevance in developing reciprocity as the knowledge I have gained on the topic.

Some have argued for changing the relationship between the two from that of strangers to one of friends with the suggestion that this relationship then be mined as a source of rich data (Lather, 1991:57). While I am arguing strongly in favour of reciprocity I do not conceive of this relationship as a friendship. Partly because I do not like the idea of making friends in order to get information from them (Acker et al, 1991:141) and also because I do not want

to denigrate the depth and value of the relationships between friends. Any ongoing friendships that might develop would be an added bonus.

In early work that argued for a reciprocal relationship between the researcher and the participant (Oakley, 1981), the argument was constructed in opposition to traditional mainstream approaches in which the researcher was to establish rapport but not to lose detachment. In these approaches the researcher should “be friendly but not too friendly” (Oakley, 1981:33). In refusing to equate reciprocity with friendship I am not returning to old notions of objectivity based on a hierarchical relationship between researcher and researched rather I am hoping to further develop an understanding of the research relationship which builds on progress made by researchers such as Oakley.

In discussions like Oakley's, issues of power are often skirted around or concealed. No matter how friendly the researcher and researched become, power issues still remain. The researcher is going to leave the situation and write about the experiences of the subject. She will have the last word and the power of interpretation. The subject may have little or no control over the final write-up of the research and the dissemination and publication of the results no matter what assurances were made prior to beginning the project. If the researcher chooses to abuse her trust there is little the subject can do. There is also the possibility that such trust could be broken by others involved in the process such as publishers, editors or the media who are outside the control of both the subject and the researcher. The subject's power lies in what she chooses to disclose and the silences she keeps. There are two elements to this. The first is that the subject is not likely to be fully aware of all her experiences and history and the meanings she has made of them. Even when she is consciously aware of relevant experiences and feelings she may choose not to disclose them. Some experiences may be too painful to disclose, some may show her in a bad light, some may be criminal. She may not wish to criticise the institution where she works because of her ethical standards or because she fears negative consequences for herself. She may for reasons of her own, deliberately mislead the researcher. She may only disclose information that fits

with her political commitments. To the extent that the subject chooses what to tell and what not to tell and with what degree of honesty, the subject retains some power in the relationship.

Rather than two friends getting together I prefer to think about this relationship as the meeting of two experts to consult on the topic before them. The participant is the expert on her own experiences and the meanings she makes of these. The researcher likewise has expertise in her own life experiences but also brings theoretical knowledge of the topic to the process. I am attracted to this analogy because it retains notions of power and agency on the part of both interviewer and interviewee and does not imply coldness, unfriendliness or an absence of rapport. In my research this analogy seems particularly applicable because I was neither 'interviewing down' nor 'interviewing up'. The women mathematicians have much greater knowledge about mathematics particularly in their own areas than I have. I assumed that I would have greater knowledge of the feminist theoretical debates and the gender and mathematics literature than they would and this was born out in the interviews.

For me the basis of reciprocity is negotiation; negotiation about the sharing of information by the participant and the researcher and negotiation about its meanings. I have the power of the last word. The participants have the power to withhold or distort their information. Often the discussions about reciprocity have centred on the researcher's power to have the last word or to interpret the participant's experiences in ways that could be detrimental to the participant but have not considered the power of the participant. I am not implying that the power balance is equal between the researcher and the researched but rather that it is complex. In a small study such as this the withdrawal of a participant could seriously affect the project. With even fewer participants the power of the participant is even greater as they may have the power to totally destroy the project by withdrawing. On the other hand the researcher could potentially manipulate the participant into revealing things she later regretted. While the participant may ask to have them deleted from the research, the researcher has still heard them and does not forget them in the same way that a tape can be

deleted. My intention here is to highlight the complex nature of the power relationships in the research project and to emphasise the need for negotiation.

While the negotiation involves a contract signed before the interviews begin, in which the subjects agree to participate and to some conditions and consequences of doing so, the process continues through the course of the interviews as the subjects consider what they will or will not say, what they wish to withdraw and what contributions they wish to make to the analysis in the course of the interviews. For me the process involved telling about myself, deciding what I would or would not reveal about myself and telling about my purposes and theoretical commitments. For both subject and researcher it means exchanging views about the meanings that can be made of what is said.

In practice the participants were willing to be very open about themselves personally but many expressed reservations about voicing criticisms they had about their own workplaces and colleagues. They wanted to protect the confidentiality of their criticisms. One participant asked for the tape to be turned off when she discussed the difficulties women had with contract negotiations in her institution and when she talked about a job offer she had received. One woman who refused to have her interview taped was motivated to a large extent by her wish to not have anything critical of her institution or colleagues recorded. She also commented on something I had said in my introductory letter. I had said I was interested in what it was like to work in a male dominated area.<sup>1</sup> She said that if I meant that the men were dominating then this question was biased but she accepted that there was another intended meaning that men dominated numerically and any other meaning was under investigation. Nobody refused to answer any of the questions but most commented on how difficult it is to describe what mathematics is.

My personal experiences did not figure much at all in the interviews. This was largely due to my not having had the same work experience as the participants.

<sup>1</sup> This letter can be found in Appendix 1.

Although I have an undergraduate degree in mathematics my work experience was as a high school teacher and in these interviews I deliberately did not focus on the teaching in which some of these women were involved. We would have had more in common in that area but my interest was in their mathematical research. As this is something I have not done myself, I was not able to relate their experiences to my own. In areas which we did have in common such as managing a family and work or being an undergraduate student in mathematics I did discuss my own experiences more. I wanted to keep the interviews focused on the questions of interest to me and not allow either the participant or myself to become distracted into a conversation about shared experiences that were not relevant. Whenever anyone asked about my personal experiences I answered them honestly and openly.

I intended to return transcripts of interviews only to those respondents who wanted them and to provide all participants with a final report on the research findings but not to involve them in collaborative theorising beyond what took place as part of the interviews. I am aware that in some senses there is an element of contradiction between this and the desire to avoid objectifying the subject and her experience. But there is a point at which I believe I must translate the experiences of the subjects into more abstract and general terms if an analysis is to be made that links individual experiences and the meanings the subject makes of them to existing social relations (Acker et al, 1991:136). I did not assume that the subjects necessarily wanted to be involved in such work beyond the interviews, just as Acker et al (1991:140) found that many of their respondents wanted the researchers to take the lead and set the questions, rather than direct the proceedings themselves. I thought and continue to think that the best service I could do these women was to maintain high standards of integrity, conduct the interviews in a style of reciprocity and be well informed and well prepared so as not to waste their precious time.

The participants were offered the opportunity to read the transcripts of the interviews but none of them took up this opportunity. However they all expressed interest in reading the final report on the research. Throughout the

interviews the participants involved themselves in theorising about the research questions. They commented on the questions themselves and discussed the meanings they made of their own experiences. Their comments in this regard will be discussed more fully in Chapters 7 and 8.

### **Objectivity**

While feminist critiques have been successful in undermining traditional claims to objectivity there remains a need to ensure that “the danger of a rampant subjectivity where one finds only what one is predisposed to look for” (Lather, 1991:52) is taken into account. Feminists have argued that traditional methods of ensuring objectivity based on eradicating the subjectivity of the researcher have only been successful in eliminating the views and beliefs of the marginalised and least powerful and have not been strong enough to eliminate beliefs and values that are culture- or nearly culture-wide (Harding, 1991). In particular the beliefs of the most powerful, principally white middle class men, have not been eliminated from the data and its interpretation.

Feminist responses to this failure of traditional notions of objectivity have been either to make no claims at all as to the possibilities of extending conclusions beyond claims of individual subjective interpretation, or to move towards reflexivity that is to locate the researcher on the same critical plane as the researched (Harding, 1987:8-9). In some cases this has involved disclosing the race, class, gender and sexuality commitments of the researcher. While this disclosure may shed some light on values influencing the research process it also appears contradictory to theoretical perspectives based on postmodern explanations of identity and subjectivity. It implies a unity about these categories that they do not have and does not allow for the multiple contradictions within them. Such a disclosure does not capture ‘an’ essence of the individual or explicate how this essence might play itself out in the research if it did exist and could be identified. Locating oneself in this way is insufficient to guarantee objectivity.

My response is to locate myself not only through explicating whatever identity categories I consider myself to occupy, no matter how precariously, but also to make the process as transparent as possible, to speak/write in my own voice(s), to be explicit about my theoretical and political commitments to and in this project, to retain the voices of the subjects as much as possible, and to encourage reciprocity in the process of data collection. In considering questions of validity and objectivity in my own research my focus is on the data collection process and the interpretation of that data.

The discussion of objectivity in this research process so far rests on the premise that knowledge and objectivity, however defined or ensured, are in principle individualistic. In this schema objectivity would be achieved as a result of the individual researcher taking her own subjectivity into account (Longino, 1990:212-3). However Longino argues, and I agree with her, that it is “the subjection of hypotheses and theories to multivocal criticism that makes objectivity possible” (Longino, 1990:213). This multivocal criticism is undertaken in the critical practices used in the disciplinary site where the knowledge is produced and includes peer review, the examination of theses, the presentation of seminars and conference papers and the review of papers presented for publication. This of course means that this objectivity is bound up in the social values and beliefs of the group participating in these practices. This theme is taken up again and again in this thesis when looking at mathematics as social knowledge but it is also relevant in considering the status of the empirical aspects of this work.

While responding personally to take my individual partiality/subjectivity into account as described above, there is also a sense in which this thesis remains tentative as the work has not been subjected to the “practices of transformative criticism” (Longino, 1990:232) yet to come. The different responses anticipated from the different communities to which this work will be presented illustrate well the social nature of objectivity. Different standards can be expected from feminist communities who are familiar with and subsequently take for granted the social nature of scientific knowledge than from

mathematicians who often assume that mathematics is above and beyond the influences of culture and society. Any claims to the contrary are likely to be met with bewilderment, confusion and rejection if the possibility of the social nature of mathematics is not first established with them. This is of course something I am trying to do throughout this thesis and it brings me back to the concept of rhetorical space (Code, 1995). Before meaningful criticism of the validity of this research can be undertaken, the rhetorical space must be established where the questions raised seem sensible to contemplate. Code (1995: ix-x.) uses this concept of rhetorical space to refer to the conceptual location in which a question can be raised with the reasonable expectation that others participating in the conversation will recognise that question as one that makes sense and is worth addressing. There is an expectation that the question will be heard, understood and taken seriously. Code describes this as “choral support”.

There is a dilemma here which is centred on who the intended audience is for this work. There is of course more than one intended audience: the women who participated in the research; feminist scholars; the community of mathematicians and mathematics educators. My political commitment in this project to speak in language that is comprehensible to the research participants and to contribute towards the increasing participation of women in mathematics, has a bearing on how this dilemma is dealt with.

### **Interpreting the data**

The choice of analytic categories, even the method of organising the data, can reflect prior beliefs or theoretical commitments. One possible response is to determine the categories before the interviews are undertaken but the danger here is that these categories are more a reflection of the prior commitments and assumptions of the researcher than indicative of the experiences of the subjects. These categories then become containers into which the data is poured and forced to fit (Lather, 1991:62). Another option that is often adopted in response to such critiques is to “let the data suggest” what analytic categories

should be chosen. Longino (1990:219) argues that this “is a recipe for replicating the mainstream values and ideology that feminist and radical scientists reject” because the data does not speak outside of a context of social, cultural and political commitments.

Scrutiny of the data does not yield a seamless web of knowledge (Longino, 1990:193) so the researcher must objectify the experiences of the subjects in order to translate those experiences into more abstract and general terms (Acker et al, 1991:136). This does not have to imply that the researcher is standing outside, above or beyond this process. What is called for, is stringent self-reflexivity on the part of the researcher in examining the impact of the analytic categories chosen; the bringing to the surface of other possible explanations; and analysis of the impact the data has on the theoretical position that is how the data has led to changes in theoretical commitments held prior to the research being done. Subsequent practices associated with peer review and publication contribute greater stringency to this process.

Taking account of the questions suggested by Lather (1991:84) assists in the process of reflection on the ways in which prior assumptions have intervened in the analysis. I have to consider whether I have imposed order and structure at the expense of ambivalence, ambiguity and multiplicity; whether I have confronted my own evasions and illusions of closure; what binaries have structured my arguments; who has been created as ‘Other’; and whether I have contributed to “producing pluralized and diverse spaces for the emergence of subjugated knowledges and for the organization of resistance” (Lather, 1991:84). Rejecting a theory of the self based on the rational fully conscious self of the Enlightenment and instead theorising it as multiple subject positions created within sometimes conflicting and contradictory discourses implies ambiguity and multiplicity rather than order and structure. If I were to find only order and structure in my data this would be a signal to me that I had imposed an order based on my own preconceptions rather than capturing the doubts, complexities and uncertainties of human experience. The ambivalence and

multiplicity within and between the participants' accounts suggests I have achieved my aim at least to some extent.

### **Validity and women's experience**

Lather (1991:112) argues that research is not about finding 'a' truth or 'the' truth because there is not 'a' truth to be found. It is more about the "development of a mutual, dialogic production of a multi-voice, multi-centred discourse" (Lather, 1991:112). While not claiming to have found 'the truth' about women mathematicians I have found some common threads and some contradictions between and within the accounts given by those participating. As I have not come up with a unified, coherent, single account of such subject positions I am claiming that objectivity has not been totally lost to my own "rampant subjectivity" (Lather, 1991:52). I am also claiming to have dislodged some of the 'untruths' in the existing gender and mathematics literature and to have found evidence for deconstructing the binaries upon which this literature is so often based.

Considering the validity of a piece of feminist research leads to questions about the place and meaning of 'women's experience' as evidence or a foundation for any conclusions drawn from the research. It is my contention here that 'women's experience' requires a more nuanced analysis than the way in which it has been used in the past by feminist researchers as evidence to support their hypotheses. Feminist scholars have been very successful in critiquing the ways in which mainstream research has ignored or abused women's experiences and the subsequently invalid conclusions drawn from such research. 'Men's experience' has often been confused with 'human experience'.

The arguments about the status of 'women's experience' in feminist research have been well rehearsed elsewhere and it is not my intention to dwell on the older debates at any great length here. When understood in opposition to the exclusion of women's experience from social research, the concept obviously does have great value to feminist scholars but the debate has moved quickly beyond these beginning stages to examine the concept itself and its

implications. As Longino, (1990:190) says “[o]ne of the tenets of feminist research is the valorization of subjective experience” but the status of this subjective experience in knowledge construction is contested by feminist scholars. “Feminists are divided over what ‘truth’ status should be accorded to feminist knowledge” (Ramazanoglu, 1993:7).

One area of contention is based on the rejection of a unified notion of ‘women’ who would be capable of having a shared experience. The usefulness of a notion of ‘women’s experience’ cannot rest on the simplistic idea that women, regardless of race, class, ability, religion, and sexuality, have sufficient common experiences and sufficient recognition and acceptance of their commonalities, upon which to rest knowledge claims. Such a unified notion of the concept also renders invisible the differing power relations operating between and amongst women and disguises the differing vested interests and alliances between different groups of women and men.

Ramazanoglu (1993:7-8) takes issue with what she describes as the “simplest position” that “a woman’s subjective knowledge is ‘true’ because it directly articulates women’s experience”. She argues that this “is simply the other side of the argument that, men’s knowledge is ‘true’ because it is rational, objective and neutral.” Basing arguments on individual experience can also lead to a kind of tyranny, for who cares to question the validity of another individual’s subjective experience? Ramazanoglu takes the position that “we always have to interpret and conceptualise accounts of women’s disparate experiences” because subjectivity and objectivity cannot ever be completely separated.

Scott (1992:31) also takes issue with the attribution of “an indisputable authenticity to women’s experience” as it takes individual identity for granted and makes individuals the starting point of knowledge. It universalises the identity of women and “conflates the imposed, the attributed and the lived,” (Riley, 1988:100). The very questions I am most interested in, questions about multiplicity and contradictions, are precluded in such a conceptualisation of women’s experience. It “closes down inquiry into the ways in which female

subjectivity is produced, the ways in which agency is made possible, the ways in which race and sexuality intersect with gender, the ways in which politics organize and interpret experience - the ways in which identity is a contested terrain, the site of multiple and conflicting claims” (Scott, 1992:31).

I am using the concept of ‘women’s experience’ not as evidence of the truth of my arguments but rather as that which I am seeking to explain and, through this explanation, to produce knowledge about the questions of interest to me. These ideas are summed up in the following quote from Scott:

Making visible the experience of a different group exposes the existence of repressive mechanisms, but not their inner workings or logics; we know that difference exists, but we don’t understand it as constituted relationally. For that we need to attend to the historical processes that, through discourse, position subjects and produce their experiences. It is not individuals who have experience but, subjects who are constituted through experience. *Experience in this definition then becomes not the origin of our explanation, not the authoritative (because seen or felt) evidence that grounds what is known, but rather that which we seek to explain, that about which knowledge is produced*<sup>2</sup> (Scott, 1992:25-26).

Aspects of ‘women’s experience’ that require explanation include: the accounts these women give of their experiences; the understandings and reconciliations they make about their experiences; and theoretical explanations of the background and meaning of these experiences. All these aspects are useful in the creation of knowledge and the further development of theory.

### **Application of methodology in this project**

In this section I focus on how I actually carried out the project. I discuss the selection of the subjects; the ethical issues and how they were accounted for; the approach to the subjects; the development of the questions to be raised in the interview; the conduct of the interviews; and the subsequent data analysis.

<sup>2</sup> My italics.

Excerpts from the interviews and the data analysis will be used at relevant points in the thesis and a detailed analysis occurs in Chapters 7 and 8.

### **The women I spoke with**

The target group was specifically and narrowly defined to include only those women mathematicians who engage in mathematical research and are therefore in a position to make a contribution to and influence that body of knowledge called mathematics. Women who have studied mathematics and pass on their knowledge as high school teachers; women whose research is in mathematics education; women statisticians; and women who use mathematics as a tool in their occupations were specifically excluded from the target population.

To work as a research mathematician a Ph.D. is usually a prerequisite. In New Zealand there are 15 women with Ph.D.s in mathematics (Day and Thornley, 1993). While these numbers are very small the proportion of women/men is not too dissimilar from that in other Western countries. In the period 1981-1990, 20.8% of those graduating with a Ph.D. in mathematics or statistics, in New Zealand, were women (Day and Thornley, 1993). In Australia, 13.6% of Ph.D.s in mathematics and statistics were awarded to women between 1980 and 1991 (Petocz, 1993). In a similar time period 1980-1990, in the US, 16.8% of Ph.D.s in mathematics were awarded to women (Jackson, 1991). Of the 15 women with Ph.D.s in New Zealand, eight were excluded from the sample because they lacked New Zealand experience or were unavailable. Nine women were invited to participate and all agreed to do so. I subsequently discarded the responses of one woman because all her experience had been in the Soviet Union and was not therefore directly comparable with the experiences of the other participants. One of the participants did not have a Ph.D. but was selected because of her experience as a research mathematician. Another participant had moved out of mathematics into operations management in recent years.

The common thread linking these women is that they work or have worked as research mathematicians. Within this group there are differences and

similarities. All of the women came from white, middle class families. None of them were disabled, none claimed a lesbian sexuality. So apart from their gender they were members of the same privileged groups as their male counterparts. All but one of them are born and bred Pakeha<sup>3</sup> New Zealanders who received all their education up until doctorate level in New Zealand. Two completed Ph.D.s in England, one in the USA, one in Canada and two in New Zealand. The exception was born and educated in the USA where she gained her Ph.D. She came to New Zealand to take up a position in a university. She is also exceptional in that at 72, she is considerably older than the others in the group.

There are also similarities and differences between these women and me. Like them I come from a Pakeha, middle class background. I share some of their experiences because I too, have a degree in mathematics and at the time of the interviews I was employed in a university mathematics department. However my previous work experience has been as a high school mathematics teacher and not in mathematical research.

In the following table I have presented a summary of the details of the participants. I have not included their names to ensure a greater degree of confidentiality. The names I do use for the participants elsewhere in the thesis are pseudonyms assigned by me to preserve confidentiality.

<sup>3</sup> Maori who are brown skinned Polynesians are the indigenous people of New Zealand. Pakeha are the white skinned people who came to New Zealand after the Maori as colonisers. They are principally of British descent.

**Table 3.1: Summary of participant details.**

Age	Family Status	Current Position	Area of Mathematics
31	Male partner, no children.	Lecturer in mathematics department.	Nonlinear geometry, dynamical systems.
51	Divorced, 3 children 20-25.	Lecturer in mathematics department.	Graph theory.
40	Married, 2 children 6 years and 9 months.	Maternity leave from position as research fellow.	Geothermal modelling.
43	Married, 5 children, 6-16.	Self-employed in software company.	Foundations of quantum theory.
41	Single, childless.	Senior lecturer in management science.	Operations management.
38	Married, 2 children 3 years and 18 months.	Lecturer in mathematics department.	Combinatorial aspects of computer science.
33	Single, childless.	Scientist at government research institute.	Operations research.
72	Single, childless.	Retired from previous position as senior lecturer in mathematics.	Combinatorics and special functions.

**Note** Lecturer is equivalent to assistant professor with tenure and senior lecturer is equivalent to associate professor in the US.

### **Ethical issues**

Ethical approval for this project was given by the Human Ethics Committee of Massey University. The major ethical issue arising from this research was that of confidentiality. The participants have their confidentiality protected to the extent that their names have been changed and their location and the name of the institution where they work is not given. It was pointed out to the participants in seeking their informed consent that:

While stringent steps will be taken to ensure the greatest possible degree of confidentiality, the small number of women mathematicians in this country may make it possible for readers of reports on the research to believe that they can identify a participant but they will be unable to confirm their suspicion with the researcher (Participant information sheet and consent form, Appendix 2).

The participants were also informed that:

You will be free to withdraw from the study or to not answer any questions or to retract any information previously provided at any time. On request you will be provided with a copy of a transcript of your interviews which you may then amend if you wish to do so. All participants will be given a report on the findings and analysis resulting from the research on completion of the project (Participant information sheet and consent form, Appendix 2).

As I said earlier in this chapter none of the participants asked to see a transcript of their interviews but all expressed strong interest in seeing the final report on the findings. The participants were also asked whether they agreed to have the interview taped. One participant did not agree to this and so I took extensive notes from her interview.

### **Approaching the women**

I wrote<sup>4</sup> to the women I hoped to interview and outlined the project and the time frame for the interviews. When they agreed to participate I sent them an information sheet on the project and a consent form<sup>5</sup>. Just prior to the interview taking place I sent the participants more information about the kinds of questions I would be asking them<sup>6</sup>. All the participants read this information carefully prior to the interview and referred to it during the interview.

<sup>4</sup> Appendix 1. Initial letter to participants.

<sup>5</sup> Appendix 2. Information sheet and consent form.

<sup>6</sup> Appendix 3. Letter to participants outlining the interview questions.

I initially approached eleven women asking them to participate. The letter to one woman was returned 'gone no address'. One woman did not respond and I tried to contact her by email still without response. Many months later she contacted me saying she had been too busy and stressed at the time to respond but by the time she did this it was too late for me to include her. The other nine women agreed to participate. They notified me of this by phone and almost invariably began by saying that they did not think I would find them very interesting but they were willing. One woman asked for more information about confidentiality before agreeing but she accepted my assurances and their limitations. Another woman asked me about my background in mathematics and what perspective I would be taking and she too accepted my assurances. The woman who has moved out of mathematics warned me that she may not fit my sample but also agreed to participate. When arranging the interview she expressed further doubts about the value of her participation. It became clear in the course of the interview that some of her experiences were still very painful for her to think about and this was obviously a factor in the reservations she had expressed about participating although she had not said so initially. While recalling her experiences was at times very upsetting for this participant, I am most grateful to her for her participation as she raised issues that are particularly relevant to the project and which were not raised in such detail by other participants. Further detail is provided in the results in Chapters 7 and 8.

### **The interview questions**

A qualitative method using semi-structured interviews was used. All respondents were asked the same questions when they were relevant to that individual. They were not necessarily put in the same order nor in identical phrasing. The purpose was to maintain a structure that was flexible enough to allow for the unexpected and for the individual voices of the women to be heard. Three factors were important in maintaining a structure without allowing the structure to dominate and dictate the outcomes. The first was the thorough familiarity of the interviewer with the interview questions. This ensures the interviewer has the confidence to allow the interview to follow its natural

course without losing its focus. The second factor was the length of the interviews. One and a half hours allowed for the establishment of rapport, the emergence of the unexpected, and the covering of the required material without the participants becoming so tired as to lose concentration. The third and particularly successful step was in providing the women with an outline of the questions they were to be asked, a week in advance. All the candidates had read this outline and spent some time thinking about the questions before the interview. Several had discussed some of the questions with colleagues and several had searched out other information they thought would be helpful such as CVs and publications. The interviews took place in their offices or homes. All interviews were taped and transcribed except one, already noted, where the respondent did not wish to be taped. In this case extensive notes were taken.

The topics<sup>7</sup> addressed included how and why they became mathematicians, the kinds of mathematics they did and how they went about it, how being women had affected their careers, descriptions of the climate they worked in and their involvement in women's groups within and outside mathematics. An important factor influencing the questions asked was the dearth of research on the practices of mathematicians. The main focus of the gender and mathematics literature discussed in Chapter 4 is on gendered practices in education and has little to say about the work and practices of mathematicians themselves. There is a noticeable lack of sociological and anthropological research in mathematics. While I was hoping to be able to provide an analysis of the gendered nature of such accounts and compare them with the accounts given by my subjects this was not possible because there is very little groundwork already done with which to make such comparisons. The consequence for my research was that I needed to seek information from my subjects as to how mathematicians go about their work and then discuss with them any gendered implications. I found it very interesting that my subjects found such questions very difficult to answer. Non-mathematicians seldom talk to mathematicians

<sup>7</sup> A copy of the interview schedule can be found in Appendix 4.

about their mathematics. As a consequence of this and the power relations operating within and around mathematics, mathematicians are not accustomed to and therefore not skilled in describing what they do at work. When a mathematician gets to work and sits down at their desk or computer what do they do? This is what I asked about.

I was also interested in the politics of mathematical careers. I wanted to know how you get ahead as a mathematician. What counts for promotion? Once again I was interested in any gendered implications. I had already developed some background in this area through discussions with members of the department where I worked and visitors to the department. Some of these mathematicians, particularly the ones with the most impressive publishing records told me about the strategies they used to achieve their success. I was interested to know whether the women were aware of these strategic approaches and whether they used them or other approaches themselves. I was also interested in their experiences with national and international networks of mathematicians in their areas.

In asking the participants about what attracted them to mathematics I was interested in comparing their responses to findings in the gender, mathematics and education literature (discussed in Chapter 4) about why women do not find mathematics attractive.

The next batch of questions specifically addressed gender issues. In asking how they thought being women had affected their career progress and what the climate was like for them in their workplaces I was not only interested in their descriptions and experiences but in how they interpreted and came to understand those experiences. This is an example of the multi-layered way in which 'women's experience' is useful as a theoretical concept. The things that happened to these women provide evidence that gender is a marked category in the community of mathematicians but the participants' understandings of these experiences are also very valuable for developing an understanding of the way in which gender operates in this community. In looking at the accounts and

interpretations the participants gave of the events they had observed or experienced, 'women's experience' itself becomes that which needs to be explained.

Part of my motivation for exploring this topic was to look at the contradictions these women may face within the binary rational/emotional. I was interested in how these women experienced conflicts between being women and being mathematicians if in fact they did so. These questions lead to a variety of responses among the women which will be discussed in Chapter 7 and 8.

The possibility that women might approach scientific problems differently has been a central issue in the feminist science debates which I discuss in Chapter 5. I was interested in trying to find out whether similar issues were relevant in mathematics and to this end I asked the participants for their opinions and experiences in this regard. I had expected to get a very negative response to this question along the lines of 'mathematics is mathematics no matter who does it'. I was pleasantly surprised to find that most of the participants thought this was a valuable question but unfortunately they were unable to shed much light on it. This was because they had little or no experience of working on their mathematics in collaborative situations with other women. They were usually isolated as the only woman if not in their department at least in their research group.

### **One interview**

When I began the project I thought it might be necessary to interview each participant twice and I allowed for this possibility when initially writing to the participants. This was because I expected to get minimal responses to many of my questions and to have difficulty in drawing out the information I wanted from the participants. I expected to get more responses along the lines of 'I am just a mathematician, being a woman doesn't make any difference'. To cope with this I intended to interview each participant, to collate the responses and then to use the responses of the more outspoken participants to draw out the reticent by asking them to comment on what others had said. After the first

interview it became clear to me that this was not necessary. I had very few responses of the kind described above and when I did the participant was able to expand sufficiently for my purposes. I decided not to conduct the second interview and wrote to the subjects advising them of this and inviting them to write, phone or email if they felt they wanted to add anything to what they had already told me. I also said I was happy and willing to return for a second interview if they wanted me to. They all agreed to dispense with the second interview and nobody added to what they had already told me. Several took the opportunity to reiterate that they were looking forward to getting the final report, one told me of an address change and one sent me a copy of a journal article she had read and thought I would find interesting.

### **Data analysis**

In order to identify the patterns and contradictions within the individual responses and between the responses of the participants, the data or participants' responses have to be categorised in some way. To do this the tapes were first transcribed and a clean copy of each transcription made. Then the data was coded. This involved assigning codes to the responses according to the topics discussed in that segment. The initial codes arose from the original interview schedule and the actual interviews and transcriptions. Further refinements were made during the course of the coding to allow for the surprising and unexpected. This was a dynamic process involving tentative initial codings being tested, developed and consolidated. The responses in a particular category from all participants were then pulled together for analysis. This analysis consists of identifying themes in the responses rather than individual case studies.

I used the following headings and broke each heading into subheadings:

**Career:** career history, shoulder tapping, career planning, career advice, career ambition, career problems.

**Family:** family constraints, family encouragement.

**Topic:** topic choice for PhD, selection of ‘hot topics’, current research topic.

**Mathematics:** culture of mathematics, attraction to mathematics, importance of applications in mathematics, philosophy of mathematics.

**Working with women:** working with women, working with men, the numbers of women in the participants’ workplaces.

**Work practices:** publishing, seminars, funding, networking.

**Climate:** feeling successful, alienation, male attitudes to women, chilly climate, inner conflicts, warm climate, describing the climate.

**Women as a marked category:** women’s career values, women as a marked category in mathematics, the effect on progress of being a woman, attracting women students, participation in women’s groups, women doing mathematics differently, why the numbers of women are not increasing more rapidly.

**This thesis:** comments about this research project.

I assigned these codes to passages of the transcripts that related to that code. I aimed to include more of the conversation rather than less so that the context would be preserved. Often the same chunk of text had more than one code attached to it as it was relevant to more than one topic. Throughout the coding process I was attempting to preserve the context and to maintain the flow and feeling of the participant’s own words and expressions.

Once the data was coded I used a word processing programme to collect the relevant material for each code together. This gave me two ways to read the data. The first was the transcript of each individual interview and the other was the collection of all the participants’ responses on a particular topic.

The analysis of the data can be found in Chapters 7 and 8.

### **Evaluation of the process**

In evaluating the interview process after it was completed I was very happy with the results I had achieved. The data I collected was rich and varied. Not all participants had responded to every question as they were not relevant to each individual, but every participant had contributed something unique and surprising. This gave me confidence that the process had been successful and that I had gone a long way towards achieving the relationship with the participants that I had been hoping for. We consulted as experts on the questions before us and I did not feel that my prior commitments had dominated the process and obscured the unexpected. At some times of course this was more difficult than others. The most difficult interviews were with those women whose views on women and feminism were most at variance with my own.

### **Working in a mathematics department**

Shortly after I began this thesis I was appointed to a position as a graduate assistant in the Mathematics Department of Massey University. If I had known this was going to happen before I began I may well have approached this project differently and undertaken a participant observation methodology. Working within this department did however give me many opportunities to observe a group of mathematicians in action and to talk to them about their work and their practices. I frequently had the opportunity to ask questions of internationally respected visitors. This provided me with excellent background information and an insight into the practices and culture of mathematics and was particularly useful in narrowing down the kinds of questions that would be most useful to ask and the kinds of practices and strategies that mathematicians are involved in. Given the scarcity of systematic research about the culture of mathematics this experience was even more valuable to my project.

## Conclusions

In this chapter a methodological justification for the empirical aspects of this thesis is given. A qualitative method was used to interview women who work as creative mathematicians. Only women who are or have recently been involved in mathematical research were included in the population as the purpose was to examine the conflicts and contradictions women who work as mathematicians may face and to question whether mathematics might be different if women were involved in greater numbers. An interview guide was developed from the theoretical concerns raised in other chapters of this thesis and then semi-structured interviews were conducted. In conducting these interviews I envisaged the relationship between the participants and me as the researcher, being developed through reciprocity and negotiation as one between two experts consulting on the questions before them. I am confident that this was achieved to a high degree. Once the interviews were completed and transcribed, the data was analysed. The results of this analysis are presented in Chapters 7 and 8. As every interview led to surprising and unexpected responses from the participants I have reason to believe that I was able to reach beyond my own 'rampant subjectivity' in seeking out and analysing the responses of the participants. The discussion in Chapters 7 and 8 will show that there are indeed conflicts and contradictions for women working in mathematics but there are also rewards and pleasures.

## Chapter 4

# Gender, Mathematics and Education

### Introduction

In this chapter I look to the literature and research on gender, mathematics and education to open the rhetorical space to address my question of whether mathematics would be different if more women were involved, that is to ask how mathematics is affected by its male gendered tradition. The focus of the literature on gender and mathematics education is on differences between girls and boys. It focuses on attempts to establish the existence of differences in achievement and subsequently on explanations for any differences found. This research is justified as an attempt to explain the differences in participation between males and females that are found both in tertiary mathematics education and mathematically oriented careers. Although this research is described in terms of 'gender' rather than 'girls' or 'women', it is the behaviours and achievements of girls and women which are problematised.

My argument is that this literature constructs the 'female mathematics student' as inferior, deficient and lacking. The 'male mathematics student' is portrayed as the unproblematic norm against which the 'female mathematics student' is found lacking even when she is successful. The research results on the relative achievements of male and female students are contradictory and do not justify the conclusion that males do better despite very popular misconceptions that they do so. I argue that discourses of masculinity and femininity, of mathematics and mathematics education and the research literature on gender and mathematics education are intimately linked. Unless this linking is brought to the surface girls' achievements and participation in mathematics will continue to be undermined even where there is a commitment to equal opportunities for girls in mathematics.

In this chapter I discuss the role of mathematics as a critical filter and its impact on girls and women. The research in this area is situated within a context of 'gender differences' but this study of gender differences is problematic as it often serves to reinforce inequities rather than remove them. I take a critical look at some of the underlying assumptions and constructs made in this literature. I look too at how girls, boys and gender are constructed and how philosophies of mathematics underpinning mathematics education can reinforce existing gender categories. In conclusion I argue that a close critical examination of this area opens up the rhetorical space for asking questions about the consequences of mathematics' male gendered traditions and history both for mathematics and for women and men.

### **Why ask questions about gendered achievements and participation in mathematics?**

The motivation for asking questions about gender and mathematics education is usually based on concerns about equity. Women are vastly under represented in careers in mathematics and related areas such as engineering and this points to the presence of some inequity. The reasoning then proceeds along the following lines. Women are under represented. Why? Because they have not done enough mathematics of the right kind and the right level. Why not? Perhaps because they are not very good at it. Those concerned with equity for girls in mathematics education are then motivated to ask why girls don't do as well in mathematics and why they don't choose to enter mathematical areas.

Secada (1995:155) argues that a commitment to equity is mediated by: a search for immediate answers; the demand for elaborated answers that fit a preset agenda; an exclusive focus on group differences; and differential standards of scrutiny for equity concerns. So although there is concern about equity, often that concern is only addressed within the confines of the status quo. Equity concerns are addressed only to the extent that this status quo is not unduly disturbed. It is much less disturbing to question the ability and behaviours of

girls than to ask awkward questions about inequitable structures in the education system or about how gender itself is constructed within that system.

### **Mathematics as a critical filter**

In order to gain entry to many areas of higher education or to certain prestigious and well paid professions one has to have been successful in passing mathematics tests and examinations. Mathematics is used as a critical filter even when the required mathematics is not essential in these professions or advanced courses. Success in mathematics is taken to be an indicator of ability, intelligence or 'braininess'. In order to understand how mathematics achieved this position as a critical filter it is necessary to look at history and to reflect on the power of mathematics in our society.

Prior to the Enlightenment access to higher education was controlled by the church and Latin was used as the critical filter. One needed to know Latin in order to participate in higher education and the Church was able to control who could and could not learn it. As power and control shifted away from the Church particularly in the period of the Enlightenment, theology gave way to science, and knowledge of mathematics replaced Latin as the tool for deciding access to education (Hacker, 1990:141-142).

One aspect of the Enlightenment was the dichotomising of binaries between mind and body, reason and emotion. Science was defined in a hierarchical opposition to nature. It was associated with the rational, moral and self-disciplined, and the work of the mind, while nature was associated with the body, sensuousness and the emotions. While nature was thought to be unruly and impulsive it should therefore be brought under the control and discipline of science through the efforts of scientists and engineers. Science represented the rational way of doing things. Learning mathematics, a manifestation of reason, meant the student learned not only the ability to curb the passions and impulses and to achieve rational thought and industrious habits but to attain control over nature. Success in mathematics demonstrated the ability to achieve this control.

Reason, morality and self-discipline were joined together to control the unruly passions (Hacker, 1990:142).

Locating pure mathematics outside the realm of the passions, the body and nature has the effect of locating it outside the realm of women because women are associated with the emotions, unruly passions, sensuousness and the body. Demonstrating an understanding of abstract mathematics confirms the ability to think rationally and not be swayed by the emotions and passionate impulses. A person who can do this proves they are capable of bringing order to the chaos of the natural world by becoming an engineer or scientist. Women are excluded from attaining such knowledge and entering these professions by their association with nature and the body. This is our legacy from the Enlightenment.

In “Doing it the hard way”, her study of engineering and engineers, Hacker (1990) describes how mathematics and the passing of mathematics tests is used to control access to the profession and to maintain the status of engineering as a profession against the pressures from trades and technicians. Professions such as engineering seek to restrict the number and types of successful applicants to the field and they use proficiency in mathematics tests and particular methods of teaching mathematics to achieve this. The emphasis in these courses is on high levels of difficulty and abstraction. The mathematics is taught independently of its applications and links to human concerns.

Hacker (1990) interviewed engineering faculty members who admitted that the calculus and other forms of higher mathematics required, may have little relevance to job performance. Willis (1990:245) also argues that those

pathways which specify mathematics as a prerequisite do not draw directly on the mathematical concepts which are used as the selection device. A number of tertiary courses, ..., do not draw on the type of mathematics contained in the subjects they used as prerequisites.

The engineers insisted on the importance of such courses “to show that you can do it” or to “develop a proper frame of mind” (Hacker, 1990:149).

There is a need for great precision in engineering as very small inaccuracies could lead to big disasters. We rely on engineers to ensure that the bridges and buildings they construct are safe. This safety is dependent on precision and accuracy which in turn is dependent on mathematical skill and precision. Arguing that mathematics is a critical filter is not to say that mathematics is not necessary to these disciplines but that the kind of mathematics that is taught; the way in which it is taught and the culture and practices of mathematical education are arranged in a particular way so as to achieve this filtering function. Those applicants that can achieve success in this milieu are then admitted into the profession.

As Hacker (1990:140) says this filtering function may “perhaps inadvertently, assure cultural homogeneity in the field.” It may be inadvertent in the sense that those controlling entry are not consciously and deliberately trying to exclude certain groups such as women, people of colour or lateral thinkers, but at the same time they do possess a common perception of what makes a good engineer and this just so happens to exclude difference. If mathematics courses have a primary function to limit the number and kind of applicants to a field then it would be possible for women and (disadvantaged men) to master that mathematics and gain access to the field. I tend to agree with Hacker (1990:140) that if they were to do so the criteria would simply shift to something else, to some other form of filtering.

Many people are made to feel powerless by mathematics (Willis, 1990:205). “Most students do not enjoy their study of mathematics... What most students learn through their ten or more years of studying mathematics is that they can’t do it” (Zevenbergen, 1994:47). Willis (1990:192) argues that “the reality of school mathematics” is that it is “used ... for intimidation, socialization and selection”. The prestige that is then bestowed upon those who are successful is seen as deserved, not only by those who are successful and but also by those who are not (Zevenbergen, 1994:47). For these unsuccessful people the power of mathematics does not lie in the power mathematics gives them to think and act but rather its power lies “in the meritocratic prestige of mathematics as an

intellectual discipline” (Willis, 1990:205). This powerlessness is reinforced in “our culture, which sees mathematics as accessible to a talented few” (Willis, 1990:206). This elitist attitude has allowed European middle class males, who make up the majority of those who are successful, to define mathematics in their own light and to insist that their particular conception of mathematics is the only proper conception (Willis, 1990:206).

A view of mathematics as culture free reinforces the use of mathematics as a critical filter because it enables mathematics to play the role of now widely discredited IQ tests. These tests have been discredited in many circles because they have been found to reflect cultural biases and are therefore not a ‘true’ measure of natural ability or raw intelligence if such a thing exists. This use of mathematics in turn reinforces the view that success in mathematics is a result of natural ability and disguises the power relations that have a place in determining this ability (Zevenbergen, 1994:2).

Willis (1990) outlines the dilemma facing girls in relation to the use of mathematics as a critical filter. Girls can be encouraged and assisted to “survive the filtering process” but this leaves in place the structures that are used to exclude a large proportion of the population. Using mathematics as a selection device excludes the very same people that IQ tests do. It would be reasonable to expect that if girls found their way through this filter it could be replaced by something just as pernicious. “[C]hanging girls is insufficient to change the system.” In the meantime girls have given up subjects they value and enjoy in order to pass through the mathematical filter (Willis, 1990:207).

Sue Johnston (1994) undertook a study of how, why and what mathematics girls choose in Year 11 in Australian High Schools. Mathematics is not compulsory at this level although English is. The vast majority of girls interviewed were swayed by arguments about the importance of taking mathematics even when they would not otherwise have wanted to. But this importance was not seen as being related to its intrinsic worth. They were not convinced by arguments about the practical everyday uses of mathematics as

their experience of the practice of school mathematics could not justify this conclusion. It was the importance of mathematics as a filter for entry into tertiary courses and employment that convinced them. Johnston's research was summed up beautifully by one girl who said "you do maths just to prove you have a brain" (Johnston, 1994:241).

Having chosen mathematics this is the only subject in which the students are then counselled into streams according to their perceived mathematical ability. Teachers channelled their students into the level of mathematics course they thought appropriate based on the students' past achievements. However if a girl was reluctant to choose a higher level course, even when her past achievements indicated she was capable of it, it was unlikely that she would be encouraged or persuaded to change her mind. Johnston (1994) concludes that in this streaming process girls are receiving the mixed message that mathematics is vitally important for their futures but that they may not have the ability to study the form of mathematics that is necessary to take up these future options.

This discussion is summed up by Zevenbergen (1994:1-2):

Mathematics becomes a social filter to sort out those who gain access to the high status, wealth and power associated with certain professions and those who can not. It is no coincidence that those who are excluded from the study of mathematics are those social groups already marginalised in society - women, the working class and non- Anglo-Saxons. The credentialing process of schools ensures that those students who are able to be successful in mathematics come to perceive their success as natural. In this way, the power, status and wealth associated with high-profile professions is legitimated for those who acquire it and for those who have been excluded from it.

Closely linked with the role of mathematics as a critical filter and the legitimization of the power and status gained by those who pass successfully through this filter is the way mathematics serves to intimidate those who are excluded. Arguments presented mathematically or statistically are likely to be accepted uncritically. Mathematics is used

in highly ambiguous ways to produce mystification and an impression of precision and profundity. Arguments that would be ridiculed if explained in everyday language are accepted when presented 'mathematically'; they are then regarded as scientific because they involve 'hard' data. Invoking numbers, statistics and formulae can be more persuasive than well-known authorities, and in the presence of mathematics many of us suspend our disbelief (Willis, 1990:208).

The research on gender and mathematics achievement is a case in point as should become clear in the discussion later in this chapter. When presented with a statistical variable that is statistically significant people are slow to question the importance of the result. If it is significant it must be important. For example, a 1% difference in the achievement of boys and girls on a mathematics test may be statistically significant but is not big enough to explain the myth that girls are not as good as boys at mathematics.

### **Historical perspectives**

Interest in questions about gender differences in mathematical achievement have a long history going back to the nineteenth century and the first wave of feminism. Any questions and answers about girls' achievements in mathematics are intertwined with the gender relations and the cultural, economic and political milieu of the time.

In the 1870s a physiologist at Harvard in the United States asserted that girls could learn algebra but if they did it would harm the development of their reproductive organs. The Board of Education in 1899 in England stated that girls lacked the same capacity for mathematics as boys. However they did not relate this to the fact that girls' schools were not staffed with mathematics or science teachers and that girls were thus not able to demonstrate their potential in these areas (Leder, 1992:598).

Hollway (1994) locates the measurement of sex differences in the psychometric tradition which emerged around the turn of the century. At this time psychology cut itself off from philosophy and underwent a paradigm shift from the experimental laboratory tradition to the use of psychometric methods to

measure 'individual differences'. This was occurring in the same period as the first wave of feminism was challenging the traditional ideas of women's place. Psychology was used to provide scientific evidence of women's differences from men. Of course in the patriarchal context of the time, the differences found supported women's inferiorities except where they could be used to support notions of women's traditional roles as wives and mothers.

Damarin (1995a) points out that both what counts as mathematics and what is acceptable for women to do change over time. In the nineteenth century mathematics was equated with calculation and computation and was not an acceptable activity for women. With the onset of the industrial revolution a need for cheap labour to keep books and therefore do calculations developed. "[S]uddenly, arithmetical competence was no longer beyond the competence of women, nor dangerous for them!" (Damarin, 1995a:251). So while arithmetic became acceptable for women, algebra was not. Today girls' ability in arithmetic is dismissed as a low level skill.

Debates about gender differences in mathematics in the early twentieth century have a striking similarity with current debates. Some attributed gender differences to innate ability (Morrison, 1915 and Thomas, 1915 in Leder, 1992) while others highlighted differences in males' and females' interests and perceptions of the future usefulness of the subject (Armstrong, 1910 and Dean, 1909 in Leder, 1992). In 1910, the feminist writer, Helen Thompson Woolley concluded that the sex difference research in psychology was poorly conceived and carried out, and biased (Hare-Mustin and Marecek, 1994:531). It was by no means clear even then that there were sex differences in achievement. Hacker (1990:140) points out that a report by the US Bureau of Education in 1911 "noted that women were outperforming men in college mathematics." This report went on to suggest "courses that would 'develop that proper sex difference which is so generally recognized' " should be stressed. This proper sex difference was women's inferiority.

Several writers claim that the publication of “The Feminine Mystique” by Betty Friedan in 1963 stimulated further examination of supposed sex differences in mathematics (Friedman, 1994:362). In the 1960s an extensive research literature was developed which was devoted to explaining girls’ supposed poor achievement in mathematics. There was a particular emphasis on psychological explanations which became part of a classic nature/nurture debate. This was fuelled by competing psychological theories about intellectual development, by the re-emergence of feminism and by changing social, political and economic realities (Willis, 1990:192).

In the 1970s there was an explosion in the amount of research on gender differences stimulated by the second wave of feminism (Hyde, 1994:508). Willis (1990:192) claims that at this time the lower achievement and participation of girls came to be seen as a problem not only to girls but to the community as a whole. The question changed from ‘Why can’t girls do as well as boys in mathematics?’ to ‘Why don’t girls do as well as boys in mathematics?’ By the late 1970s the results of extensive studies were suggesting that male superiority in mathematics was not certain. Many earlier studies were shown to contain sampling errors such as not controlling for the number of mathematics courses taken (Willis, 1990:193). Looking at the history of this research suggests to me that gender differences were never clearly established but were assumed right from the beginning and then led to biased and inaccurate research. If girls are never given the opportunity to learn mathematics they can never hope to achieve in the subject!

By the 1980s it was clear that where gender differences in achievement exist, they are very small, are not found consistently across age and ability ranges, and are not consistent for all topics and types of mathematical learning (Willis, 1990:193). Through feminist critiques of sexism in schools gender became conceptualised as an intervening variable. The kinds of questions asked were questions like: Are teachers spending more time with boys? Are textbooks biased against girls? How can mathematics be made more attractive to girls? (Atweh and Cooper, 1995:294). Education came to be theorised as an

institution not only where gender inequalities are reproduced and maintained but where they are produced (Busato et al, 1995:677). Whereas in the 1970s gender was seen as a fixed and independent variable, by the 1990s gender came to be understood as a dependent variable, not a given factor but a social construct shot through with power and value. Researchers began to address questions about how mathematics is constructed in relation to the learner and how the learner is constructed with respect to mathematics (Atweh and Cooper, 1995:294-295).

It is not my intention here to give a prescriptive chronological history of the research on gender differences in mathematics education but to demonstrate that this research is clearly located within the social, economic and political forces of its particular historical moment. Although I have discussed this history in terms of particular time periods I am not claiming disjunctures between one period and another. I am only attempting to highlight trends and tendencies. In any particular time period a variety of different approaches and theoretical underpinnings are at play. What is clear from this history and will become even clearer as the argument continues is that gender differences in mathematical achievement are not and never have been well established by empirical research.

### **The development of Elizabeth Fennema's research**

Two papers by Elizabeth Fennema illustrate my arguments about the historical development of this research (Fennema and Hart, 1994; Fennema, 1995). Elizabeth Fennema is one of the major contributors to this research. In the first paper "Gender and the JRME" co-authored by Laurie Hart, the authors review the history of this journal's publishing record in this area. The Journal for Research in Mathematics Education is one of the premier journals in the field of mathematics education (Fennema and Hart, 1994:657). In the second paper Fennema (1995) reflects on her own changing attitudes, beliefs and concerns about girls and mathematics.

All articles published about gender and mathematics in the *Journal for Research in Mathematics Education* from 1977-1992 have been reviewed by Leder (1992) and Fennema and Hart (1994). They found that approximately 10% of the articles dealt with the topic of gender and mathematics (Fennema and Hart, 1994:649). The articles covered:

the nature and extent of differences in the mathematics achievement of females and males, contributing factors in various areas of mathematics, the roles played by affective and attitudinal factors and school-based variables, the nature and quality of teacher-student interactions, exploration of a possible link between sex-role orientation and mathematics learning, the influence of previous course taking, and differential participation in post-compulsory mathematics courses (Fennema and Hart, 1994:649).

Possible research topics that have not been represented in the journal include: the evaluation of various programs designed to achieve equity, investigations of teachers' or students' cognitions related to gender and mathematics, few qualitative studies and no scholarship from a feminist perspective. There were few exceptions to the use of empirical-scientific-positivist approaches to research (Fennema and Hart, 1994:651-652).

Fennema and Hart (1994:657) call for the publication of more papers taking a feminist perspective and say that such papers "should be actively solicited and published by the JRME". They do not speculate that the reasons why such research has not been published in the past may have been that "[a]rticles of publication quality have not been submitted, reviewers and editors have thought work within certain areas inappropriate for JRME publication, or there just have not been any studies representing the area submitted for review" (Fennema and Hart, 1994:651). They comment that "[a]s far as we have been able to ascertain, there has been little if any bias against publication of submitted articles that dealt with gender, and gender research has occupied a prominent place in the pages of the JRME" (Fennema and Hart, 1994:650). However the lack of evidence of the numbers of and types of papers submitted and rejected for publication, makes it impossible to draw any conclusions about

whether this is actually so. What is interesting is that the journal has been dominated by empirical-scientific-positivist approaches.

Fennema (1995) presented a paper “Mathematics, gender and research” at the International Commission on Mathematics Instruction Study: “Gender and Mathematics Education” held in 1993 in Sweden. In this paper she reflected on her personal commitment to work in this area and how her attitudes and beliefs have changed over time. In 1974 her first article about gender was published (Fennema, 1974). In the course of writing this article she became an active feminist as she was compelled to recognise the biases against females. Her subsequent professional career has been based on the belief that research can facilitate the better learning of mathematics by female students.

Fennema claims that the Fennema-Sherman studies (Fennema and Sherman, 1977; Fennema and Sherman, 1978; Sherman and Fennema, 1977), which looked at sex-related differences in mathematics achievement and related factors, are among the most quoted social science and educational research studies of the last two decades (Fennema and Hart, 1994:650). Walberg and Haertel (1992) identify Fennema and Sherman (1977) as the fifth most cited paper in an educational psychology journal published between 1966-1988. Fennema attributes the impact of these studies not to their innovation or uniqueness. She says they were neither.

However, they were published in highly accessible journals just when the concern with gender and mathematics was growing internationally. Partly because the studies were accessible and not generally controversial and because they employed fairly traditional methodology, their findings have been accepted by the community at large, and many have used them as guidelines for planning interventions and other research (Fennema, 1995:23).

In recent years Fennema has started to question the conceptual basis of her previous research and this has led to her raising different questions. As Fennema has interpreted the questions from a feminist standpoint she has changed her focus from interpreting the problem as a problem with females and

mathematics to looking at how a male view of mathematics has been destructive to both males and females.

I am coming to believe that females have recognized that mathematics as currently taught and learned, restricts their lives rather than enriches them. [W]e should be open to the possibility that we have been so enculturated by the masculine society we live in that our belief about the neutrality of mathematics as a discipline may be wrong, or at the very least incomplete (Fennema, 1995:34).

She says a better set of questions could be

What would a feminist mathematics look like? Is there a female way of thinking about mathematics? Would mathematics education, organized from a feminist perspective, be different from the mathematics education we currently have? (Fennema, 1995:34).

Her changing views are summed up by her:

[T]he decision by females not to learn mathematics nor enter mathematics-related careers because mathematics has not offered them a life they wish to lead is an indication that my old view about learning and teaching mathematics, as well as about gender and mathematics, was immature and incomplete (Fennema, 1995:34).

Fennema's work is thus another path leading into the rhetorical space where it seems sensible to ask the question 'Would mathematics be different if more women were involved?'

### **Curriculum changes**

In this section my aim is to show that regardless of changes in mathematics education, girls' performance is described as lacking. This is because recognition of their performance is related to gender politics in society and because gender inequalities are not only reproduced within education they are produced there. I look at the characteristics of and influences on two major reforms in mathematics education and then relate these to what was being said in the gender and mathematics education research about girls' performance at the corresponding times. The first reform was the introduction of "New Mathematics" in the sixties and the second the "Mathematics as problem

solving” movement (Pitman, 1989:106) which occurred in the eighties in the United States and in the nineties in New Zealand.

Pitman(1989, 102) identifies the characteristics of “New Mathematics” as:

- \* It was international in effect.
- \* The reforms occurred at a time of intense military and scientific competition between the West and the Soviet Union, symbolised by the satellite Sputnik for the United States.
- \* The mathematical content and approach was determined by professional mathematicians. The Bourbakists redefined the nature of mathematics in terms of formalism and this interpretation was mediated by educators who tied this formalist view of mathematics to Piaget’s learning theories.
- \* The discourse of reform was embedded in the language of military power and the struggle between ideologies.
- \* Mathematics was seen as an individualistic enterprise in which individual expertise would serve to maintain military-scientific superiority over the Communist bloc.
- \* The form of mathematical knowledge was strictly formal and based on the axiomatic structures of formal logic (Pitman, 1989:102).

Two characteristics which I wish to emphasise here are the relation between the reforms and the political situation and the emphasis on mathematics as an axiomatic structure of formal logic. Just when it had become well established that girls achieve as well as boys in arithmetic, the emphasis in mathematics education shifted to formal algebraic structures.

The characteristics of the reforms of the 1980s in the U.S. introduced into New Zealand (in the 1990s) through the new curriculum, Mathematics in the New Zealand curriculum (Ministry of Education, 1992:7) are identified by Pitman as:

- \* They are international in effect.

- \* They followed concern that schools were not producing citizens that were able to apply the necessary mathematical skills in the workplace.
- \* The most vocal advocates came from outside the ranks of professional mathematicians.
- \* The discourse was in terms of economic war particularly with Asian countries.
- \* Mathematics was now held to be non-individualistic. Capacity to work in a group was seen as an integral part of doing mathematics.
- \* The focus was on “problem solving” with emphasis on manipulating data to reach reasonable solutions (Pitman, 1989:101-102).

Once again the political situation has influenced the reforms and the definition of mathematics upon which the reforms are based. This time there is a shift from power politics based on military supremacy to power based on economic success. The aim is to assist in the development of more efficient national economies rather than demonstrate the superiority of a political ideology or military power. New technologies and forms of work influenced the desirability of a problem solving emphasis (Pitman, 1989:116). Now that problem solving is the most prized aspect of mathematics education we find that it has become well established that girls achieve as well as boys in arithmetic *and* in algebra *and* formal logic but their area of supposed weakness is in problem solving skills. These skills are coincidentally identified as higher order skills.

The new mathematics curriculum in New Zealand outlined in the document “Mathematics in the New Zealand curriculum” was introduced in 1992. It reflects the characteristics outlined above by Pitman. In the introduction a particular view of mathematics is presented:

Mathematics is a coherent, consistent, and growing body of concepts which makes use of specific language and skills to model, analyse, and interpret the world. Mathematics provides a means of communication which is powerful, concise, and unambiguous. (Ministry of Education, 1992:7).

I will be taking issue with some aspects of this description in various places throughout this thesis. What I particularly dispute is the view of mathematics as a coherent body of knowledge that is unambiguous. There are enough disputes and contestations as to what is or is not mathematics to invalidate the claim that mathematics is coherent and unambiguous. (See Chapter 6) It is unfortunate that this view of mathematics will continue to be passed on to new generations of mathematics students.

The following extracts from the introduction are relevant to the points made by Pitman:

In an increasingly technological age, the need for innovation, and *problem-solving*<sup>1</sup> and decision making skills, has been stressed in many reports on the necessary outcomes for education in New Zealand. Mathematics education provides the opportunity for students to develop these skills, and encourages them to become innovative and flexible problem solvers.

The ability to communicate findings and explanations, and the ability to work satisfactorily in team projects, have also been highlighted as important outcomes for education. Mathematics education provides many opportunities for students to develop *communication* skills and to participate in collaborative problem-solving situations thereby contributing to the development of many *social and co-operative* skills (Ministry of Education, 1992:7).

This New Zealand curriculum emphasises the same characteristics identified by Pitman, that is problem solving, team work and collaboration, and data handling skills.

As different mathematical skills are valued, girls are found to lack them and the skills that it has been established girls are proficient in are devalued.

<sup>1</sup> Italics as in the original.

## **Should we study sex differences?**

The study of sex differences may well act against women and further consolidate existing categories and prejudices rather than having the emancipatory results we are hoping for. I am using the term sex difference interchangeably with gender difference because these terms are used uncritically in the literature. This use does not imply a disregard for the feminist theoretical developments made around the concepts of gender and sex.

Damarin (1995:251) points out that “even the continued study of women and mathematics (and the publicity that surrounds it) reminds women that their mathematical ability is a question worthy of scientific study.” It reminds everybody including students, their teachers, their parents and all those who make up the education system that girls’ and women’s achievements are questionable. There is evidence to show that after the publication of the results of such research the expectations by parents of their daughters’ potential for success can fall rather than rise. Jacobs and Eccles (1985 in Hyde, 1994) interviewed mothers before and after media coverage of a study which supposedly showed gender differences in mathematically precocious seventh graders in the US. Mothers gave lower estimates of their daughters’ ability after they had heard the media coverage than they had given previously.

Discussions of whether we should study sex differences fall into three broad categories all of which are relevant to the question of sex differences in mathematics achievement. The first feminist empiricist approach argues that we should study differences but we should do it better according to feminist guidelines. The second approach is a social constructionist approach in which gender is theorised as socially constructed and not a biological given. Questions are asked prior to undertaking such research about the purposes and uses of the research and how gender is constructed in these discourses. Those committed to the third position, a post structuralist account, argue that rather than looking at gender or sex differences we should look at how these discourses and the

discourses produced within or by such research produce and reproduce women's difference as inferior.

Both Hyde (1994:507-508) and Eagly (1994:518) use feminist empiricist arguments to support their views. They argue that questions about sex or gender differences will be asked regardless of whether feminists are involved. Feminists should be involved in order to ensure that the research is based on better science and is used for women rather than against them.

Hyde (1994:508-509) identifies a number of problems with this kind of research:

- \* Publication bias: only research that finds differences is published. A general impression develops that there are many gender differences and few similarities.
- \* The proliferation of unreplicated findings: when one study reports a difference which is not supported in further studies, the original study retains authority because the contradictory evidence is not reported.
- \* The failure to report effect sizes: tiny gender differences are given more attention than they merit.
- \* Gender differences are often interpreted as indicating female deficits.
- \* The findings may be used against women, for example leading to girls being discouraged from studying mathematics
- \* Often gender differences are attributed to biological factors even though no biological data was collected in the study.

Eagly (1994:519), in supporting research on sex differences, argues that the most important outcome of this research is the interpretation given to the results.

Feminist theoretical positions would only be weakened by constraints on the reporting of comparisons between the sexes, because it is the rich diversity of findings that allows compelling arguments to be made for these theories.

Halpern (1994:524) also supports this research. She claims:

Stereotypes about women and men existed long before psychologists applied their research skills to understanding the unique and shared aspects of group membership. Empirical research doesn't create stereotyping, as its critics imply; the systematic study of sex differences using scientific rules of evidence is the only way to dispel stereotypes and to understand legitimate differences.

What Halpern fails to take into account are the criticisms made by feminists and others about the so-called objectivity of scientific research. This research has not been successful in dispelling gender stereotypes despite the evidence they provide. The research on differences in mathematics achievement is an excellent example of this. Despite overwhelming evidence against gender differences in achievement in mathematics, the same questions are asked over and over again, always with the assumption that differences will be found. If the stereotype was going to be dismissed by the results of empirical research surely people would have moved on to more important issues by now. A problem with any area of research is that people build their publishing records and careers upon it and cannot afford to step aside from the sometimes enormous intellectual and emotional commitment they have made. They are also likely to be supervising postgraduate research in the area and thus introducing new generations of scholars to the field who in turn become committed to carrying on the tradition.

Hare-Mustin and Marecek (1994:531-535) take a different view of the study of sex differences. They take the position that, historically, such research has "been used to argue women's inferiority, to limit their spheres of action, and to restrict their autonomy and freedom of movement." They say that the "implicit question was whether women are the same as, different from, or even as good as men" which means that men are the norm against which women are judged. They examine what meanings and interpretations are being constructed within these debates. Sex difference research reaffirms an essentialist model of gender which locates gender within the person and portrays it in terms of stable inner qualities. It presupposes there is a category 'woman' and highlights the ways in which women differ from men while overlooking the differences between women. In this research gender is made to seem natural and the practices which

produce gender are rendered invisible. While Hare-Mustin and Marecek agree with the goal of combating gender stereotypes they see this research as having other political consequences including diverting the energies of feminists away from issues of their own choosing. This is well illustrated in the gender and mathematics literature in which there are vast amounts of energy and resources expended on establishing differences but disproportionately little expended on the development and evaluation of interventions to improve the performance, participation or enjoyment of girls and women.

There is another problem in that this research is descriptive but develops 'prescriptive force' by proclaiming what men and women are and so what they ought to be. This is a dilemma I am exploring in my research on women mathematicians. If women are not as good as men at mathematics, the assumption is made that no women are good at mathematics. With this 'prescriptive force' in place how do we explain the women who are successful in mathematics? Are they real women? If they are not, what are they?

On the one hand some for example Hyde, Eagly, and Halpern, argue that we should not leave this area clear for non-feminists, while Hare-Mustin and Marecek (1994) argue that participating prolongs the agony. Rather than seeing sex difference research as "a record of cumulative knowledge about the 'truth' of what men and women are 'really' like", Hare-Mustin and Marecek see it as "a repository of accounts of gender organized within particular assumptive frameworks and reflecting various interests." They cannot imagine ways to reform this research because they see it as asking the 'wrong question' in the first place. Instead they "urge the study of ongoing relations of privilege, power, subordination and rebellion among individuals provisionally demarcated by their gender, class membership, race/ethnicity and sexual orientation."

In addressing the question of whether we should study sex differences Hollway's (1994, 538-544) answer is an emphatic 'no'. According to Hollway, what we should study are the "differences and similarities between and among women and men." She explains the study of sex differences as caught up in

power-knowledge-practice relations which produce knowledge that legitimises and reproduces women's subordination. Feminist social psychology has remained trapped within two dualisms: sex versus gender and similarities versus differences. She argues that "it is possible to transcend this dualism with an account of the psychodynamics which are continuously flowing between people in power relations and which reproduce or challenge gender-differentiated positions in discourses and practices." She says that feminist psychology has "attempted to challenge discourses that produce and reproduce women's difference as inferior" but now it is time to analyse the reach of this concept of differences and to ensure that gender differences are not, like sex differences, conflated with the categories 'women' and 'men'. We should be problematising simple boundaries around the categories 'women' and 'men' and seeking to understand differences among women and similarities between women and men without falling into the old universalisms of 'human being'.

The history of the study of sex differences tells a contradictory story in which the prior commitments of the researchers have influenced the questions asked, and kinds of evidence accepted, in answering the questions. The research has been used to counter feminist moves by trying to establish women's inferiority while at the same time feminists have used it to prove women's capabilities and thus argue against their exclusion. The answer then to the question of whether we should study sex differences cannot be satisfactorily resolved by adopting one of the positions outlined to the exclusion of the others. The resolution can only be in choosing that position which is appropriate to the situation one finds oneself in.

Should we study gender differences in mathematics? If feminists had never been involved in this research it is very likely that the assumption that men are better than women at mathematics would never have been questioned and this assumption would continue to be asserted even more loudly and regularly than it is today. As a result of feminist work in this area we can state quite clearly that girls do at least as well as boys in mathematics when like is compared with like. Gilah Leder (1995:195) argues that we need to continue to monitor the

situation and she is probably right as we continue to be vulnerable to 'backlash'. However we should be wary of diverting too many resources and too much energy into addressing these questions when there are more pressing concerns. The potential of this descriptive research to become prescriptive and the role that it has in producing discourses of gender is a concern. This is particularly so within a political context in which the aim is to increase the participation of girls and women in all aspects of mathematics and its creation - the pleasures of mathematics, access to the power of mathematics and mathematical thinking, and access to mathematically related careers.

Statements about girls and mathematics in the New Zealand curriculum demonstrate how the research results can be of mixed benefit to girls. Of interest here are the statements and assumptions about girls and their relationship to mathematics and mathematics education. The following paragraphs are taken from the section entitled "Catering for individual needs"<sup>2</sup> in the document "Mathematics in the New Zealand curriculum" (Ministry of Education, 1992:12-13):

In many cases in the past, students have failed to reach their potential because they have not seen the applicability of mathematics to their lives and because they were not encouraged to connect new mathematical concepts and skills to experiences, knowledge, and skills which they already had. This has been particularly true for many girls, and for Maori students, for whom the contexts in which mathematics was presented were irrelevant and inappropriate. These students have developed deeply entrenched negative attitudes towards mathematics as a result.

An awareness of this has led to improved access for girls to mathematics, but the participation rate of female students in mathematics continues to be lower than that of male students at senior school and beyond. This limits later opportunities for girls and women.

The suggested learning experiences in this document include strategies that utilise the strengths and interests that girls bring to mathematics.

<sup>2</sup> This section included one paragraph on children with special learning needs and two on Maori students.

Techniques that help to involve girls actively in the subject include setting mathematics in relevant social contexts, assigning co-operative learning tasks, and providing opportunities for extended investigations.

The suggestions also describe experiences which will help girls develop greater confidence in their mathematical ability. Girls' early success in routine mathematical operations needs to be accompanied by experiences which will help them develop confidence in the skills that are essential in other areas of mathematics. Girls need to be encouraged to participate in mathematical activities involving, for example, estimation, construction, and problems where there are any number of methods and where there is no obvious "right answer".

The development of more positive attitudes to mathematics and a greater appreciation of its usefulness is the key to improving participation rates for all students.

A close reading of this text reveals some interesting underlying assumptions. This text comes from a section headed "Catering for individual needs"<sup>1</sup> but girls are treated as one undifferentiated group. No recognition is given to differences between girls or similarities between girls and boys. It is girls who have and are the problem. "[T]hey have not seen the applicability of mathematics to their lives". Their lack of confidence is a problem: "experiences which will help girls develop greater confidence in their mathematical ability". There is scant recognition given to the role others may have had in 'the problem'. The solution lies in the students, not in the teachers, gendered discourses, discriminatory practices or educational or societal structures. "The development of more positive attitudes to mathematics and a greater appreciation of its usefulness is the key to improving participation rates for all students."

Where girls are acknowledged to be successful, their success is dismissed as routine: "Girls' early success in routine mathematical operations". The statement about where girls need to be encouraged also signals an assumption about a lack in girls: "Girls need to be encouraged to participate in mathematical activities involving, for example, estimation, construction, and problems where there are any number of methods and where there is no obvious 'right answer'." Girls' confidence is also problematised outside of any

context in which the gendered nature of the construct 'confidence' is discussed.: "help girls develop greater confidence in their mathematical ability". This text is based on an unspoken and unacknowledged concept of girls as lacking.

Another assumption, one that is probably particularly ill founded in my opinion and experience, and one not especially related to gender or ethnicity, is the assumption that the mathematics children are taught in schools can be and is related to their own experiences.

Any reader familiar with research on gender and mathematics education could see that this part of the document draws on the results published in this research literature. The writers have gone beyond their own assumptions and experiences but at the same time it highlights the limitations of this literature and the dangers for all students in its conceptualisations and conclusions.

### **The research literature**

There is a huge literature covering the results of research in gender differences in mathematics education and on 'the problem' of girls and mathematics. It is not my intention to cover this whole literature in any detail in this chapter as this lengthy task is outside the purpose of the principal arguments in my thesis. I have included a bibliography of the literature in Appendix 5. Even this bibliography is not completely comprehensive as it only includes easily accessible recent publications.

I present a summary of the results found so far and a critique of the assumptions upon which much of this research is based. It is my contention that in much of this work girls are constructed as lacking or deficient in terms of an unproblematised male norm. The construction of mathematics as value and culture free is also unproblematised. Fortunately the unexpected and contradictory results found in this research have forced a problematising of these implicit assumptions.

### Who do better - boys or girls?

Given the time, energy and resources that have gone into exploring questions about gender differences in achievement and performance in mathematics one would expect to find big differences in achievement. This is not the case. I am making the assumption that to ascribe a difference to gender implies that it cannot be ascribed to other known causes. For example if people who take more mathematics courses get better results and it so happens that boys take more mathematics courses, then I would say that it is not a difference in the abilities of the genders that causes the difference. It is caused by differential course taking. This assumption is not shared by all researchers in this area.

In a meta-analysis of 100 studies of the achievement of girls and boys published since 1963, Hyde, Fennema and Lamon (1990) found the following results. When studies of the general population were included they found a superiority in female performance of negligible magnitude. They found effect sizes yielded a mean of  $d = -0.05$ . When selective samples of high and low achievers were included males outperformed females by a small amount. The effect sizes yielded a mean of  $d = 0.15$ . Of the effect sizes 51% were positive reflecting superior male performance, 6% were exactly zero, and 43% were negative, reflecting superior female performance. There is a slight female superiority in computation  $d = -0.14$ , no gender difference in understanding of concepts  $d = -0.03$ , and a slight male superiority in problem solving  $d = 0.08$ . There was a small female superiority in the elementary and middle school years and a bigger male superiority in the high school and college years but this was based on relatively few effect sizes (Hyde, Fennema and Lamon, 1990:146-147). When  $d = -0.05$  the size of the differences is about 3% that is 51.5% of females and 48.5% of males score above the mean for the general population (Hyde, Fennema and Lamon, 1990:150-151).

According to Leder (1992:607-608), whether or not gender differences in achievement are found depends on: the content and format of the test administered, the age level at which testing takes place, whether classroom grades or standardised tests are use, the cognitive level of the test and the

achievement level of the students. Some argue that the performance gap is narrowing over the years. In international studies and comparisons, although there are gender differences, girls in some countries perform better than boys in others.

Kimball (1989:198-199) points out that sex differences can be different for different teachers and schools. She also provides evidence that sex related differences based on grades or marks given by class teachers almost always favour girls, and are consistent across samples.

Differences in course selection account for at least some of the gender differences in performance in high school and college years (Kimball, 1989). This can be seen in the case of New Zealand students. In the last year of high school most students sit an examination commonly called 'Bursary'. At this stage mathematics is no longer a compulsory subject. Two mathematics options are offered, Mathematics with Calculus and Mathematics with Statistics. There is some overlap between the two. Some students take both mathematics subjects and some only one. The examinations are based on a national curriculum so all students should have been exposed to the same mathematics regardless of school or location. Results from these examinations have been used to examine gender differences in achievement. Initially Morton et al (1989) concluded that boys had done better than girls in Bursary Mathematics with Calculus in 1988. However, when they re-examined the results to compare girls and boys who had done Mathematics with Calculus and Mathematics with Statistics with each other and boys and girls who had only done Mathematics with Calculus with each other, the gender differences disappeared (Morton et al, 1991). The 1988 results for Mathematics with Statistics showed a mean mark of 51.1% for boys and 47.0% for girls. The corresponding figures for students who only took Mathematics with Statistics were 36.9% for boys and 37.7% for girls. The means for those taking two mathematics papers were 59.0% for boys and 58.3% for girls.

No matter how the data is analysed, and what levels of significance are found in the data, these differences are too small to warrant any claims that girls' achievement in

mathematics is a problem compared to the boys'. Participation rates are another question. The magnitude of any differences in achievement are insufficient to explain differences in participation (Hyde et al, 1990). As soon as mathematics becomes an optional subject girls are more likely than boys to opt out (Leder, 1990b; Willis, 1990). In New Zealand Bursary examinations in 1990, 3775 boys and 3137 girls took one or two mathematics subjects (Morton et al, 1991). Even when they have achieved well in mathematics and science at high school or undergraduate level, girls are less likely to go on to mathematics related careers or postgraduate study in mathematics (Dick and Rallis, 1991; Purser and Wily, 1990).

Extensive research has been done on the causes of gender differences in participation and achievement. Much of this has focused on girls and their attitudes and behaviours, teacher attitudes and behaviours and socialization processes. I have listed the topics addressed here because I am attempting to show that a very large number of factors have been hypothesised and investigated in attempts to answer questions about girls' achievement and participation. I am not claiming that all these factors do have an influence and I will go on to criticise the assumptions upon which many of these investigations are based.

### **Girls' attitudes and behaviours**

Confidence, perceptions of the usefulness of mathematics, sex-role congruency of mathematics, fear of success, attributional style, learned helplessness, persistence, independence, low career aspirations, autonomous learning behaviour, spatial visualisation, expectancy for success, the student's perceptions of these attitudes and expectations, the student's goals and general self-schemata or self-image, achievement behaviours, task-specific beliefs, past events as well as their interpretations, the different aptitudes of the student, spatial abilities, number of maths courses taken, girls' greater dependence, good behaviour and teacher orientation, attributions of success and failure, and internal belief systems have all been examined (Armstrong and Price, 1982; Battista, 1990; Fennema et al, 1990; Hanna et al, 1990; Kimball, 1989; Leder, 1982; Leder, 1986; Leder, 1990b; Leder, 1992; Meyer and Koehler, 1990; Reyes and Stanic, 1988).

### **Teacher attitudes and behaviours**

Differential treatment and interactions favouring boys, girls with high ability being less likely to be assigned to high ability group by teacher, stereotyping of mathematics as a male domain by the teacher, teacher expectations, mathematics curricula and activities offered, teacher's attributional style, cultural content of curriculum, gender biased texts and worksheets, modes of teaching employed - competitive vs. co-operative, female role models, overt sexist beliefs and behaviours, less encouragement and reinforcement to work independently and persistently given to females than males, teachers' explanations of the successes and failures of their male and female students, girls expectancies were higher when they achieved equal teacher attention, and scheduling problems have all been considered (Armstrong and Price, 1982; Ernest, 1991; Fennema, 1990; Fennema and Peterson, 1985; Fennema et al, 1990; Kimball, 1989; Koehler, 1990; Leder, 1990a; Leder, 1990c; Leder, 1992; Reyes and Stanic, 1988).

### **Socialisation processes**

Sexist beliefs and behaviours, cultural domination of masculine values, encouragement of parents, teachers, counsellors, coercive inducements, male image of mathematics, parents encourage sons more, focused and diffuse worlds of men and women, media reports about gender differences, socio-economic status and ethnicity have all been considered (Armstrong and Price, 1982; Burton, 1988; Eccles, 1985; Ernest, 1991; Isaacson, 1988; Kimball, 1989; Leder, 1986; Leder, 1992; Maines, 1985; Walkerdine, 1989).

### **School variables**

Gender segregated education, timetabling of courses, choice of curriculum, text book selection and content, availability of equipment, methods of assessment, counsellor's advice, administrators' implementation of instructional policies, students' own perception of learning climate have all been considered (Leder, 1992).

### Peer group

The following have all been considered: mathematics perceived as a male domain, differences in leisure time activities and attitudes to mathematics, career expectations, disapproval by peer group for contravening prevailing mores, males believed more strongly that maths is a male domain, girls do not receive as much information from their peers particularly boys when working in small groups (Kimball, 1989; Leder, 1992).

My point in providing these lists is that the large number of hypotheses is disproportional to the size of the problem and leads me to wonder whether we want there to be a problem and why that might be so? Why are we so unwilling to accept that girls do not have a problem with achievement in mathematics?

The following pairs of quotes illustrate some of the contradictions and ambiguities found in publications of this research. Each pair is taken from the same paper.

Leder (1992) first states that there are differences:

While generally there is much overlap in the mathematical performance of females and males, where they occur, *significant differences in performance tend to favour males*<sup>3</sup>, particularly on higher cognitive level questions (Leder, 1992:608).

Then she describes them as 'small':

When *gender differences are found they are typically small*. Nevertheless, they indicate the extent to which students' own beliefs, expectations, and achievement behaviours reflect those of the wider society (Leder, 1992:616).

The use of the term 'significant' is crucial in creating and understanding the ambiguity presented in these quotes. As I will discuss in the next section there is confusion between the meanings of 'statistical significance' and 'importance'.

<sup>3</sup> My italics.

Blithe et al (1994) provide another pair. The first quote is taken from the abstract:

An examination of gender differences in these papers (Bursary exams) over several years shows *a consistent difference in mean performance in favour of boys* (Blithe et al, 1994:427).

This sentence clearly states that a sex difference was found. The second quote contradicts the first statement:

Overall, the mean performance of secondary school boys in final year examinations is higher than girls, but when the amount of mathematics studied is controlled for, *gender differences disappear* (Blithe et al, 1994:437).

These two statements taken from the same paper by each author(s) demonstrate the ambiguous way in which such results are presented. In both cases the authors contradict themselves. In one statement they say the differences are 'non existent' or 'small' and in the other they are 'significant' or 'consistent'. Of course this contradiction can be partly explained by the ambiguity of the results found but they also indicate an unwillingness to let go of the assumption that boys do better. "Most studies work from the premise that girls *are* worse at Mathematics and then attempt to explain this by global generalisations about females" (Walkerdine, 1989:8). These contradictory statements have greater ramifications when the results are being quoted by someone else as a basis for their own research questions. The qualifications and ambiguities accompanying statements in the original publication are often lost when they are cited by subsequent researchers. What began as a tentative conclusion can quickly become solidified as 'fact' through subsequent publication and citation practices.

### **Critiques of the research**

It would be too time consuming and not particularly relevant to critique each theoretical construct developed to explain the mathematical achievement of boys and girls and their differential participation in advanced mathematics

courses and mathematical careers. I will just look more closely at a few particular issues that lead on to the more relevant critique of how girls, gender and mathematics are constructed in these debates.

Sex differences grab media attention where similarities do not. I have previously pointed out that this same preference can be found in the research literature as publishing practices favour the publication of differences. A study that finds that there were no statistically significant differences is treated as if it found nothing. No difference is a non-result (Walkerdine, 1989:13). It is therefore less likely to be published (Hyde, 1994:508-509). Kimball (1989:199) suggests that the decrease in differences now being reported may reflect a change in publication policies rather than a change in the differences found. More research finding non- differences may be published as a result of policy changes.

Another area of concern is the use of the term 'significant' as mentioned above. As Walkerdine (1989:13-14) pointed out, the meaning of the term 'statistically significant' is often confused with 'importance'. A result that is 'statistically significant' indicates that it is unlikely, with varying degrees of certainty, to have occurred by chance and is therefore likely to be found in the general population from which the sample was drawn. This is not the same as saying that the result was important. Because there is a close link between sample size and statistical power, large surveys can lead to trivially small differences being highly significant statistically (Walkerdine, 1989:14). A difference of 1-3% in the results of boys and girls as has been reported here by Hyde et al (1990) and Blithe et al (1994) is not necessarily an indication of a serious problem. The difference is certainly not large enough to explain the disparity in numbers studying mathematics at higher levels and pursuing mathematical careers.

The third area of concern is the uncritical use of constructs to explain gendered behaviours and results. Constructs such as 'confidence', 'maths anxiety' and 'autonomous learning behaviours' are taken as neutral in relation to gender. The meaning of confidence and anxiety and the consequences of exhibiting

these behaviours have gendered consequences. There are constraints on how girls may demonstrate confidence that are not the same for boys, just as there are constraints on how boys may exhibit anxiety. These are not gender neutral constructs and they cannot be separated from complex social processes involving how we come to think about masculinity and femininity (Walkerdine, 1989:9).

The lack of attention given to the effects of peers' attitudes to girls' participation is a surprising aspect of the research. The behaviour and attitudes of teachers have received close scrutiny but for teenagers the attitudes of their peers would seem to be of particular importance particularly as it is in teenagers that any gender differences are first found. This omission is particularly strange given that the one gender difference that is consistently found across studies is that boys are more likely to perceive mathematics as a male domain than girls. Do boys communicate this attitude to girls at a time when girls are particularly vulnerable to the opinions of their male peers? Is this attitudinal difference likely to discourage girls' participation in mathematics? What are the implications for the future of girls' participation if boys continue to hold these attitudes?

### **The construction of girls, boys, and gender in this literature**

Most of the research in this area is an attempt to either prove what it is that girls lack so that it can be put right or to demonstrate that there is no lack at all.. This is a trap in which girls remain the problem. They have something wrong with them, while boys continue to be taken as the norm. To avoid falling into this trap we need to ask what assumptions lie behind these questions and why they are asked in these particular ways (Walkerdine, 1989:1-2). We also need to consider the consequences of asking these questions and the answers we accept.

Most empirical quantitative research in this area is based on a conceptualisation of gender as either a fixed independent variable or as an intervening variable. Taking gender as an independent variable leads to the asking of questions about

the effect of gender on attitudes, achievement or participation in mathematics (Atweh and Cooper, 1995:294). The conceptualising of gender as an intervening variable provides the basis for research such as whether teachers interact with boys and girls in different ways or whether text books may have a sexist bias. Feminist critiques and analyses of sexism have been the most important source of this kind of research (Atweh and Cooper, 1995:294-295).

These conceptualisations of gender can lead to a victim blaming approach where girls come to be seen as responsible for their own problems. It is girls who have to change (Campbell, 1995:225). These approaches focus on a liberal discourse of education in which education and the curriculum is supposedly accessible to all students or at least to all those with sufficient ability or industry. These students can take advantage of these supposedly equal opportunities. This approach disguises the ways in which social disadvantage is constructed within the education system, the curriculum and the construction of 'intelligence' and 'natural ability' (Zevenbergen, 1994). The behaviours of successful male students are identified in order that girls may be taught, encouraged or forced to adopt them. These strategies will ultimately not be very successful. Changing girls and putting them back into the same environment and situations in which they were not achieving or choosing to do mathematics will lead to them reverting back to their previous behaviours, attitudes and choices (Campbell, 1995:226). What is not studied and needs to be more frequently and deeply is the nature and meaning of the behaviour of girls in their mathematical education (Damarin, 1995a:246).

In this section I am more interested in looking at the question from a poststructuralist position in which gender is taken as a dependent variable. This leads to asking questions about how 'gender' and 'the female student' are constructed through the discourses and practices of mathematics, mathematics education and this research literature. These questions "are intrinsically related to issues of power and value" (Atweh and Cooper, 1995:295-297). Other related questions concern what counts as mathematical knowledge and ability and who is excluded by these definitions. These approaches "shift the problem

from girls to mathematics and ultimately to the practices of society itself” (Atweh and Cooper, 1995:295-297).

Women and girls experience mathematics as an area of competing discourses. “Simultaneously they are told that it is important to learn mathematics and that it is not important (for girls and women ) to learn mathematics”. Our society is permeated with the message that mathematics is male so that no matter how mathematically competent women become they cannot escape the reification of mathematics as a male domain. Their continued participation requires them to continually reject and resist the message that they are operating outside their ‘feminine’ domain (Damarin, 1995a:250). Not only must they resist this message but also their competence is continually questioned.

There is a persistent finding in the research literature that girls excel at computational skills and boys at problem solving skills but these findings are interpreted to girls’ disadvantage. Problem solving in which boys are said to excel is described as ‘higher level’ and calculation as ‘lower level.’ This “is consistent with the general tendency to describe all female behavior as less competent than male behavior” (Damarin, 1995a:246).

The discussion of excerpts from the New Zealand curriculum statement earlier in this chapter illustrates these points.

This distinction between doing well at computation and doing well at problem solving is used to explain girls’ supposed poor performance compared to boys’. “Girls are still considered lacking when they perform well and boys are still taken to possess something when they perform poorly” (Walkerdine, 1989:4). However the same body of research that shows that girls do better at one and boys at the other also shows that the differences between girls’ and boys’ achievement are very small and at younger age groups favours girls. Saying that girls do better at computation comes to be equated with saying that girls do poorly at other aspects of mathematics even though the evidence does not support this. Although boys may do *slightly better* at something, some girls just like some boys are doing very well indeed. Many of these conclusions are based

on average results and so the subsequent analysis is subject to what (Linn, 1994) calls 'the tyranny of the mean'. There are large numbers of girls and boys who are achieving standards much higher than the mean. Knowing the mean for a sample does not enable us to predict the results for any individual child. We certainly do not have the evidence to predict that any particular girl will achieve less than any particular boy. All girls do not achieve less (or more) than all boys.

Walkerdine (1989:204-207) locates stories about girls' failure "within a set of scientific strategies for producing the modern order and the idea of the rational unitary subject: the individual". This modern order is founded upon ideas of reason and rationality which exclude women and girls. Walkerdine argues that rational discourse is produced out of a need for control and power over nature and the universe and that mathematics, as higher order reason and logic, is part of the mechanism of control. While calculation is held to be low level mathematics, higher status is given to mathematics that is separate from meaning and referents and which is thought therefore to be universal and applicable to anything (Walkerdine, 1989:72-73). Girls do well in calculation and mathematics at school and women's traditional work in the home and as secretaries, nurses and teachers, involves considerable calculation (Walkerdine, 1989:198) but we continue to question their achievement. Even when we find that girls are successful we still continue to describe their performance as a lack. Boys are described as having 'flair' and 'brilliance' where girls are dismissed as being 'well-behaved' and 'hard working' (Walkerdine, 1989:203). Some forms of mathematics are privileged over others<sup>4</sup> and this dismissal of female achievement is an aspect of this.

The position of girls within mathematics education is intimately linked with what we believe mathematics to be and what 'truth' and power we assign to it.

<sup>4</sup> This will be discussed further in Chapter 6.

## Philosophy of mathematics in education

The philosophy of mathematics that informs the education system will have a large part to play in the views of mathematics developed by the students; in how they experience and come to know mathematics; and in what opinions and feelings they develop about it. These questions are examined here in relation to how gender interacts with these to affect the relationships between the gendered learner and mathematics and how mathematics itself becomes gendered.

Absolutist philosophies of mathematics<sup>5</sup> are not concerned with describing mathematics or mathematical knowledge but “with the epistemological project of providing rigorous systems to warrant mathematical knowledge absolutely” (Ernest, 1995:450). According to these philosophies mathematical knowledge is timeless, superhuman and ahistorical. It is pure isolated knowledge with universal validity and is value and culture free. If philosophers, mathematicians and teachers view their subject like this they communicate it to their students by giving students mainly unrelated routine tasks which involve the application of learnt procedures. It is stressed that every task has a unique, fixed and objectively right answer and this is coupled with disapproval and criticism of any failure to get this answer (Ernest, 1995:451). This view of mathematics as difficult, cold, abstract, ultra-rational, and important is also associated with stereotypical views of masculinity. Such a philosophy of mathematics and subsequent teaching practices “offers access most easily to those who feel a sense of ownership of mathematics, of the associated values of western culture and of the educational system in general. These favour males, the middle classes and white ethnic majorities” (Ernest, 1995:454). I need to clarify here that what I am talking about is a stereotype or hegemonic ideology of masculinity and femininity and does not represent an essential reality of

<sup>5</sup> A brief explanation of these philosophies can be found in Chapter 6.

masculinity or femininity<sup>6</sup>. Masculinity has come to be associated with separated values and femininity with connected values but that is not to say that all men are one way all the time and that all women are the other. There is a great deal of overlap and intersection within and between genders and a particular individual may hold a range of seemingly contradictory values and views at any one moment or across time.

However the association of mathematics, and the values outlined here with masculinity presents a dilemma for female students as conforming to mathematical standards conflicts with the standards of femininity. Women must choose to be feminine or successful at mathematics or to live with the contradiction (Ernest, 1995:456).

At the same time as this absolutist image of mathematics presents a problem to some groups of students and individuals, this is precisely what attracts other people to it. “[M]any mathematicians love mathematics just for its absolutist features” (Ernest, 1995:456-7). Others would not recognise these descriptions as the mathematics they know and practice (Ernest, 1995:451).

Nancy Shelly (1989:5) argues that thinking of mathematics as an unchangeable subject, a system which is closed and static means mathematics learning is translated into absorbing as much of the system as possible and becoming a skilled operator. Creative thinking is seen as inapplicable. Mathematics belongs to other peoples’ knowledge, and as such, confers only power of a manipulative kind on those who learn it. The learning process is reduced to memorising and the basis of knowing mathematics is embedded in insecurity because it is grounded in someone else’s experience and not one’s own.

Shelly (1989:5) wants to “move the emphasis away from content and algorithms toward ways of thinking which require decision making and judgement and are linked with the exploration of ideas. This is alive, vibrant,

<sup>6</sup> I am not intending to assume there is such an essence.

powerful.” This move is more consistent with a fallibilist philosophy of mathematics in which the human side of mathematics is emphasised (Ernest, 1995:452).

[Fallibilism] claims instead that mathematics has both a front and a back. In the front, the public are served perfect mathematical dishes, like in a gourmet restaurant. Here the impression of absolute mathematics is preserved, but in the back, mathematicians cook up new knowledge amid mess, chaos and all the inescapably associated features of human striving. Fallibilism admits both of these realms: the processes *and* the products of mathematics need to be considered an essential part of the discipline (Ernest, 1995:452).

Such a philosophy of mathematics and mathematics education could support different approaches to the teaching of mathematics in which humans discover mathematics through a variety of means (Ernest, 1995:453). In this approach the learner is privileged as the constructor of their own mathematical meanings and understandings arising out of the interplay of their own life experiences and skills and the mathematics they learn in school.

Exposing students to the back, messy side of mathematics should theoretically mean that mathematics would be more accessible to girls and others outside the privileged group of white middle class males. The New Zealand curriculum seems to take the opposite view:

*Girls' early success in routine mathematical operations* needs to be accompanied by experiences which will help them develop confidence in the skills that are essential in other areas of mathematics. *Girls need to be encouraged to participate* in mathematical activities involving, for example, estimation, construction, and problems *where there are any number of methods and where there is no obvious "right answer"*<sup>7</sup> (Ministry of Education, 1992:12-13).

This statement contradicts what others are claiming should be a view more consistent with our stereotypes about girls, femininity and their learning. This

<sup>7</sup> My italics.

contradiction arises from the construction of girls as inferior in *any* discourse about gender and mathematics education.

## **Conclusions**

Despite the best emancipatory intentions of many of the researchers in this area, research on gender and mathematics education has not achieved the results hoped for. Questions about gender differences in achievement continue to be asked time and time again despite the evidence that any differences are not important. When differences are found they certainly do not explain the lower participation rates of girls and women in higher mathematics education and mathematics related careers. I have argued here that this is at least partly caused by the intimate linking of our understandings of femininity and masculinity and mathematics. This linking of mathematics with discourses of gender leads to an opening up of the rhetorical space to ask questions about whether mathematics might be different if more women were involved. The implications of these questions for mathematics and epistemologies for mathematics are taken up and discussed at length in later chapters.

# Chapter 5

## The Feminist Science Debates

### Introduction

In the previous chapter I discussed feminist critiques and analyses of gender mathematics and education. Similar work has been done in science but the analysis has extended beyond education to include all aspects of science and the work of scientists. In this chapter I use this analysis of science to create the rhetorical space in which to ask similar questions about mathematics. I am particularly interested in how mathematics, its practices, knowledges and epistemology are influenced by the male gendered traditions of mathematics.

In *Whose Science? Whose Knowledge?* Harding (1991:21) identifies five areas of analysis that have been developed in feminist inquiries into the sciences and their technologies:

the analyses of women's situation in science, the sexist misuses and abuse of the sciences and their technologies, sexist and androcentric bias in the results of biological and social science research, the sexual meanings of nature and inquiry, and androcentric theories of scientific knowledge.

In this chapter I focus on the last two areas, "the sexual meanings of nature and inquiry, and androcentric theories of scientific knowledge" and examine how this analysis can be extended to mathematics. Analyses of gendered metaphors used in science have shown how science itself carries into its theories, social values about gender. Feminists have drawn attention to examples of this in the identification of nature as female and the scientific mind as male and "the persistent privileging of explanatory models constructed around relations of unidirectional control over models constructed around relations of interdependence" (Longino, 1993:104). Epistemological values that are central

to science and justifications of its knowledge claims are also shown to have been influenced by gendered commitments.

### **Choice of theorists**

In choosing which of the many writers in the area of feminism and science to draw on in my own arguments, my personal commitments are an important factor. My political motivation for this thesis is to assist in encouraging more women to develop their mathematical abilities and interests and to become involved in the discipline of mathematics and other mathematically related careers. This commitment carries the underlying assumptions that there is nothing intrinsic or essential to women that prevents them from doing mathematics and that mathematics is not part of any kind of patriarchal plot against women. At the same time I seek to problematise the gendered traditions of the discipline. The theorists I have chosen share this commitment to women and to science in their case, while problematising the relationships in different ways.

The relationship between scientific knowledge and in my case mathematical knowledge and the world outside the individual knower is also problematic. Some theorists argue that scientific discourse is merely a 'text' or 'fiction' and deny the possibility of any truth claims based on representations of a real world. This theoretical position is unable to explain the experiences of many practising scientists who have their theories and hypotheses, their 'texts', disrupted by unexpected happenings in the natural world. Theorists who take a different stance and deconstruct the subject/object dichotomy without dismissing the possibilities of a world 'out there' fit well with my own views.

One of the problems with some feminist analyses of the sciences is the essentialising of the feminine as intuitive and emotional and the masculine as objective and rational. Science and mathematics can then be dismissed because they appear to exclude the feminine. In making such an analysis women are restricted to particular kinds of qualities and attributes, the very ones that have traditionally served to exclude women from many areas of life. This also places

the many women who are involved in science and mathematics in a very dubious position. As women they should not be objective and rational, as mathematicians and scientists they must be. The theorists I have chosen do not get caught in this dilemma as they do not essentialise women in these ways. They do not assume women are incapable of reason and objectivity and at the same time an important aspect of their work is to redefine objectivity in ways that are not dependent on such hierarchical and gendered dualisms.

In this thesis I am looking at both philosophical accounts of mathematics and science and the practices and experiences of mathematicians in order to understand the resonances and conflicts between them. Theorists who are also interested in reconciling accounts of practices and philosophy are therefore attractive to me. For all of these reasons I have chosen to draw on the work of Evelyn Fox Keller, Sandra Harding, Donna Haraway and Helen Longino. These theorists deal with the kinds of questions I am interested in, in ways which I find useful for my project. More detailed analysis of their work follows in this chapter.

### **Science and mathematics**

Reading the feminist science debates led me to think about how they might be applied in mathematics because of the similarities between the sciences and mathematics and the position and status of women within them. Mathematics is even more male dominated than many areas of science with the possible exception of physics. Like science, mathematics is associated with masculinity. This association is at least in part a result of the value given to particular conceptions of reason and objectivity in both the sciences and mathematics. Discussion of these values and the binaries upon which they are based are central to the feminist science debates.

Science is not however exactly the same as mathematics. Science is principally empirical and mathematics analytical. Although mathematics is sometimes described as 'the queen of the sciences', this tension between the analytical and empirical calls such a description into question. Mathematics is often used in

science to analyse results and as the language in which scientific theories are expressed and explained. Science has as its aim the development of explanations of the natural world but this is not always true of mathematics. Many areas of mathematics, described generically as 'pure', are disassociated from any link with the 'real' world 'out there'. Such a link would be regarded amongst those who do 'pure' mathematics as an unnecessary tainting of mathematics. On the other hand many developments in mathematics have come about as the result of trying to answer the sort of 'real' world problems one expects to find in science and in this sense mathematics can also be described as having an empirical base. The distinction is blurred somewhat in quantum theory where mathematical objects are necessary for thinking about the objects of quantum theory (Rav, 1993:101). Mathematical problems do not spring up from nowhere. The borders between science and mathematics are neither clearly defined nor impermeable. This makes mathematics fertile ground for the application of the feminist science debates.

One of the important ways in which feminists have shown gender permeating science is through language. This occurs through the use of gendered metaphors. I am unable to show the same thing happening directly in mathematics because mathematics involves the development of specialised symbolic languages that do not appear to be dependent on metaphor. However I will be arguing that the gendered metaphors that enter science influence the kinds of analysis that is deemed necessary and this in turn influences the kinds of mathematics that are developed and used in such scientific theories. My discussion of this will centre on the use of hierarchical as opposed to interactive models.

### **Outline of the chapter**

In this chapter I use the work of particular participants in the feminist science debates to show how gender permeates mathematics. This occurs through the association of mathematics with masculinity through individual gender identities, the gendered division of labour both within and without mathematics

and the symbolic work of gender. Gender works symbolically through the tales we tell about mathematics, the language and metaphors used and the association of core values in mathematics with masculinity.

### **My vision for this argument**

My aim in developing a feminist analysis of mathematics is not to reject mathematics or to replace it by something that is radically different or unrecognisable as mathematics (Keller, 1985:177). The first dooms women to remain in their present positions, outside full participation in society. The second possibility assumes that mathematics and science are purely ideological, socially constructed or merely 'text'. As Haraway (1988:577) says we want to do more than insist "on the rhetorical nature of truth, including scientific truths" and we do not want to "end up with one more excuse for not learning any post-Newtonian physics" because "[t]hey're just texts anyway, so let the boys have them back" (Haraway, 1988:578).

Longino joins in this chorus in rejecting the possibility of a new or different science (or in my case mathematics) based on the expression of a feminine temperament or essential qualities of the feminine. Such arguments conflate the feminine with the feminist. As what we know as 'feminine' is constructed within patriarchal societies and cultures our definitions of the feminine reflect patriarchal commitments. Feminist projects not only reject masculine domination but also these limiting and limited definitions of the feminine. Attempts to develop science or mathematics as an expression of a feminine temperament universalise women's experience and disguise the multiple and contradictory locations and commitments of women. There is not one expression of the 'feminine' or one 'women's experience' upon which such science could be based (Longino, 1989a:46-47).

A science or mathematics that emphasises intuition, feeling, connection and relatedness could be considered for description as 'feminist science' and the argument could be made that the presence of more women would lead to the endorsement and adoption of that vision. This argument ignores the

enculturation processes that all new members of the scientific and mathematics communities, including women, are exposed to. A woman becoming a scientist or mathematician involves the rejection of traditional feminine stereotypes so there is unlikely to be such a sharp differentiation between women and men scientists and mathematicians. The argument for a feminist science based on 'feminine qualities' also presupposes that objectivist and rationalist accounts of mathematics and science are accurate descriptions and that all forms of intuition, feelings and emotion are excluded. My argument includes the point that these accounts are not good descriptions. Mathematics, like science, is more pluralistic than any description of either of them usually claims (Keller, 1985:173).

What I am hoping for in mathematics is not merely the addition of women's visions to mathematical and scientific enterprises but a thorough transformation. The participation of large numbers of women would undermine the commitment of mathematicians and scientists to the masculinity of mathematics and science (Keller, 1985:175) but this is not a sufficient guarantee of change. Like Keller, my vision for mathematics is not for a complementarity of male and female, nor the substitution of one for the other. It is for a transformation of the very categories of male and female, of mind and nature and a reunification of emotional and intellectual labour and the objects and subjects of knowledge (Keller, 1985:178). Such a vision is dependent not just on recognising how 'false beliefs' can influence science and mathematics but on how any beliefs including those we take to be 'true' or 'good' influence our knowledge construction (Keller, 1992:24-25). "[I]t is not necessarily in the nature of science to be value free" (Longino, 1989a:50).

Haraway (1988:579) says about science that what we need is:

to have *simultaneously* an account of radical historical contingency for all knowledge claims and knowing subjects, a critical practice for recognizing our own 'semiotic technologies' for making meanings, *and* a no-nonsense commitment to faithful accounts of a 'real' world, one that can be partially shared and that is friendly to earthwide projects of finite freedom, adequate material abundance, modest meaning in suffering, and limited happiness.

I am expressing a similar need for mathematics. We need to be able to develop an account for mathematics that includes all of the following: the contingent nature of claims to mathematical knowledge; the influence of the location of the knowers; the way language influences our mathematics and its meanings; the relationship between mathematics and 'real' world phenomena; and the truth claims of mathematical proofs.

### **How gender enters science and mathematics**

Sandra Harding provides a useful model for managing the discussion of how gender enters, influences and appears in mathematics arising from her own work in science. In any given culture there are sometimes mutually supporting and sometimes oppositional relationships "between the preferred expressions of gender symbolism, the way labor is divided by gender, and what counts as masculine and feminine identity and behavior" (Harding, 1986:52). These relationships are fundamentally asymmetrical as gender itself "is an *asymmetrical* category of human thought, social organisation, and individual identity and behaviour" (Harding, 1986:55). "[C]entral to the notion of masculinity is its rejection of everything that is defined by a culture as feminine" (Harding, 1986:54). I am going to examine how asymmetrical gender relations have been played out in mathematics, its culture and practices, by looking at individual gender identities, the division of labour by gender within and without mathematics and the symbolic work of gender in mathematics.

### **Individual gender identities**

The relationship between mathematics and individual gender identities is a circular process of mutual reinforcement. Through the association of mathematics with masculinity, mathematics receives extra validation from the cultural preference for the masculine. Anything called feminine, whether women themselves, ways of thinking or particular branches of knowledge, become further devalued by their exclusion from the value placed on

mathematics and science. Mathematics and science are reinforced as models for all forms of intellectual work and knowledge making (Keller, 1985:92).

Keller (1985) traces the association of science and gender through the use of sexual metaphors in the historical development of science. Keller uses Bacon's descriptions of science as a particular example of this. For Bacon the aims of science were the control and domination of nature. Bacon uses a sexual metaphor of science as "a chaste and lawful marriage between mind and nature" (Keller, 1985:36). In science man exercises sovereignty, dominion and mastery over nature. Men can thus achieve power and mastery but it is power exercised in a constructive, noble and humane outlet. In this conjunction of science and power, science is described as a force virile enough to penetrate and subdue nature (Keller, 1985:48). There is a strong emphasis on a disjuncture between mind and nature in which men, science and mind are linked with purity and chastity. Women, nature and the body are linked with sexual excess, social disorder and disintegration. The new science while banishing 'woman' promised protection from this chaos and disorder (Keller, 1985:60).

In the ideological system that emerged and prevailed, science was a purely male and chaste venture, seeking dominion over, rather than commingling with, a female nature; it promised, and indeed helped promote, the simultaneous vanquishing of nature and female voracity (Keller, 1985:61).

Over time ideologies of gender change and by the 18th century a new ideal of womanhood gained ascendancy in which women are portrayed as chaste, desexualised, harmless, dependent, and treated with sentimental regard and protective solicitude. Nature was increasingly represented in mechanical terms but women were still excluded from positions as knowledge producers as the dichotomies between objective and subjective, between reason and feeling were increasingly polarised and women were associated with the latter and men, science and mathematics with the former (Keller, 1985:61-2).

Keller argues that science, while claiming to be objective, to be beyond and removed from subjectivity, contains what it rejects. Science contains an image

of the self as autonomous and objectified and this subjectivity permeates science. While claiming to have escaped the influence of desires and beliefs, the belief in the self as autonomous and the desire to be severed from the objects of science and the scientist's self permeate science. Concepts of the self and other, subject and object, and masculine and feminine develop in interaction with each other and in the context of ideals shared by dominant cultural groups. This leads to connections between subjectivity and science that are subtle and complex but are maintained by an ideology that denies their existence (Keller, 1985:70).

While claiming to be above and beyond individual subjectivity, science and mathematics' association with power and control, with objectivity and rationality and the exclusion of emotion, feelings and the intuitive means that particular kinds of subjectivities or individual identities are valorised within science and mathematics. To be a man is to be rational and objective and to value power and control. As mathematics is portrayed as rational and objective, to be a mathematician is to 'think like a man'. A woman thinking scientifically or objectively is said to be 'thinking like a man' whereas a man using non-rational, non-scientific arguments is arguing 'like a woman' (Keller, 1985:77). This attribution of scientific thought to masculinity and masculinity to scientific thought, may lead to the attraction to science of particular kinds of people who once within science are attracted to particular themes, theoretical approaches and results that reflect these views of science and mathematics. The questions that mathematics is used to answer will be those arising from men's lives, for example, military applications. This association in turn reinforces a story of mathematics as being hard, controlled, objective and rational even though these stories bear little resemblance to the every day practices of every day mathematicians. Any account of mathematics that emphasises the intuitive and creative aspects of mathematics is likely to find little favour because it is associated with femininity, the antithesis of mathematics.

For a woman to enter this world she has to find some way of negotiating these associations. A 'woman mathematician' becomes an oxymoron bounded by

inauthenticity and subversion. She occupies a precarious position in a site where the 'feminine' is denigrated. She can resist the denigration or attempt to subvert it with the possible consequences of emphasising her femaleness on the one hand or becoming 'one of the boys' on the other. Her own personal experiences of mathematics as being different from the mythical stories told about it will be of assistance in this accommodation process.

### **The gendered division of labour within mathematics**

Asymmetrical gender relations affect the kinds of work women and men do and the value that is placed on this work. Men do the public, intellectual and abstract, conceptual work and women do the private, caring and emotional work. Part of the caring work of women involves taking care of men's bodily needs and the needs of their children. This work done by women for men is necessary if men are to be free to fully participate in abstract work. Dorothy Smith (1979:168) goes even further to say that not only is this work necessary to free up men to enable them to undertake the abstract and conceptual tasks but that women's work involves making the work women do, invisible. What women do often does not even count as work and when it does it is not valued as highly as men's.

A man entering the abstract world of mathematics usually does so without the responsibility for the emotional caring work required in his family and emotional relationships and may not even be responsible for meeting many of his own bodily needs. A woman on the other hand entering the same arena not only knows she will be taking care of her own needs but she is also very likely to be responsible for meeting the needs of others within her family or close personal relationships. These caring responsibilities within the family can make it more difficult for women to attain high positions in the mathematical hierarchy. Many women are unwilling to give up their caring work as they value it highly so they seek to combine rather than choose between the two. Men are unlikely to have to choose between or combine the two. It is taken for granted in this public world of professional work that emotional and bodily

needs are provided for in a way that will not interfere with participation in the profession (Smith, 1979:166).

Having entered the public world of work, in this case in mathematics, the gendered division of labour does not cease. Within mathematics itself men are more likely to be involved in mathematical research and the doing of mathematics. While women are often involved in teaching at all levels of the education system or in the tertiary level in mathematics education rather than mathematics itself. Women who work in a university mathematics department and are involved in mathematical research are still subject to the same phenomena. They are often seen as the best teachers and so are assigned the very large first year classes. This is often a conflict for women as they value their teaching work but they know that it is research results and publications that provide credentials for the promotions they also value.

The assumption that an individual's private caring work will be taken care of elsewhere, is hidden but underlies two commonly accepted myths in the world of mathematics. The first is that a mathematician does 'his' best work when 'he' is young. For example the Fields Medal, the equivalent to the Nobel Prize<sup>1</sup> in mathematics is awarded to mathematicians under the age of forty. This clashes with the peak child bearing period for women and therefore the time at which they are most likely to be distracted from their mathematics. Women's career paths do not follow the traditional male trajectory. This myth is often retold in conversations about older mathematicians in terms of 'whether these older mathematicians have any mathematics left in them'. Sharon Traweek (1992) found a similar myth is told in the world of high energy physics.

The other myth which excludes women is that 'you cannot take time out from mathematics, because if you do you will never catch up again'. There is an assumption here that mathematicians will not have to take time out for child bearing, taking care of the sick or elderly and that there will be someone else to

<sup>1</sup> There is no Nobel Prize for mathematics.

do so for the mathematician. Women mathematicians are less likely to be able to make this assumption or they are unwilling to evade these responsibilities. This same myth does not seem to apply to those who take time out for administrative positions such as chairing departments or being seconded to government think tanks.

It is not unusual for mathematicians to change their research focus throughout their career as new areas open up, new technologies are developed or new opportunities arise to work with people with different expertise. This practice does not serve to dispel the myth unfortunately.

This division and the concealment of women's work influences the directions of mathematical research. If men are most likely to be undertaking and directing mathematical research and they are not involved in some areas of life and have little perception of them, then research questions arising from those areas will not be raised. Research based on the interests, concerns and experiences of those groups who are not involved in caring work will dominate the mathematical research agenda.

### **The symbolic work of gender**

The symbolic work of gender extends into science and reinforces the hierarchical nature of the gendered dichotomies. This symbolic work also occurs in mathematics. Gender works symbolically through the stories told about science and mathematics, what they are and their relationships to the natural world. It also works through the language and particularly the metaphors used in scientific explanations. Core values in mathematics and science such as objectivity and rationality and the definition of these values based on their opposition to subjectivity and emotion are another aspect of the symbolic work of gender as the former are associated with masculinity and the latter with femininity. In this section I will discuss each of these aspects.

### **Stories of what mathematics is**

The association of masculinity with objectivity and rationality in a context in which masculinity is privileged influences the stories we use to understand the development and progress of mathematics. In describing the development of mathematics the logical deductive aspects of mathematics are emphasised while the importance of intuitive thinking, the valuing of relational complexity and the nurturing of new ideas and conjectures are not spoken of publicly. Our stories of what mathematics is and how it is done are informed by the privileging of practices that are related symbolically to masculinity.

Asymmetrical gender relations in which masculinity is privileged can be used symbolically to mutually reinforce particular kinds of stories about mathematics and science. Earlier in the chapter I discussed how sexual metaphors have been used to describe the relationship between science and the natural world. This relationship has been described in terms of a sexual union between science and nature either in terms of marriage or rape with science being the male partner who rips aside the veils to reveal the natural world. In these stories nature is equated with the feminine, the unruly, chaotic abundance waiting to be tamed and controlled by the male scientist. These stories are less applicable to mathematics because mathematics is described as dwelling in even higher realms of purity. Describing mathematics as 'pure' appears to remove it from the sexual realm but it does so by placing it above the physical, bodily and emotional world and maintains its alignment with masculinity through the association of masculinity with the intellectual, abstract and rational.

Stories about what mathematics is, describe mathematics as being objective, value neutral and universal. They describe its advancement as being dependent on the logical, deductive and progressive unfolding of new mathematical developments. Tying such descriptions in with notions of purity suggests a discipline "so lofty and civilized that the ordinary person can scarcely aspire to it" (Appelbaum, 1995:8). This story reinforces the idea that only a few people can do mathematics as only a few can be so detached from their emotions and achieve such 'purity'. Those few are going to be predominantly white, middle

and upper class men. This story reinforces the elitism of mathematics, its role as a critical filter (discussed in Chapter 4) and its high status in the hierarchy of knowledges. In this hierarchy those disciplines that are, or can appear to be, the most remote from ordinary people's everyday concerns hold the highest positions.

Appelbaum (1995:8) says that one irony in describing mathematics as universal is that it "actually excludes more than it encompasses. Among other things it excludes fallibility, ambivalence, passion and most of instinctual life." This irony is more an irony of the story mathematics tells about itself than of the practices and everyday experiences of mathematicians. For in the practices of mathematics, intuition, emotion and even passion find a place. Telling this side of mathematics, however, exposes the private realm of mathematics and places mathematics dangerously close to the feminine in a world in which the feminine is either not privileged or is denigrated.

The stories of mathematics and science are also the stories of 'great men's discoveries'. The development of these disciplines is told as if they developed from the insights of a few individual geniuses. Often these stories describe these supposedly individual achievements as accidental. Some accident happened in a laboratory where such a genius was working and as a result of this 'he' made a brilliant discovery. The intense work that the individual and 'his' team had been doing for perhaps many years previously is discounted (Milne, 1996). In mathematics this individualism is often celebrated by naming theorems after such individuals for example Fermat's Last Theorem. Such stories serve to reinforce the extraordinariness of the individuals involved in science and mathematics and further reinforce the elitism of these disciplines. They also disguise the communal and collective nature of mathematics and science and the social processes through which new developments are made and published. It is a social process within which new ideas are shared, criticised and developed, rejected or accepted and exposed to the scrutiny of the wider mathematical community.

## Language and metaphor

Another way in which gender operates symbolically in mathematics and science is through the use of language and, within that, metaphor. In this section I am going to begin with a discussion of language in science and then show how the ways in which language structures scientific explanations impact on mathematics.

In order to function as a community, a group of scientists has to have a common language with which individuals can communicate. This language involves the 'correct' names for things, the 'right' syntax and an understanding of what constitutes legitimate questions and meaningful answers. Membership in the scientific community depends on knowing this language and being able to use it 'correctly'. Such a language is based on implicit assumptions which in the case of science include the assumption that this language is transparent and neutral and that knowledge of the universe or nature is directly accessible through this language (Keller, 1985:130). A belief in the neutrality of this language also serves to define membership of the scientific community, and to secure the borders of the scientific disciplines (Keller, 1985:131). The highly specialised symbolic nature of mathematical language makes it particularly potent in defining membership and securing boundaries.

Keller has done considerable work on deconstructing this assumed transparency of language in science. She has looked at the use of metaphor in scientific discourse in order to show how hierarchical dualisms such as culture/nature; knowing/ feeling; reason/emotion; men/women enter into scientific discourse and social and cultural norms are thus solidified into the basic and central concepts of science. She has also traced the influence of more specific metaphors and the use of colloquial terms in technical contexts. An example of the latter is the use of the term 'competition' which is given specific technical definition in the biological sciences but there is confusion with the colloquial meaning of this word. The technical definition serves to hide this confusion and the ways in which the colloquial meanings seep into the science.

Scientists can hide behind the disclaimer that a new technical meaning was intended (Keller, 1985, 1992).

In science the 'laws of nature' are assumed to be beyond language and "encoded in logical structures that require only the discernment of reason and the confirmation of experiment" (Keller, 1985:130). Keller argues that this concept of the 'laws of nature' is a metaphor deeply entrenched in scientific language and has its own political history. Historically the 'laws of nature' were thought to be imposed on nature by God with nature being seen as blind, obedient and simple. Scientists inherit the mantle of authority from God as they work to uncover the 'laws' and to control and predict the course of nature (Keller, 1985:134). This metaphor supports the search for the one 'unified' law of nature that embodies all other laws and is immune from revision (Keller, 1985:132).

This concept of law implies a hierarchy between the scientist/God and nature as well as within scientific knowledges and in the kinds of explanations that are accepted. Disciplines that can most closely resemble the classical laws of physics which are causal and deterministic are valued most highly as are explanations that exhibit hierarchies of control (Keller, 1985:132-133). Such laws are restricted to those that can be expressed by the language of science which in most cases will be mathematical language. Physicists continue their search for the "theory of everything" in which "[t]he idea is to describe all matter, all energy, all the fundamental forces of nature in one tidy, elegant set of equations" (Time, 1996:30). "To assume that all perceptible regularities can be represented by current (or even by future) theory is to impose a premature limit on what is possible in nature" (Keller, 1985:133). To assume that all regularities in nature can be described by 'laws' may limit what we believe to be possible in nature and accordingly limit our understanding (Keller, 1985:133-134).

Keller (1985) proposes an alternative metaphorical base for scientific thought in the concept of 'order'. Keller's argument is that even though the concept of

law is subject to expansion and revisions, it remains tainted by its political and theological origins. An interest in order rather than law “would imply a shift in the focus of scientific inquiry from the pursuit of the unified laws of nature to an interest in the multiple and varied kinds of order actually expressed in nature”. There might be a shift from “hierarchical models of simple, relatively static systems toward more global and interactive models of complex dynamic systems” (Keller, 1985:134). Nature is conceptualised as “blind, obedient, and simple” in the metaphor “laws of nature”, but the use of “order allows for nature to be generative and resourceful, complex and abundant. Nature is seen as an active partner in a reciprocal relationship to the equally active observer fostering a relationship between mind and nature in which one ‘listens to the material’ rather than assuming data can ‘speak for themselves’ ” (Keller, 1985:134).

Such a change has already begun as physicists have examined more complex phenomena. New mathematical techniques have been developed which make it possible “to replace time-dependent differential equations, which describe systems evolving in time according to specific laws, with equations better suited to describing the emergence of particular kinds of order that the internal dynamics of the system can generate” (Keller, 1985:135).

My interest in these metaphors is in the influence this language has on the development of mathematics. Different metaphorical systems require different kinds of mathematics to express such scientific explanations. Keller suggests that explanations involving hierarchical relations of domination, for example by a central governor of a process, appear “both more natural and conceptually simpler than global, interactive accounts” (Keller, 1985:155). She asks what part our mathematical explanations/models might play in this. “Mathematical tractability is a crucial issue, and it is well known that, in all mathematical science, models that are tractable tend to prevail” (Keller, 1985:155). Such models are easier to mathematise. “We risk imposing on nature the very stories we like to hear” through imposing causal relations on complex interactive systems (Keller, 1985:157).

I am arguing that there is a dynamic relationship between our commitments to particular metaphorical explanations and the mathematical tools available with which to express them. Hierarchical models encourage the development of particular kinds of mathematics. The development of this kind of mathematics makes such explanations more tractable mathematically. They are easier to model in part because the necessary analytic tools have been developed and mathematicians and scientists are familiar with them. This reinforces the choice of such metaphorical models. A preference for hierarchical models will be increased in the knowledge that the mathematics necessary for their expression is readily available. Dynamic, interactive models require different kinds of mathematics. As this mathematics is developed more mathematicians and scientists become familiar with it and the kinds of explanations accepted can more easily include such dynamic interactive models.

There are many other factors affecting these developments of course. Of particular interest to me is the role of nature and technology. Developments in computer technology affect the development of the mathematics of dynamic, interactive systems. If the equations and calculations required are too complex and time consuming for one individual or small group of individuals to evaluate then that mathematics is not going to be seen as useful for solving and representing a particular problem. If the same work can be done quickly and cheaply by a computer it's usefulness is enhanced. The natural world itself is another constraint on the value of a particular model. A metaphorically based model that does not explain the phenomena under examination is of little use and is therefore unlikely to be taken further in its development. Thinking about this leads to questions about the relationship between mathematics and the 'real' or 'natural' world. I will begin by looking at what feminists have said about science and its relationship with the natural world.

### **Science, mathematics and nature**

It is no longer possible to think of nature as a given, or that our theories can mirror nature, thanks to the work of historians, philosophers and sociologists

of science which shows how science, our account of this natural world, is structured by cultural processes and commitments (Keller, 1992:3). There is a world 'out there' which shapes us (humans) and we shape it. We are part of it but its existence is not dependent on any particular individual. We need a name for this world and Keller (1992:3) chooses to call it 'nature' and I will follow her lead. Knowledge of nature is not directly accessible to us. It is only accessible through the representations we make of it and these are structured by language and therefore by culture. While acknowledging that our accounts can never directly correspond to reality Keller (1992:5) claims that some representations are better than others because they are more effective in the uses and practices they facilitate.

Scientists laugh at the idea that science is only cultural or ideological because they know that nature disrupts their own theories and experiments. They know that some theories 'work' and others do not because they know that not all theories support successful interventions. Beliefs, interests and cultural norms do influence the course of scientific goals but they cannot in themselves generate either epistemological or technological success. It is only when they mesh with the opportunities and constraints afforded by material reality that science can 'work' (Keller, 1992:35).

Keller (1992:6) is interested in how our representations are constrained on one hand by "our social, cultural and disciplinary location" and on the other by the recalcitrance of 'nature'. Haraway has similar interests and argues that the world encountered in any knowledge project is an active entity. She describes the world "as a witty agent" and as "a coding trickster." The world is not "raw material for humanisation" or "raw material for culture" but a "material-semiotic actor" "with whom we must learn to converse" (Haraway, 1988:592-596).

Mathematics does not give order to an otherwise disorderly nature. Nature is already full of pattern and rhythms. We do not make these.

mathematics does not *make* one's heart beat rhythmically, nor does it *make* the patterns of a blue jay's call, nor does it *make* the cycles of breath and day and season. Rather, the makings of mathematics are

threaded within a fabric of makings that are always already at work (Jardine, 1994:110).

In making mathematics we are *part* of nature. Rather than imposing order on chaos, mathematics is part of “an order that goes beyond human wanting and willing”. The exactness of mathematics is not something we have to look up to.

It is right in front of us, at our fingertips, caught in the whorl patterns of skin, in the symmetries of the hands, and the rhythms of blood and breath (Jardine, 1994:112).

## Objectivity

Now I return to my argument about how gender works symbolically in mathematics through looking at how a central value in science and mathematics, objectivity, is associated with gendered dichotomies. In this section I discuss what effects the association of objectivity with masculinity has on mathematics. The particular notion of objectivity which predominates in Western science knowledge making is based on the dichotomising of the objective and subjective; the subject and objects of knowledge; reason and emotion; mind and body; the masculine and the feminine (Harding, 1986:23). To be objective in this context is to assume the ability to step outside one’s emotional, personal commitments and social location and to take up a position in some Archimedean point from which the knower can gaze down upon the objects to be known. Such ability is assumed to be one that men can achieve and women cannot because of their associations with the emotional and the body.

This notion of objectivity serves as a powerful rhetorical device to legitimise particular kinds of knowledge claims, methods, theories and stories about mathematics and science (Harding, 1986:67). It also legitimises the exclusion of particular kinds of people from the scientific and mathematical communities. It is based on particular theories of self and the relationships between science, the scientific knower and the natural world. If a theory or result can be described as ‘objective’ then it is assumed to be true.

The *Concise Oxford Dictionary* (Allen, 1990) definition of objective as “dealing with outward things or exhibiting facts uncoloured by feelings or opinions; not subjective” gives the commonly accepted meaning of the term in a scientific/mathematical context. While intending objectivity to be value neutral and socially impartial the very definition of the term contains implicit values and commitments (Harding, 1986:67). These values and commitments are gendered and privilege masculinity. This definition depends on the severance of the subject of knowledge from the objects of that knowledge which in turn are assumed to be outside the subject (Keller, 1985:117). A criteria for achieving such objectivity is emotional distance from and potential control of the object of knowledge. The search for objectivity is thus misidentified in Keller’s view, with the search for control over natural phenomena (Longino, 1990:205). Science based on such objectivity promises power and domination over nature and an adversarial approach to knowledge making and selects for those individuals who have those concerns (Keller, 1985:124).

Objectivity is also criticised for the implicit notion of the self that underlies this concept.

Value free objectivity requires also a faulty theory of the ideal agent - the subject - of science, knowledge, and history. It requires a notion of the self as a fortress that must be defended against polluting influences from its surroundings. The self whose mind would perfectly reflect the world must create and police the borders of a gulf, a no-man’s-land, between himself as the subject and the object of his research, knowledge or action (Harding, 1991:158).

The mind is assumed to act like a mirror which reflects a world that is out there already made. This self underlying such notions of objectivity is an individualist, who can presumably not only sever themselves from their own feelings and opinions but can sever themselves from the entanglements of the natural and social worlds within which they are located. Because women are associated with the emotions, feelings and nature, such a concept of objectivity carries the implication that this individual person is male.

If women are systematically excluded from the management and design of science and their work devalued, and if scientific 'knowledge' about them reflects the devaluing of the feminine, as it does, then we have to ask whether science is really intended to be value neutral, objective and socially impartial<sup>2</sup> (Harding, 1986:67). As scientific method is incapable in itself of detecting and eliminating values and beliefs that are culture wide or nearly culture wide, it is incapable of identifying and eliminating the genderisation of science that occurs through these processes.

However the methods and norms in the disciplines are too weak to permit researchers *systematically* to identify and eliminate from the results of the research those social values, interests, and agendas that are shared by the entire scientific community or virtually all of it. Objectivity has not been 'operationalized' in such a way that scientific method can detect sexist and androcentric assumptions that are 'the dominant beliefs of an age' - that is, that are collectively (versus only individually) held (Harding, 1993b:52).

She goes further to say:

The norms themselves have been constructed primarily to produce answers to the kinds of questions an androcentric society has about nature and social life, and to prevent scrutiny of the way beliefs that are nearly or completely culturewide in fact cannot be eliminated from the results of research by these norms. ... It is not only that the underlying general principles of scientific method are not powerful enough to detect culture wide sexist and androcentric biases but also that the particular methods and norms of the special sciences are themselves sexist and androcentric (Harding, 1991:117).

This conceptualisation of objectivity and its association with masculinity serves to support the inclusion of particular kinds of people as scientists and mathematicians at the same time as it serves to disguise that this is what is happening. Men from dominant cultural groups, that is, white, middle and upper-class men, are included and women and all members of other racial and

<sup>2</sup> Similar points are made about race and ethnicity in (Harding, 1993a).

ethnic groups are excluded. This systematic exclusion is both disguised and legitimated.

Particular kinds of methods which are based on separation and reductionism are privileged, and theoretical models that are based on hierarchy and control are likely to be preferred to interactive models. The kinds of stories told about the knowledge making will give accounts of the rational and objective aspects of the story at the expense of the intuitive and creative as I discussed earlier.

This rhetorical device is very powerful in relation to mathematics as mathematics is particularly closely associated with objectivity and therefore its role in establishing truth claims. If something can be expressed mathematically, it is assumed to be objective and therefore it must be true. 'Numbers don't lie.' This reinforces the high status of mathematics in the hierarchy of knowledges and establishes mathematicians as members of an elite and superior group. It also reinforces the association of mathematics with masculinity and the exclusion of women from the group 'mathematicians'. This is not equivalent to saying that women are incapable of being objective but that is how we have come to think of them.

### **Objectivity as a social concept**

Accounts of objectivity often reduce it to an individual attribute or achievement. In this section I draw on Longino's work to discuss objectivity as a social practice and examine the social processes involved in establishing it.

Longino (1989b:265) takes issue with individualistic accounts of objectivity in which objectivity is seen as being the result of an individual's ability to detach themselves from their 'feelings and opinions'. She argues that objectivity is a consequence of inquiries being social not individual enterprises. Science is produced not by collecting individual efforts into one whole but through a process of critical emendation and modification of those products by the rest of the scientific community. Peer review determines what research gets funded and published in journals, what gets to count as knowledge or what becomes a

candidate for that status. It is then absorbed into more complex processes such as subsequent citation and modification by others. What gets taken up and then counted as 'knowledge' depends on more than the objectivity of the individual scientist. If theories and explanations are rejected by other members of the relevant scientific community, or are not taken up as stepping stones in further knowledge making activities then they are very unlikely to be given the status of 'knowledge'.

Proof is an important example of how objectivity is practised in mathematics. A mathematical proof is accepted as establishing the objective truth of a theorem or result. In describing how a new proof or result becomes part of 'mathematics' (de Millo et al, 1986:272-273) highlight the social nature of this practice.

When mathematicians grasp a new proof they do not usually sit back content with the truth of their theorem. They seek out those colleagues who can appreciate the significance of their breakthrough and attempt to convince them of the certainty and value of their finding. If their colleagues are convinced, the mathematician writes it up and circulates a draft and then submits it for publication. If referees agree it will be published and circulated more widely and may be taken up by reviewing publications.

If the proof is believed the results will be internalised by other mathematicians, none of whom will internalise it in exactly the same way. These multiple versions of the same theorem reinforce the feeling of the mathematical community that the original statement is likely to be true.

A believable theorem gets used and may be transferred from one branch of mathematics to another. Eventually after enough internalisation, transformation, generalisation, use and connection, the mathematical community accepts that the truth of the theorem has been established. "The theorem is thought to be true in the classical sense - that is in the sense, that it could be demonstrated by formal deductive logic, although for almost all

theorems no such deduction ever took place or ever will” (de Millo et al, 1986:272-273).

Not all mathematical developments proceed in exactly this fashion but de Millo et al’s example illustrates the social nature of the process and the importance of the usefulness of the results and its connections to other areas of mathematics in establishing the result. This ‘usefulness’ is more important than ‘objectivity’ in the truth claims made for the new finding.

According to Longino (1989b:265-267) “an important and distinctive feature of scientific inquiry ... is that it is public.” The public in this case is “anyone with the appropriate background, education, and curiosity.” Objectivity is a matter of degree and depends on the extent to which scientific communities satisfy four criteria: there are recognised avenues for criticism, there are shared standards that critics can invoke, the community as a whole responds to criticism, and intellectual authority is shared equally among qualified practitioners. This is where I take issue with Longino as she does not discuss how the power relations operating within and outside scientific communities influence the criteria she proposes. The public she describes is actually very private in that those controlling what background and education are appropriate are the very same people whose work is being subjected to scrutiny. The general or lay public may have little or no opportunity to scrutinise the work and may not be aware of the controversies that can surround particular theories and results. While at the same time science and mathematics are highly specialised and are not easily understandable by those unfamiliar with the area, this specialisation also serves to protect the power and prestige of those ‘in the know’.

Power relations also operate within the groups responsible for peer review. Most of what we describe as ‘peer review’ is carried out by senior and high status members of those disciplines. Along with their reviewing of publications they may well control access to funding, equipment, job opportunities and career advancement. Those submitting their work to such review could be

vulnerable to the same kinds of prejudices and allegiances that exist in any social group. Given the gendered and racial mix of the scientific and mathematical communities, scientists and mathematicians who are not members of the dominant groups, who do not come from prestigious institutions, may well have their work judged by different standards.

In Longino's (1989b:267) schema, objectivity is dependent on shared standards and shared intellectual authority. An individual's objectivity is dependent not on their detachment but on their participation in critical discussion processes. My concern is that these shared standards and authority are not shared very equally at all. They are only shared by particular groups with particular vested interests both within and outside. As Harding (1991:117) has pointed out, the standards are not sufficiently robust to illuminate values shared by most members of the particular community. Vested interests could prevent the development of some research and support other areas where that support is not justified.

Just as it is in science, publication is vitally important to the career of the mathematician. Mathematicians are not just working for the joy of discovery. They are under considerable pressure to publish in order to gain tenure and promotion in their careers. This pressure extends to include publishing in 'prestigious' journals. Because of the highly specialised nature of mathematics in the latter half of the twentieth century, only small numbers of people will be capable of comprehending a particular area and new developments within it. This has implications for publishing in prestigious journals. It is conceivable that the system could become, if it is not already, extremely rigid, with new and possibly exciting developments being rejected because they are outside the area of expertise of the reviewers. The mathematicians reviewing new work need to have an understanding of the field and the significance of the new work. Because of the specialisation and the small numbers working in a particular field the person attempting to get their work published may well have a good idea of who is likely to be reviewing their work and will present their papers accordingly in ways that they judge will appeal to those they think will be reviewing their work. In mathematics it is standard practice for blind review to

be only one sided. The reviewer knows who wrote the paper but the writer does not know who is reviewing it, unless of course they can work it out from other unofficial sources, which they often do. The importance of having good networks cannot be underestimated. The quality of supervision and the access the supervisor has to relevant networks is also vital for the future success of postgraduate students looking for their first steps up the ladder.

This brings us back to central concerns of this chapter that the male domination of science extends not only to the population of scientific communities but also to the methods, and results of scientific activity and the standards by which those are judged.

### **Do we need 'objectivity'?**

There are good reasons to retain a notion of objectivity. It has a valuable political and intellectual history. This notion has supported political arguments in favour of allowing the pursuit of ideas and explanations that were unacceptable to dominant groups and the ideas they clung to at particular historical moments. It supports being able to scrutinise things that powerful groups would prefer left alone (Harding, 1991:160).

While objectivity has its mystifying aspects in that it allows scientists who are members of dominant groups to avoid having to examine their own historical commitments and beliefs (Harding, 1993b:71), it also has its usefulness. Scientists and mathematicians know that 'nature' can surprise them, that their accounts can be undermined by natural phenomena they had not expected or accounted for. Science in its progressive and visionary aspects requires some mechanisms by which theories and results are challenged and scientists are forced to rethink their theories and understandings.

Like Harding, I am reluctant to abandon objectivity:

The notion of objectivity is useful in providing a way to think about the gap that should exist between how any individual or group wants the world to be and how in fact it is (Harding, 1993b:72).

## Objectivity reconfigured

I have established that traditional concepts of objectivity have not lived up to the claims made on their behalf. This is not because objectivity is too rigorous but, as Harding argues, it is

*not rigorous or objectifying enough; it is too weak to accomplish even the goals for which it has been designed, let alone the more difficult projects called for by feminists and other new social movements (Harding, 1993b:50-51).*

In trying to develop “a usable doctrine of objectivity” “we could use some enforceable, reliable accounts of things not reducible to power moves and agonistic, high-status games of rhetoric or to scientific, positivist arrogance” (Haraway, 1988:580). The question becomes how can we achieve “faithful accounts of a ‘real’ world” (Haraway, 1988:579) knowing that traditional doctrines of objectivity have served to conceal many prior commitments rather than expose them. To do this we need to distinguish the ideal of objectivity from the belief that this ideal has been satisfied, because it is this belief in the ideal having been satisfied that has the really potent ideological power (Antony, 1996).

It is fundamental to the ideal of objectivity being presented here that both ‘good’ and ‘bad’ beliefs have social causes. Objectivity is therefore not just about eliminating bias but about identifying how our locatedness informs our frameworks and theories (Longino, 1989a:54). Sometimes this gives rise to limiting frameworks that restrict the kinds of theories we develop and sometimes these frameworks are very effective. Objectivity then is not just about eliminating masculine biases from the sciences but also about investigating how our gendered commitments both restrict and enhance our knowledge making and about recognising the possibilities of other frameworks for our theorising.

Harding (1991) proposes a concept of ‘strong objectivity’ which extends the notion of scientific research to include systematic examination of powerful background beliefs in order to maximise objectivity. It requires analysis not

only of the micro processes in the laboratory but also of the macro processes in the social order which shape scientific practices. This requires 'strong reflexivity' to examine the beliefs that shape our own thought and behaviour and not just the thought and behaviour of others. As our society is structured by gender hierarchy Harding argues that 'starting thought from women's lives' increases the objectivity of science by making strange what appears familiar to those controlling the agendas and methods of science (Harding, 1991:149-150). This requires starting thought "from multiple lives that are in many ways in conflict with each other, each of which itself has multiple and contradictory commitments" (Harding, 1993b:66). In order to enact strong objectivity scientists have to value the 'Other's' perspective and to pass over in thought into the social condition that creates such perspectives in order to "look back at the self in all its cultural particularity from a more distant, critical, objectifying location" (Harding, 1991:151). This is achieved not through appropriating the thoughts of marginalised groups but by making oneself " 'fit' to engage in collaborative, democratic, community enterprises with marginal peoples." This requires learning to listen attentively to marginalised people, educating oneself about them, putting one's self on their line for 'their' causes, critical examination of dominant institutional beliefs and practices and critical self-examination to discover how one unwittingly participates in generating disadvantage (Harding, 1993b:68).

In any relationship between members of a dominant group and members of oppressed groups, particularly when 'subjugated knowledges' are involved, there is the ever present possibility of the colonisation and appropriation of such knowledge or of its reframing in terms of the dominant discourse. The question must be asked as to whether such knowledge is just providing a bit of 'colour' in the conversation without challenging any fundamental assumptions, practices or structures. It is difficult for even the most self-reflective amongst us to 'know' whether we are actually 'fit' to converse with 'others'. The notion of challenge is useful here. If what you are hearing from the subjugated other is not challenging your own assumptions and practices or has not in the past (there is the possibility that change has taken place already and been absorbed)

then the indication is that more 'fitness' training is required. This term 'fit' is a very interesting and useful choice because within it are subsumed notions of change, preparation, practice on a strenuous and ongoing basis and commitment to improvement. This is what is required in collaborating with the 'others'. Fitness is not something to be achieved and moved on from, it requires continual ongoing struggle and exercise. There is not a moment or location at which we are 'fit' and stronger objectivity is achieved.

Achieving strong objectivity requires not a strengthening of a dichotomy between subject and object but a rejection of that dichotomising through including an investigation of the relationship between subject and object (Harding, 1991:152). This idea is echoed in Keller's (1985) concept of dynamic objectivity. While Harding's emphasis is on the locatedness of the subject or knower, Keller's concept of dynamic objectivity is more concerned with the relationship of the knower to the objects of knowledge. Keller (1985:117) is aiming "at a form of knowledge that grants to the world around us its independent integrity but does so in a way that remains cognizant of, indeed relies on, our connectivity with that world." It is not unlike empathy. Rather than science promising power and domination over nature and an adversarial approach to knowledge making (Keller, 1985:124), Keller (1985:117) is advocating science based on love and empathy, where scientific objectivity remains. Rather than cutting off the existence of self, Keller's (1985:117) dynamic objectivity uses subjective experience and the struggle to disentangle the subject and object as a source of insight.

For Haraway (1988:581-4) "[f]eminist objectivity means quite simply *situated* knowledges." It is "not about transcendence and splitting of subject and object". It is about "the loving care people might take to learn how to see faithfully from another's point of view" Understanding how the systems work, "technically, socially and psychically, ought to be a way of embodying feminist objectivity." " '[S]ubjugated' standpoints are preferred because they seem to promise more adequate sustained, objective transforming accounts of the world. But *how* to see from below is a problem". There is a danger of romanticising or

appropriating the vision of the less powerful while claiming to see from their positions. This is a danger in Harding's concept of strong objectivity that requires positioning oneself with the marginalised which Harding tries to avoid through the concept of making oneself 'fit'.

Haraway (1988:584-5) rejects any possibilities of relativism which she describes as "the perfect mirror twin of totalization". "[P]artial locatable, critical knowledges sustaining the possibility of webs of connections" are not relativist. She is arguing for "a doctrine and practice of objectivity that privileges contestation, deconstruction, passionate construction, webbed connections, and hope for transformation of systems of knowledge and ways of seeing." "Passionate detachment requires more than self-critical partiality." It requires a commitment to "constructing worlds less organized by axes of domination." Haraway's call here is echoed in Harding's call for those attempting to achieve strong objectivity to have commitments to all liberation movements not only feminism (Harding, 1993b:66). Haraway (1988:585) is not building her concept on binary opposition but is incorporating both poles of these binaries as she calls for the linking of the 'imaginary and the rational' and the 'visionary and the objective'. As she says "Science has been utopian and visionary from the start." I will go on to argue further in this thesis that this is a more faithful account of the practices of mathematicians as they link the imaginary and the rational, intuition and reason and the visionary and objective. Science including mathematics has its regressive *and* progressive elements but the story of mathematics privileges only some aspects of those stories; the objective, the rational and their linkage with the masculine. Mathematics isn't only what it says it is.

"Situated knowledges are about communities, not about isolated individuals". They are about "the joining of partial views and halting voices into a collective subject position" that promises a view from somewhere (Haraway, 1988:590). This has resonances with Longino's accounts of science as social knowledge although she speaks in very different language. She too claims objectivity as social but in her language it is a 'social practice'.

I have argued that scientific knowledge is the result of complex processes of criticism, modification, and incorporation, that is, of the transformative interrogation of ingredients that are themselves socially produced, if also individually claimed. It is not the individual recognition of partiality or, as used to be said, of one's subjectivity but the subjection of hypotheses and theories to multivocal criticism that makes objectivity possible. ...Reflexivity is community wide, and the openness of partial knowledge facilitates transformation (Longino, 1990:212).

To do feminist science we need to change the social and political context in which science is done (Longino, 1989a:56). The greater the number of points of view represented in a given community the more objective its practice (Longino, 1989b:268-9).

In summary then a new doctrine of objectivity that is usable requires the recognition that all knowledge is influenced by its location in the social world and therefore is informed by 'good' and 'bad' beliefs. Objectivity means examining the ways these beliefs and locations expand and restrict our theories and frameworks. Objectivity is not a position of impartiality that can be attained and rested within but represents a continual striving to disentangle ourselves as knowers from the objects of our knowledge. Location in privileged social positions enables us to see certain aspects of the world and to see the world in particular ways. Attempting to see the world from other positions enables us to see different connections but carries with it the responsibility to recognise the dangers of attempting to do this. Colonisation and appropriation run very close to the loving empathy that is required.

Objectivity is not the attainment of an individual scientist but arises within the communities within which our knowing is done and requires processes of critique and review. These processes will be more effective, the more diverse the group participating. To transform objectivity in these ways requires change in the social and political contexts in which science is done and requires relinquishing the power traditional claims to objectivity have supported.

## Relevance to mathematics

The focus of the discussion in this chapter has been on mathematics in relationship to science. Other aspects of mathematics will be discussed in more detail in Chapter 6. The relationship with science is not the most important or only strand of mathematics but it does influence the direction of mathematical progress through advancements in mathematical knowledge and through funding and technological developments. ‘Science as truth’ articulated through ‘mathematics as value free’ plays an important role in the elitism and mystification of science and mathematics. This association disguises the social values and commitments that are inherent in mathematics and science and makes it difficult for outsiders to raise questions about these commitments. In my case the ways in which gender impinges on science and mathematics are hidden and the rhetorical space for questioning such associations is severely restricted.

If we relinquish the search for absolute and unitary truth as the aim of science and accept instead the aim of building models of some aspects of real world systems, then we can devise a notion of objectivity while simultaneously recognising the way values enter the process. We make models of real world systems on the basis of some analogy between the model and the system, that is that they have some features in common. These models often start from metaphors, for example the earth is a ball, and include the “use of elements of gender ideology and social relations as metaphors” (Longino, 1993:114).

This is relevant to my project as these models are mathematised and if the relationships can be expressed in mathematical formulae it is assumed they are objective and value free. The mathematics itself is not responsible for the introduction of new metaphors although limitations on available mathematical techniques may be, but the metaphors chosen influence the development of mathematics. Interactionist vs. hierarchical models may influence the mathematics used and developed. The importance of tractability in mathematical modelling may in turn influence the metaphors chosen, for

example hierarchical models may be more tractable and therefore preferred. On the other hand they may be more tractable because more time and resources have been used to develop them because of prior commitments to such models. The use of mathematics serves to disguise the values introduced through metaphors and supports claims to objectivity and value neutrality.

We are constructing models and in doing so we pick on some particular features to include in our model. What we choose will be determined by our interests in particular interactions and interventions. As both linear-reductionist and interactionist models reveal aspects of natural processes (Longino, 1993:116), this is not a question of developing the best feminist model on the basis of some particular commitment to a particular kind of model but rather looking for “many models that can be generated from the different subject positions” (Longino, 1993:117). In a society built on hierarchical power relations, the inclusion of models based on different metaphors and questions than the ones favoured by the members of the dominant groups will be a matter of conflict (Longino, 1993:117). In order to make our knowledge making more objective the social structures of society and science must change so that “[n]o segment of the community, whether powerful or powerless, can claim epistemic privilege” (Longino, 1993:118).

## **Conclusions**

In this chapter I have borrowed from the feminist debates about science to show how hierarchical gender relations enter, influence and impinge on mathematics. I have used Harding’s paradigm of gender entering through individual gender identities, the gender division of labour and the symbolic work of gender (Harding, 1986:52) to show the workings of gender relations in mathematics. Mathematics is associated with masculinity through its association with the rational, objective and abstract while the feminine is associated with emotion, intuition and the body. These associations mean that individual women entering mathematics have to either ignore or reject these traditional associations. The gender division of labour in our society means that

the abstract work of mathematics is assigned to men. When women break out of this division and enter mathematics they still face gender divisions of labour within mathematics as they are more likely to be assigned the caring and nurturing work within mathematics. Gender works symbolically in mathematics in the association of the kinds of stories told about what mathematics is and its relationships to the natural and social worlds, through the language and metaphors used, and through the core values of the discipline. These values, such as objectivity and rationality, are defined in opposition to qualities associated with femininity. The stories told about mathematics in a society which privileges masculinity are partial stories. Those features which are associated with masculinity are highlighted and those associated with femininity are not. The mathematics itself is not responsible for the introduction of new metaphors although limitations on available mathematical techniques may be, but the metaphors chosen influence the development of mathematics.

# Chapter 6

## Mathematics

### Introduction

In Chapter 2, I identified questions to be addressed in developing my own position on a feminist epistemology for mathematics. I reiterate these questions here because in this chapter I am going to consider how mainstream epistemologies and sociologies of mathematics deal with them, when they do. The questions I raised were:

Who can be a knower?

What are the processes that determine and legitimate the practice and act of knowing?

What kinds of things can be known?

Traditional mathematical epistemology has been concerned with aspects of the second and third questions about the kinds of things that can be known and how, and more particularly with establishing grounds for the certainty or truth of those knowledge claims. These projects have not been completely successful and the philosophy of mathematics has taken a new turn in which attempts are being made to develop a philosophy that is true to the reality of mathematical experience (Hersh, 1986:18). Sociologies of mathematics that consider many of the same questions are also being developed with the consequence that the boundaries between the two disciplines are blurred somewhat. In these newer approaches some aspects of the second question about the processes involved in the act of knowing are raised but questions about who can be a knower, a central concern of feminist epistemology, are very rarely raised. Ernest (1991 & 1995) is one of the exceptions to this as I will discuss later in this chapter.

Rather than taking up a position in support of any one of the approaches of traditional epistemology or even of any of the ‘new directions’<sup>1</sup> in mathematical philosophy (Tymoczko, 1986), I take a similar position to Appelbaum (1995:10):

[W]e can interpret various epistemologies of mathematics as parts or aspects of mathematics; that is, they are parts of a woven fabric of truths, facts, fantasies, hopes, relationships of power, and practice. The point then will be to appreciate how such complexes of practice come to be, and how and through what relationships of power and identity fluctuation they are created by those involved in their maintenance and production.

Such an epistemological approach suggests “a focus on the study of processes rather than remote origins: on multiple rather than single causes” (Appelbaum, 1995:11). Mathematical epistemology has been concerned with establishing the answers to its questions through “objectively determined, absolute, and universal interests” (Appelbaum, 1995:12) but I refute the separation of theory and practice, of object and idea and of mind and body upon which the concepts of objectivity, absolute and universal truths are based. I am assuming that my epistemology will be “unstable, open to contest and redefinition” (Appelbaum, 1995:11).

In this chapter I will discuss philosophies and sociologies of mathematics and use the theoretical construct of the public/private binary to show aspects of how gender constructs and is constructed within mathematics. I will take some examples of prevalent values and practices in mathematics to demonstrate some of the ways in which power operates in mathematics and the inclusions/exclusions that result. Some of these examples are further illustrated in findings from my research with women mathematicians. A feminist epistemology for mathematics has to take a much wider view of mathematics

<sup>1</sup> The expression ‘new directions’ comes from the title of a book “New Directions in the Philosophy of Mathematics” which “investigates the nature of mathematics as it is currently practised - and not as it ‘ought to be’ according to preconceived ideas” (Tymoczko, 1986).

than traditional foundationalist projects have done. In order to understand truth claims in mathematical knowledge the values and practices within and outside mathematical culture have to be considered.

### **Traditional philosophy**

Foundationalist<sup>2</sup> philosophies of mathematics such as formalism, intuitionism, logicism and Platonism, are concerned with providing rigorous systems to warrant mathematical knowledge absolutely rather than to describe and define the nature of mathematics (Ernest, 1995:450). Put very briefly these positions can be characterised as:

Formalism: the view that mathematics is the rule-governed, or *formal* manipulation of symbols and nothing else. Formalism denies the objective reality of intuitive constructions.

Intuitionism: this view is that mathematics consists of intuitive constructions, the formal manipulation of symbols which is their external expression and nothing else. Intuitionism denies the existence of any mathematical reality external to the mathematician.

Logicism: In this view there are mathematical truths, but they are true solely by virtue of their own internal structure and their relations to one another. They do not describe any actual state of affairs; they are empty of factual content. Mathematics is merely logic. Logicism not only denies the objective reality of such structures but does not take mathematical intuition into account.

<sup>2</sup> In his works Ernest generally uses the term 'absolutist' when referring to foundationalist projects. Ernest (1994a:33) clarifies their interchangeability. I will use the two terms interchangeably.

Platonism: Platonism holds that mathematics consists of truths about abstract structures existing independently of ourselves, of the logical arguments that establish those truths, of the constructions underlying those arguments of the formal manipulation of symbols that express those arguments and truths and nothing else. Platonism does not account for applied mathematics (Carter, 1993:1-2; Goodman, 1986:79-94).

Although these projects continue to have a powerful influence on our thinking about mathematics, they have not been successful in establishing the certainty they were attempting to find. Within the boundaries of their own discourses logical inconsistencies have been found that have rendered impossible the establishment of certainty. They have also been unsuccessful in explaining or accounting for mathematical developments in the latter part of the twentieth century (Ernest, 1995:450).

Fallibilist philosophies of mathematics (Ernest, 1991), which include constructivist and postmodernist positions, reject absolutism and accept mathematics as an essentially social phenomenon. They are concerned with describing the nature of mathematics and the practices of mathematicians and include historical accounts of mathematical developments. Most proponents of these positions agree on the social role of proof which is to “persuade the appropriate mathematical community to accept the knowledge as warranted” (Ernest, 1994a:34).

I am not concerned here with describing the difficulties arising within the foundationalist projects in any detail but with looking at some of the responses to important and interesting philosophical questions that have remained unanswered. The new directions in mathematical philosophy have arisen in opposition to foundationalist philosophies so in many respects are confined by the issues raised within those positions. They are, therefore, largely concerned with issues about whether mathematics exists only in the mind and its objects are mental creations, or whether nature has a mathematical reality which

mathematicians are concerned with discovering. These are the kinds of issues raised in my epistemological framework by my third question: ‘What can be ‘known’, that is to say, what factors affect the establishment of adequate objects of knowledge? What kinds of things can be known?’

These questions are concerned with the nature of mathematical objects and the relationship between mathematics and the ‘real’ or ‘natural’ world. Philosophers and mathematicians are puzzled by the power of mathematical abstraction to explain diverse situations. They wonder how “[m]an-made mathematics, concocted solely from ideas springing up in the human mind” (Kline, 1980:282) could prove useful in understanding nature.

Why should long chains of pure reasoning produce such remarkably applicable conclusions? This is the greatest paradox in mathematics. ... Why does mathematics work even where, although the physical phenomena are understood in physical terms, hundreds of deductions from axioms prove to be as applicable as the axioms themselves? And why does it work in domains where we have only mere conjectures about the physical phenomena but depend almost entirely upon mathematics to describe these phenomena (Kline, 1980:340)?

If mathematics exists in a world outside man, how can it be that abstractions built upon abstractions, upon abstractions, for example in group theory, can eventually be found to have numerous unexpected applications? Rota (1991:165); Bishop (1988); Hersh (1986); Kitcher (1986); Thom (1986); and Wang (1986) address similar questions.

### **The nature of mathematical objects**

In taking up a position on whether mathematical objects are purely mental constructs or are a result of a relationship between mathematics and the physical world many mathematical philosophers have opted for one side or the other of the dichotomies mind/body or culture/nature.

Kline (1980:295), for example, disputes arguments based on the idea that pure mathematics is later found to be applicable. He argues such supposedly pure mathematics was originally created in the study of real physical problems or

those bearing directly on physical problems. He concedes that good mathematics is often found to have new applications that were not foreseen, but maintains that the original concepts and axioms came from observations of the physical world (Kline, 1980:328).

Mathematics is an empirical science much as Newtonian mechanics. It is correct only to the extent that it works and when it does not, it must be modified. It is not a priori knowledge even though it was so regarded for two thousand years. It is not absolute or unchangeable (Kline, 1980:332).

He uses the example of radio and television to support his case. He argues that radio and television do not exist solely as a result of our minds predetermining what we see in nature. Rather, our observations of the physical world lead to the mathematics necessary to the development of radio and television.

Radio and television do not exist because the mind organised some sensations in accordance with some internal structure which then enabled us to experience radio and television as a consequence of the mind's conception of how nature must behave (Kline, 1980:342).

Hilbert (1900 in Kline, 1980:344-345) argues for the existence of an objective physical world which we strive to get mathematics to fit. We achieve this 'fit' through the "ever-repeated interplay of thought and experience" between our striving to resolve the problems posed by the external world and the ongoing processes of pure thought. As new questions arising from phenomena in the external world are addressed, their solutions often provide solutions to other outstanding unsolved problems:

But even while this creative activity of pure thought is going on, the external world once again reasserts its validity, and by thrusting new questions upon us through the phenomena that occur, it opens up new domains of mathematical knowledge; and as we strive to bring these new domains under the dominion of pure thought we often find answers to outstanding unsolved problems, and thus at the same time we advance in the most effective way the earlier theories. On this ever-repeated interplay of thought and experience depend, it seems to me, the numerous and astonishing analogies and the apparently preestablished harmony that the mathematician so often perceives in the problems, methods, and concepts of diverse realms of knowledge (Hilbert 1900 in Kline, 1980:344-345).

For Weyl (1949 in Kline, 1980:347) nature had a design which is revealed in mathematical laws:

There is inherent in nature a hidden harmony that reflects itself in our minds under the image of simple mathematical laws. That then is the reason why events in nature are predictable by a combination of observation and mathematical analysis (Weyl 1949 in Kline, 1980:347).

Hersh (1986:23) postulates that mathematics is a third kind of reality “a reality that is ‘inner’ from the view point of society as a whole, yet ‘outer’ from the viewpoint of each individual member of society.” It is part of our nonmaterial culture which includes the customs, traditions, and institutions of our society. For him the answer to the question of how the mathematical objects created by people can often turn out to be useful in describing aspects of nature is “easy and obvious” (Hersh, 1986:23). It is for the same reason that our biology is suited to the planet.

Human beings live in the world and all their ideas ultimately come from the world in which they live - refracted through their culture and history, which are in turn, of course, ultimately rooted in man's biological nature and his physical surroundings. Our mathematical ideas fit the world for the same reason that our lungs are suited to the atmosphere of this planet.

Once created and communicated, mathematical objects are *there*. They become part of human culture, separate from their originator. As such, they are now objects, in the sense that they have well-determined properties of their own, which we may or may not be able to discover (Hersh, 1986:23).

These positions are all based in the dichotomies that are fundamental to Enlightenment epistemologies: subject/object; mind/body; culture/nature; reason/emotion. I have argued in Chapter 2 that these dichotomies are gendered and reflect the fundamental dichotomy male/female. In all these positions there is an implicit assumption that the mathematician stands outside nature, that is he<sup>3</sup> occupies an Archimedean point as a knower which is

<sup>3</sup> In this paragraph I am using male pronouns for two reasons, I am following the style of the writers whose work I am engaging with and because the mathematician in these accounts is

somehow outside the forms and patterns of nature which he is trying to know through his mathematics. Either his mathematics and his mathematical objects occur in his mind or they arise from nature. The knower and his mind are assumed not to be a part of or inside nature itself. The mathematician undertakes the “god trick of seeing everything from nowhere” (Haraway, 1988:581), of seeing nature from the outside. Hersh (1986:23) comes close to taking a different position when he suggests (as I have quoted above) that “[o]ur mathematical ideas fit the world for the same reason that our lungs are suited to the atmosphere of this planet.” But he avoids disrupting the dichotomy by introducing a third level of reality, a mathematical reality.

I wish to take a different position in which these dichotomies do not hold such sway, in which the knower, the mathematician, does not stand outside nature, does not split between mind and body but represents the embodied mind thinking and knowing within and as a part of nature and capable of reflecting on nature itself. Mathematicians ask themselves whether nature operates according to mathematical laws or whether we impose mathematical laws and regularities upon it. Davis and Hersh (1980:310) highlight the absurdity arising from the consequences of the first position:

If we accept the common belief that the natural universe is governed by mathematical laws, then we understand that the universe and all within it are perpetually mathematizing - carrying out mathematical operations. If we are fanciful, we can think of each particle or each aggregate as the residence of a mathematical demon whose function is to ride herd and say: ‘Mind the inverse square law. Mind the differential equations.’ Such a demon would also reside in human beings, for they too, are constantly mathematizing when they cross the street in fierce traffic, thereby solving mechanistic-probabilistic extremal problems of the utmost complexity. They are mathematizing when their bodies constantly react to transient conditions and seek regulatory equilibrium, a flower seed is mathematizing when it produces petals with six-fold symmetry (Davis and Hersh, 1980:310).

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assumed to be male although this assumption is secreted behind unspoken assumptions about the possibilities of ‘he’ being used generically. My use of ‘he’ implies an unreconstructed gendered subject.

Nor can mathematics “simply impose its own makings” on the earth. “[T]he Earth and our Earthly lives are *already*<sup>4</sup> full of patterns and rhythms of interdependency and kinship”. Neither we nor mathematics “*make* these Earthly relations”. “Mathematics cannot simply impose its own makings on this fabric of relations *as if* the Earth can or must live up to the clarity and distinctness that mathematics demands *of itself*.” Even in the pursuit of mathematics, we are deeply and inevitably *of* this Earth. Mathematical formulations don't *make* trees ‘symmetrical’” (Jardine, 1994:110-111).

This offers a different way of understanding Hersh's (1986:23) statement that “Our mathematical ideas fit the world for the same reason that our lungs are suited to the atmosphere of this planet.” Our mathematics “erupts out of life as it is actually lived”, rather than being “graciously bestowed ‘from above’ ” (Jardine, 1994:112). Our mathematical ideas fit the world because at the same time as we are part of nature we can look back at nature and describe nature's patterns with our mathematics. Nature is far more complex than our mathematical descriptions of it, however. We are inside nature and able to investigate processes occurring in nature but our mathematical symbols do not capture or contain all of nature.

The questions mathematical philosophers have asked have arisen out of the unspoken dichotomies within which their thinking has been submerged. Because they conceive of a split between man and nature, between mind and body, between subject and object, they are compelled to take up a position as to whether mathematics belongs to the mind or the body, the subject or the object. Like Jardine (1994) I am attempting to articulate a position in which the subject and object, the mind and the body are intertwined, interconnected, inseparable.

Out of these debates (and of course influenced by myriads of other things) mathematical philosophy has moved towards greater concern with the social nature of mathematics.

<sup>4</sup> Italics in the original.

## **Philosophy takes account of the social**

The decline of foundationalist accounts as explanations for the ‘truth’ of mathematics as a result of their inability “to establish a universally acceptable, logically sound body of mathematics” (Kline, 1980:331) has opened the “rhetorical space” (Code, 1995) for “social talk about mathematics” (Restivo, 1993:248). The inability to establish a rigorous definition of rigour or proof has given support to the conclusion that a proof is rigorous if it wins acceptance. This acceptance has to come not just from anybody or everybody but from those who are “adequately educated and prepared to understand it” (Thom, 1986:72).

Many mathematical philosophers have taken up this direction in the philosophy of mathematics which points to the social/cultural character of mathematical knowledge. For example, Davis and Hersh (1980:410) attribute mathematical knowledge to its cultural context:

The meaning is to be found in the shared understanding of human beings, not in an external nonhuman reality. ... [I]t deals with human meanings and is intelligible only within the context of culture (Davis and Hersh, 1980:410).

Kline contrasts a formal, logical account of mathematics, which he regards as a fiction, with a description of mathematics as a human activity:

Mathematics is a human activity and is subject to all of the foibles and frailties of humans (Kline, 1980:331).

When Goodman describes mathematics as :

Mathematics is a public activity. It occurs in a social context and has social consequences (Goodman, 1986:82).

he refers to mathematicians working in social contexts in which mathematicians communicate their work to each other and acknowledge and critique the work of other mathematicians.

Polya refers to processes like guessing and checking, proving and adapting when he says:

Yet mathematics in the making resembles any other human knowledge in the making (Polya, 1986:100).

Wilder, too, understands mathematics as being socially determined:

by the general complex of cultural forces both within and without mathematics. ... As individual mathematicians we are just as susceptible to cultural forces as botanists, economists and farmers (Wilder, 1986:198).

Absolutist or foundationalist philosophies have been concerned with warranting mathematical knowledge absolutely and accordingly they assume and portray mathematics as timeless, superhuman, ahistorical, universally valid, value-free and culture-free (Ernest, 1995:450). This philosophical approach sanctions a view of mathematics as “rigid, fixed, logical, absolute, inhuman, cold, objective, pure, abstract, remote and ultra-rational” (Ernest, 1995:451). But the results of mathematics are “no more certain or everlasting than the results of any other science” even though “our histories of mathematics tend to disguise that fact” (Goodman, 1991:125). Our mathematical textbooks either ignore history completely and expound mathematics “in its contemporary form without mentioning that it was ever different” or they describe developments in mathematics as the correction of mistakes rather than as revolutionary breakthroughs (Goodman, 1991:125). They do not depict the controversies within which mathematical ideas were formed, refined, debated and clarified. The social nature of these processes is heavily disguised.

Fallibilist philosophies, which are associated with constructivist and post-modernist thought, portray mathematics as the outcome of social processes. In these philosophies the practices of mathematicians, the history and applications of mathematics, the place of mathematics within the wider culture, the values permeating mathematics and mathematics education are all legitimate concerns. Any notion of mathematics having a fixed, permanent, hierarchical structure is rejected in favour of the portrayal of mathematics as consisting of many

overlapping structures. Mathematics including mathematical proofs and concepts, is understood to be fallible and always open to revision (Ernest, 1995:452).

[M]athematics is associated with sets of social practices, each with its own history, persons, institutions and social locations, symbolic forms, purposes and power relations. Thus academic research mathematics is one such practice (Ernest, 1995:452)<sup>5</sup>.

These philosophical approaches to mathematics stimulate the asking of quite different questions, questions that closely fit more sociological approaches to mathematical knowledge. These are questions about the culture within which mathematics is done; the relationships between this culture and that of the wider society; questions about the history and values of this culture and the interests served and power relations produced (Ernest, 1991:25; Restivo, 1993:269; Restivo, 1988:218).

In taking up a sociological approach I am interested in examining the processes that determine and legitimate the practice and act of knowing and in part determine who can be a knower and how these processes are involved in the determination of the kinds of things that can be known (Braidotti et al, 1994:34; Harding, 1987:3). It is my contention that philosophies of mathematics and the social values and practices of mathematics have served to support and legitimate the position of mathematics in our culture and that they are closely aligned with dominant discourses of masculinity. This alignment helps to secure the place of mathematics in existing power relations, to ensure that mathematics retains a powerful position, and assists mathematicians to retain access to resources which enable them to produce their work. These

<sup>5</sup> The philosophy of mathematics is concerned with the practice of academic research mathematics and seldom addresses philosophical issues surrounding the mathematics of everyday life.

relationships are of course subject to threat, change and realignment. The coincidence of values in mathematics with modernist values serves to exclude the feminine and subsequently the position of women as knowers in mathematics. Stories of mathematics are partial accounts which emphasise the public face of mathematics, the logical and deductive, while the private more feminine face, is kept hidden. For women to take up positions as knowers they have to 'penetrate' the public and gain access to the private.

### **Sociology of mathematics**

In the following discussion I focus on the social/cultural in relation to my epistemological framework and in so doing I continue to undermine the dualistic construction of the social/intellectual binary. In taking up the 'social' there is a danger of privileging 'culture' in the nature/culture binary. This is not my intention.

Restivo (1993:250) as a sociologist, rather than a philosopher of mathematics, looks for the foundations of mathematics in social life not in logic or systems of axioms. The basis for this sociological approach lies in the conviction that "*all* talk is *social*; the person is a *social structure*; and the intellect is a *social structure*" (Restivo, 1993:248). Entering mathematics as a social world illuminates the "networks of human beings communicating in arenas of conflict and cooperation, domination and subordination" that make up "math worlds". The "connections to and interdependence with other social practices" and "the continuity between the social networks of mathematics and the social networks of society as a whole" are revealed (Restivo, 1993:249). This analysis illuminates the ways in which power relations, social processes and values such as specialization, autonomy and purity serve to legitimate the position of mathematics in society.

As mathematics does not produce the material resources necessary for its reproduction it must depend on others for them; so for its own survival it has to be concerned with its "productivity, social legitimacy, and professional autonomy". A systematic analysis of the social status of mathematics has to include "the

position of the discipline in the larger system of the sciences, the power of experts in politics or the economy, and the role of instrumental rationality in modern societies” (Mehrtens, 1993:220).

The deontologization of mathematics during the nineteenth century (Mehrtens, 1993:224) results in no specific objects of mathematics being presupposed. “Anything can become the object of mathematical thought” (Mehrtens, 1993:225). But if particular methods and axioms are accepted there is no way to avoid their consequences. This gives mathematics a kind of universality in which the cognitive products of mathematics can be applied to anything. The linguistic features of mathematics mean that no other field of knowledge can intervene in mathematics without becoming a part of mathematics, that is, without being formulated in mathematical language. So mathematics achieves cognitive autonomy. Cognitive autonomy is therefore linked to the cognitive products of mathematics. Another consequence of these linguistic features is to produce a highly esoteric core to mathematics which is inaccessible to outsiders (Mehrtens, 1993:225). I have discussed this aspect of mathematics in terms of its function as a critical filter in Chapter 4 and in this chapter I will discuss it further in terms of its role in the exclusion of particular social groups. Defining the social system of mathematics by its cognitive product serves to veil the power structure and social relations within the system (Mehrtens, 1993:229).

Mathematical knowledge has two other important characteristics that are influential in the establishment of autonomy. It is an important linguistic and theoretical tool in the production of scientific knowledge and it has no well-defined object in the material world and therefore no clear boundaries to its applications (Mehrtens, 1993:220). Social legitimacy for mathematics is achieved through the utility of mathematics and through its cultural value. This cultural value is depicted in such phrases as ‘an expression of the human spirit’, ‘basic training for the mind’ or ‘the core of modern rationality’. Professional autonomy is “ensured mainly by monopolizing competence for the specific type of knowledge production” (Mehrtens, 1993:221).

Specialization, professionalization, and bureaucratization are aspects of the organization of mathematics. They have the effect of generating closure in which the boundaries between mathematics and non-mathematics and between different specialities within mathematics are thickened. As these boundaries thicken they become increasingly impenetrable. This closure can have advantages and disadvantages. Some degree of closure is necessary to demarcate the social and cognitive worlds of mathematics. It facilitates innovations and progressive change but on the other hand too much closure inhibits them. If the boundaries are too thick the exchange of information and the stimulus of external problems is cut off and there is a danger that mathematical work will lose its applicability in other areas (Restivo, 1993:255). This in turn affects the autonomy of mathematics and its ability to attract resources necessary to its functioning.

As specialization proceeds, increasingly abstract objects are generated at the same time as the material and social origins of their production are obscured. The idea that this mathematics is the result of pure mental activity becomes increasingly prominent and plausible (Restivo, 1991:168). As specialisation is accompanied by generational continuity mathematicians work more and more within mathematics and less and less outside it. It becomes more difficult to discuss their mathematics in everyday language (Restivo, 1993:258). “Workers forget their history and fail to reflect on the social aspects of production as sources of their thoughts” (Restivo, 1991:168). Others who are more aware of the social dimension of their work can set out deliberately to protect this ‘purity’. This serves as a means of gaining and retaining control over their specialised knowledge against threats from other agencies who could compete for the scarce resources mathematics needs to continually reproduce itself (Restivo, 1991:168). The most ‘practical’ or ‘empirical’ forms of mathematics, those that can be seen to be most closely tied to applications are particularly threatening to the autonomy of the mathematical community (Restivo, 1993:266). There is a risk that those aspects of mathematics could be taken over by the community which controls the application. For example, mathematics with applications in physics, could become the property of physicists.

## Purity

In this section I discuss the place of notions of purity in the power relations of mathematics. Purism is a power strategy used to both protect and contain mathematical knowledge and to achieve status and prestige both for mathematics and for the society in which it is practiced. Purity also has a role in the inclusion and exclusion of particular social groups from mathematics, including women.

“Purism is an intellectual strategy that has multiple roots and functions” (Restivo, 1992:156). Historically it has connections in the relationship between mathematics and theology. In the challenges to traditional sources of knowledge brought about by the Copernican revolution and the Enlightenment, notions of purity served a useful function in appearing to diminish the threat to the established order of the church by continuing a commitment to the established moral order. Purity extricates mathematics from the unclean, polluting or from earthly pleasures. Through the hallmarks of pure mathematics, consistency and completeness, mathematics is aligned with the Holy (Restivo, 1992:156).

Claims to purity helped to establish the high status of mathematics in the hierarchy of knowledges as it places mathematics beyond the limitations of the senses. Such claims to purity are the product of the extreme separation of mind and body, of brain and hand (Restivo, 1992:171). Even now they continue to provide support for the ‘objectivity’ of knowledge as an association of knowledge with purity implies that the knowledge will not go out of date, will not depend on one’s political affiliations, and will not vary from country to country. ‘Purity’ supports claims to the universality of particular knowledge (Bishop, 1988:75).

This universality supported by notions of purity is however limited because the ‘purity’ of mathematics has powerful implications for gender. In the association of the male with the mind and the female with the body, ‘purity’ is associated with masculinity, and specifically a masculinity unsullied by sexual excesses of

the feminine. To keep mathematics pure it must be kept away from the temptations of the body, the flesh, the feminine. This universality does not include women.

In a society and historical period in which ‘science’ and ‘reason’ occupy such a high status in the hierarchy of knowledges and as exemplars of the very best in knowledge production, pure research occupies a relevance that is more than just the production of new knowledge (Restivo, 1992:156). It functions as a demonstration of the capacity for research in a society and thus establishes the prestige of that society in relation to others. Pure mathematics plays an important role in this, both in itself and in establishing the purity claims of other scientific disciplines. Knowledge that can be expressed mathematically is thought to be more ‘pure’.

Purism serves as a power strategy for both the producers of knowledge and the elites of society. Mathematicians can use claims to the purity of their knowledge to demarcate their knowledge from “military, economic, and political interests” (Restivo, 1992:156). Restivo (1991:166) interprets G. H. Hardy’s defense of pure mathematics in which he said “I have never done anything ‘useful’”, less as an argument for the purity of his mathematics than as “a manifestation of his hatred for war and his opposition to applying mathematics to problems in ballistics and aerodynamics”. Powerful elites can use ‘purity’ as “a way of keeping tabs on and control over creative and innovative thinkers by giving them ‘academic freedom’ so long as what they do keeps them from becoming active critics of the government or actively interfering with efforts by ruling elites to try to put their discoveries or inventions to use in the interest of military, economic, or political ‘advances’ ” (Restivo, 1992:156).

Arguments for the purity of mathematical knowledge are not just consequences of the often extremely abstract nature of mathematics, the objectivity of such knowledge and the social processes of autonomy and specialization. They arise out of the social conflicts within which knowledge is produced (Restivo, 1992:171). Purity serves an ideological purpose but it may be “the impurity of

actual mathematical practice” that can better account for the richness of mathematics (Restivo, 1992:174).

Walkerdine (1994:74) rejects the purity of mathematics and instead indirectly equates such a notion with a kind of “forgetting”. Walkerdine argues that we need to “recognize that thinking is produced in practices, replete with meaning and complex emotions, that thinking about thinking is deeply connected to the way that power and regulation work in our present social order.” The purity of mathematics allows us to forget these connections between thinking and power, and the connections between mathematics and abstract reasoning and the precarious present state of the world’s ecosystem. It is a “forgetting” of “the power of ‘western rationality’ which has understood nature as something to be controlled, known, mastered.” Mathematics and abstract reasoning may be “an enormous and dangerous fantasy” of the “omnipotence of scientific discourses that can control the world” (Walkerdine, 1994:74).

Restivo (1993:275) presents a similar argument in different terms. In his view modern mathematics can be seen as a social problem in that it tends to serve ruling class interests. It allows a professional and elite group of mathematicians to pursue material rewards without regard to the social, personal, and environmental consequences. Mathematical ‘education’ may serve more as a critical filter controlling access to prestigious professions (as discussed in Chapter 4) than as education in ingenuity, creativity, and insight.

Mathematics has been a tool of powerful ruling elites from ancient civilizations to the present. As knowledge, including mathematics and science, is a crucial resource in any society, the most powerful groups have sought and generally won the ability to control the development of systems of knowledge in ways that serve their own interests. The nature and transmission of knowledge comes to reflect and reinforce social inequalities (Restivo, 1993:274). Efforts to change this will fail if mathematics is accepted as pure knowledge (Restivo, 1993:275). It is necessary to look more closely at the practices of mathematics and the power relations within and outside the social worlds of mathematics.

Restivo concludes his discussion of these inclusions and exclusions at this point and does not go on to discuss the particular groups of people who are excluded from mathematics through these processes. I move further than Restivo's account by looking at the gendered implications of these power relations. Women and other marginalised groups are specifically excluded from participation.

Restivo (1983:266) argues, and I agree with him, that:

A radical change in the nature of our social relationships will be reflected in radical changes in how we organize to do mathematics - and these changes will in turn affect how we think about the content of our mathematics.

This thesis itself represents a change in thinking about mathematics as a result of changes in our social relationships brought about by feminism. According to Restivo (1993:276): "New social circumstances and arrangements will give rise to new conceptions and forms of mathematics" but "[w]e cannot anticipate these new conceptions and forms"; "we cannot even imagine them". I disagree with Restivo that we cannot anticipate them because feminist theory and research gives us insights into some new possibilities for mathematics and our conceptions of mathematics which I discuss later in the chapter. Restivo argues that any "revisions, reforms, and revolutions in mathematics" cannot be carried out in isolation "from broader issues of power, social structure, and values" (Restivo, 1993:275-276). Anticipating and imagining new possibilities necessitates looking critically at how "power, social structure, and values" (Restivo, 1993:275) operate within mathematics as currently practiced and in the relationship between mathematics and the wider society within which it is embedded. This requires us not to be seduced by the stories mathematics tells of its own 'purity'.

### **Mathematics and masculinity**

The popular image of mathematics as abstract, ultra-rational, logical, deductive, difficult and cold (Ernest, 1995:454) which is sustained by the privileging of 'rational' and 'scientific' knowledge in our society and is

confirmed by stories of mathematics as 'pure', offers access most easily to those who most closely identify with those values. Those tend to be middle or upper class males who are members of white ethnic majorities. Because these "values and masculinity are identified together in western culture, mathematics is identified as a stereotypically masculine domain, and as antithetical to the cultural stereotypes of femininity" (Ernest, 1995:455). Women entering mathematics face conflicting expectations between mathematics and femininity to which they may be expected to conform. The simplest and starkest rendition of this dilemma says that "women must choose to be feminine or choose to be successful at mathematics. If they opt for both, they have to live with the contradiction  $\text{mathematics} \neq \text{feminine}$ " (Ernest, 1995:456).

There are problems with such a stark portrayal of masculinity and femininity and, as I will go on to discuss, with this portrayal of mathematics. These are only stereotypes of masculinity and femininity and are not so useful in describing and predicting the behaviour of individual men and women. I am not making the argument that women are not capable of reason and abstraction and therefore cannot do mathematics, nor am I making the argument that men are not emotional or caring. My argument is that the privileging of masculinity, rationality, science and mathematics coincide. This coincidence leads to stories about mathematics and its practices that in turn privilege the rational and deductive while suppressing the intuitive. The stories of mathematics that could associate it with the feminine are suppressed. A " 'regime of truth' is established in which *maths = male*, *maths  $\neq$  female* and *female = inferior* are confirmed and sustained as 'lived truths' " (Ernest, 1995:456). Mathematics is not the "most pure and perfect form of rational knowledge" as "it is intertwined with power" and "it is power that institutes it as a regime of truth" (Tsatsaroni and Evans, 1994:88).

## Values

Feminist theory has used the concept of the public and private very successfully to analyse the position of women in society. In this representation of social

relationships men are assigned the public and women the private, the world of home and family (Code, 1991:243). This public/private distinction is also useful in the analysis of mathematics and the culture within which it is produced. There is a slight difference in the use of this theoretical construct - public/private - here from the use of it in feminist theory. Women as agents of knowledge are generally excluded from the private worlds of mathematics but what takes place in these private worlds of mathematics is closely associated with the 'feminine'. This association is suppressed however. Hersh (1991) talks about the front and back of mathematics but what he is describing can more usefully be described as the public and private for my purposes.

In this section I am going to discuss the practices and values operating within mathematics and analyse them to show how the public stories of mathematics privilege the masculine while stories of the feminine operating in the private worlds of mathematics are suppressed. The feminine operates in these worlds independently of female knowers.

The public front of mathematics is mathematics as it is known from school classrooms, textbooks and journals. This public mathematics is "formal, precise, ordered and abstract. It is separated clearly into definitions, theorems, and remarks. To every question there is an answer, or at least, a conspicuous label: 'open question'. The goal is stated at the beginning of each chapter, and attained at the end" (Hersh, 1991:128). The private back of mathematics is the mathematics of working mathematicians as they work on it and talk about it together informally. This private mathematics is "fragmentary, informal, intuitive, tentative. We try this or that, we say 'maybe' or 'it looks like' " (Hersh, 1991:128).

This public/private, front/back separation preserves a myth in which the public face of mathematics is taken at face value without an awareness of how this mathematics is created in private. Outsiders are taken in by the myth but insiders are not (Hersh, 1991:129). Hersh does not go on to analyse how this myth serves as a sifting device for determining who does and who does not

become an insider. The association of the public face of mathematics with masculinity and the suppression of the private leads to the sifting out of women from the private worlds of mathematics. For a woman to become a mathematician she has to enter the private worlds of mathematics and in Chapters 7 and 8 I will discuss at greater length, the experiences of women mathematicians who did just this. These women experience and participate in the private practices of mathematics which involve the informal, the tentative and the intuitive. They do so in a social context in which they often experience contradictions and difficulties as women in a male dominated culture.

Hersh (1991:130) identifies four myths about mathematics that serve to support and validate mathematics and are told in the public accounts of mathematics. They are:

- \* Unity: There is only one indivisible mathematics.
- \* Objectivity: Mathematical knowledge is the same for everyone irrespective of who or whether it is discovered.
- \* Universality: Mathematics as we know it is the only mathematics there can be.
- \* Certainty: ‘Rigorous proof’ assures absolute certainty of the conclusions, given the truth of the premises.

The rifts that often exist between pure and applied mathematics, and the inability of most mathematicians to understand much of the mathematics outside their own particular field dispel the myth of unity (Hersh, 1991:131). Although there is a strong consensus among mathematicians about what is ‘correct’ there are differences in the criteria applied to “what is ‘interesting’ or ‘important’ or ‘deep’ or ‘elegant’” that dispel the myth of objectivity. Mathematics is only universal to the extent that there are ‘enough like us’ to understand and communicate it (Hersh, 1991:132). The certainty of mathematics is dispelled by both the inability of mathematicians to define a ‘rigorous proof’ and the history of mathematics which reveals that proofs once

established are not established for ever. Insiders in the private world of mathematics are therefore unlikely to adhere to these myths.

To become a mathematician, a person has to move from the public to the private, from the front to the back and “to develop a less naive, more sophisticated attitude toward the myths of the profession” (Hersh, 1991:132). What Hersh does not expose is how these myths and the public/private dichotomy serve in the power relations of mathematics.

If the private style of mathematics were presented in public “few would believe in its universality, unity, certainty, or objectivity” (Hersh, 1991:131). Why then, would mathematicians want to preserve these myths if they are not accurate accounts of the practice of mathematics? They serve to sustain the power and privilege of mathematics and to demarcate mathematics from other disciplines. Mathematics has a vested interest in maintaining them and restricting access to the private worlds of mathematics as long as this public face continues to shore up the position of mathematics in the hierarchy of knowledges and therefore assist in the acquisition of the resources necessary to maintain mathematics.

Restricting access to insider status in mathematics has been useful in maintaining the status of mathematics in the past and in maintaining its position as a critical filter. It has guaranteed the reproduction of the population of mathematicians in sufficient numbers to maintain the community but not enough to threaten the position, power and status of existing members. The association of these myths with masculinity means that many women are discouraged from becoming insiders. Changes in society and technology external to mathematics which I will discuss at greater length later in the chapter, now threaten the effectiveness of these strategies. Demands from marginalised groups to be allowed full participation and a move towards discourses of accountability challenge the status gained by restricting access to mathematics.

In addition to these myths that are told in the public stories of mathematics, mathematics is associated with a set of values. These values are implicit rather

than explicit for the supposed objectivity of mathematics supports a view of mathematics as value free. Bishop (1988) identifies the following values associated with mathematics: rationalism, objectism, control, progress, openness, and mystery. I will argue that these values are implicated in the gendering of mathematics.

Rationalism is the value which has been singly most responsible for guaranteeing the power and authority of mathematics. I claim that it is also very influential in the exclusion of many women from mathematics. The association of women with the emotions generally precludes them from being recognised as rational. Rationalism focuses on deductive reasoning as “the only true way of achieving explanations and conclusions”. It depends on “ ‘internal’ criteria of logic, completeness and consistency” as opposed to empirical validation, tradition, religious dogma, personal status or experience” (Bishop, 1988:62). Although on closer examination mathematics does have quasi-empirical elements, and the establishment of mathematical knowledge does often depend on mathematical traditions and the personal status of mathematicians, these practices function in conjunction with deductive reasoning and logic.

Mathematics represents a particular way of theorising in which ideas are abstracted from material objects and explanations. Bishop argues that the ability to abstract in this way was dependent on the existence of a leisured class such as existed in early Greek society where this approach to mathematics had its origins. The leisured class did not have to be concerned with menial work as they had slaves to do it for them. This gave them the freedom to be able to see the value of separating thought from concrete reality (Bishop, 1988:64). A parallel can be seen in modern times with the freedom men gain for mental work by having women undertake their menial work for them. The split between the public work of men and the private work of women means that men are more likely to have the opportunity to indulge in and value abstract mental work.

Rationality is strongly associated with masculinity through the gendered association of the dichotomies mind/body; reason/emotion; objective/subjective. As I argue throughout this thesis the association of men and masculinity with the mind, reason, and objectivity, and women with the body, emotion, and subjectivity, provides ideological support for the exclusion of women and the reinforcement of masculine privilege.

Bishop identifies objectism as another value intrinsic to mathematics although it operates in tension with rationalism. Objectism is a world view which is dominated by material objects (Bishop, 1988:65). These objects are inanimate phenomena and they provide the “intuitive and imaginative bases” for mathematics in which mathematicians work with ideas as if they were objects (Bishop, 1988:66). Objectism in mathematics coupled with the high status of mathematical knowledge legitimates and sustains the hierarchical relationship between the subjects and objects of knowledge which I have discussed elsewhere in this thesis.

There is a tension between the values of rationalism and objectism as rationalism involves the separation of objects and ideas and objectism privileges material objects. In mathematics however, the ideas which are valued are ideas about material objects and come to be treated as if they were objects. Both objectivity and rationality support a dehumanised world view which relies on an objective not subjective view of reality. This further privileges male inclusion as women are associated with the private, daily, human and subjective aspects of life.

Objectism influences a picture of reality as a kind of complex mechanism “with nature being composed of objects moving in ways akin to machinery” (Bishop, 1988:68). The ‘extreme’ version of this view is the determinist view in which it is believed that “not only can natural phenomena be explained by mathematical principles but also these principles actually *determine* the natural phenomena”. While this view may no longer attract many adherents, the ever increasingly technological character of our environment does strengthen the perception of

reality as incorporating “consistent and determined phenomena.” Just as mathematics reinforces a materialistic technological world view because of mathematics’ association with technology, our increasingly “determined, planned, organised, predictable, efficient and precise” and technological lives, reinforce the “belief in the fundamental nature of mathematics in our society” (Bishop, 1988:69). The exclusion of women from participation in many aspects of technology mutually reinforces the position of women and the feminine in mathematics.

“Mathematics so clearly is about control.” In mathematics facts are facts, theorems are proved, abstract objects behave predictably. Once something can be mathematized “order reigns where all seemed chaos.” (Bishop, 1988:71). Bishop (1988:71) argues that mathematical algorithms can offer feelings of security and control because if the rules are followed the results are inevitable. However, this security is not offered equally to all participants in mathematics education. For those who cannot trace the preformulated steps, mathematics arouses a range of other feelings: panic; fear; and a sense of being out of control. A discussion of reasons why many girls and women have this ‘other’ experience of mathematics is found in Chapter 4.

Mathematics is a tool used to develop explanations of natural phenomena which leads to the ability to predict these phenomena. Once they can be predicted we feel a measure of control over them. This form of control arising from the ability to predict is extending to the social as mathematics is increasingly being used to explain social phenomena. To do this we need first to objectivise social phenomena and then quantify them. From this quantification comes the possibility of prediction and thus control (Bishop, 1988:70). Women’s subordinate position in society means that they are more likely to be among those being controlled, than among those doing the controlling.

The association of mathematics with technology is another manifestation of this desire for control as technology can have control built into it. The flip side is

that the behaviour of the person doing the controlling is also modified by the technology. There is a risk of becoming 'cogs in the machine' (Bishop, 1988:71). Once again women's complex relationships to technology see them placed in greater numbers amongst the 'cogs' than the controllers. An example is in the computer industry where large numbers of women are employed but their employment is disproportionately in the factory production of chips and components or in data entry, rather than in controlling the design, manufacture or programming. Mathematics and its association with technology is a factor in ensuring more women are 'controlled' than 'in control'.

A complement to feelings of 'control' in mathematics is the feeling of 'progress'. Developing an algorithm to solve one problem fosters the confidence that other problems are solvable and that progress can and will be made. There is an "exciting feeling that it is possible to understand more, that one need not forever be ignorant about certain phenomena." The generational continuity and the abstractions of mathematics sustain this belief that progress is achievable (Bishop, 1988:72). But who is it achievable by? For those unable to achieve the solution of the first algorithm they encounter, 'progress' appears to be an impossibility.

Technological developments also encourage the pursuit of progress although this is a twin-edged sword. Seeing progress as its own reward can disguise whether such 'progress' actually represents an improvement in human conditions. The result of 'progress' can be the proliferation of technologies that are wasteful of scarce resources; harmful to the environment (Bishop, 1988:74) and destructive of human relationships and lives. Progress for some is at the expense of poverty for others. These others are increasingly women and children. A conflict between progress and change, and control and security develops. This is not to say that mathematics is *the cause* of these problems but that reflective mathematical practice needs to be developed in which mathematicians consider the potential for negative outcomes and do not abdicate from their responsibilities behind a screen of mathematical 'purity'. Mathematics is not associated with progress by everybody, but only by those

who benefit materially and through acquiring control. Gender plays a part in determining membership of these groups.

Bishop (1988:76-77) sets great store by the value of openness in mathematics and claims that this openness “reinforces and stimulates feelings of democracy and liberation”. “Mathematical knowledge is open to everybody and anybody to ‘own’. ...Provided that you perform the correct procedures, and keep to the rules, logic will do the rest”. “Nobody has to persuade you.” Formalising practices in mathematics mean that the ideas are made explicit and thus open to criticism and objective analysis. Bishop does provide the caveats that to participate in this openness “one needs to know the conventions of the symbols and of the logic being used” and “exposing arguments and propositions doesn’t necessarily make the ideas or the conclusions appealing” (Bishop, 1988:76-77). Bishop sees rationalism, logic and precision as the *desirable* but not always socially acceptable and therefore sometimes unsuccessful alternative to “[e]motion, social mores, vested interests, politics, interpersonal attractions and repulsions” (Bishop, 1988:76-77).

What Bishop does not see is how these very things he is hoping to overcome with an ethic of rationalism, are integral parts of mathematics. These vested interests, politics and emotions are an integral part of mathematics along with an ethic of rationalism and a particular kind of openness. While mathematics is open to anybody and everybody who can perform the correct procedures, the ability to perform these correct procedures is restricted to the privileged few. Women figure largely amongst those excluded. Thus the openness of mathematics is only experienced by this few. The values and myths of mathematics are an intrinsic part of the processes which construct this restriction and discourses of gender are inherent in them.

According to Bishop (1988:77) there is a paradox between the supposed openness of mathematics and the ‘mystery’ of mathematics. While I dispute the degree of openness Bishop claims for mathematics, there is certainly a contradiction between the claims made for the ability of rational scientific

thought to dispel the mysterious, and the mysteriousness associated with mathematics.

Mysteriousness in mathematics is represented in many different ways. One aspect is in the popular view of mathematics spoken as ‘it is all a mystery to me’. This mysteriousness can be attributed to a lack of understanding of mathematics and mathematical concepts often brought about by the processes which exclude particular groups. There is another mystery in that “people still feel very mystified about just what mathematics is” (Bishop, 1988:78). There is also a long tradition of associating mathematics with the mystical through numerology, secret brotherhoods, or theological initiatives such as Thomas Aquinas’ attempt to fuse Catholic doctrine and Aristotelian philosophy. Mathematicians themselves often have an air of mystery about them. The abstraction of mathematics also serves to keep mathematicians abstract, remote and exclusive (Bishop, 1988:79). They ‘know’ what remains a mystery to many others. The close association of computers with mathematics compounds the mysteriousness as one has to be an ‘expert’ to understand computers so computers take on the mysteriousness of a ‘black box’ for general users (Bishop, 1988:80).

“The mystery of mathematics has grown, along with its power and influence” (Bishop, 1988:81) but this association is not merely coincidental as the mysteriousness enhances the power of mathematics and mathematicians. Despite the hours spent in the education system being taught mathematics, many students emerge still mystified as to what mathematics is and how to do it, so those people who can do it, acquire even more prestige and power. They are the ‘experts’ who hold the keys to this mysterious world. As these experts at the highest level of mathematics are disproportionately men, male privilege and power is reinforced.

The mysteriousness of mathematics also makes mathematics intriguing and attracts people who desire to unlock the secrets of this ‘queen of the sciences’. Keller (1985) has explored the gendered and sexual nature of these metaphors

in relation to science. I discussed this further in Chapter 5. A very similar analysis applies here. Kline (1980:4) alludes to the association with mystery and the power and control that goes with dissolving mysteries:

Mathematics, then provided a firm grip on the workings of nature, an understanding which dissolved mystery and replaced it by law and order. Man could pridefully survey the world about him and boast that he had grasped many of the secrets of the universe which in essence were a series of mathematical laws (Kline, 1980:4).

While Bishop himself does not link the values he identifies in mathematics with gender, these values support the privileging of masculinity in mathematics and the exclusion of women and the feminine.

In the next section I identify and analyse the gendered implications of some mathematical practices.

## **Practices**

According to Walkerdine (1994:70), thinking is produced within practices which are historically and culturally located. Mathematical thinking is no exception. I look now at some practices occurring within the culture of mathematics in order to see how gender is constructed within mathematics and how mathematics is constructed as gendered.

“Outsiders see mathematics as a cold, formal, logical, mechanical, monolithic process of sheer intellection” but for insiders “mathematics is a social, informal, intuitive, organic, human process, a community project” (de Millo et al, 1986:269). I am going to describe a few of these human processes or practices to show how gender is implicated in them and to reinforce that the difference between the outsider and insider views, the public and private, has gendered implications.

We do not know very much about mathematical practices (Restivo, 1990:130), and this lack of knowledge is a result of the way power works in relation to mathematics. If everybody knew about the private practices of mathematicians,

mathematics would lose its mystique and privilege and everybody might think they could do it. So mathematics has a vested interest in maintaining this ignorance rather than dispelling it, although this position is under threat from other wider societal changes which I will discuss later. There appears to be a contradiction in that mathematics, the supposedly most rational and objective of human knowledges only has subjective accounts of its own culture and practices. We have individual accounts such as Davis and Hersh (1980) but very few systematic studies of the culture and practices of mathematics. This represents the power of mathematics to resist the domination of scientific accounts and to protect its prestige through maintaining its public/private divide.

What is known is that mathematical practices have more in common with tinkering<sup>6</sup> than the formal and deductive fronts with which we are usually confronted (Restivo, 1990:130). The women mathematicians I interviewed gave descriptions of the way they did their mathematics which confirm this view.

The public face of mathematics presented to outsiders fits with the view of masculinity in which masculinity is associated with the logical, mechanical, deductive and intellectual and femininity with the intuitive, organic, and emotional. This view reinforces the association of mathematics with masculinity and together with the privileging of the masculine in our binary worlds produces a strong resistance to exposing the private feminine world of mathematics to the outsider's gaze.

### **Doing mathematics**

Making mathematics resembles the making of any other knowledge. Guesses are made and confirmed or rejected, the overall idea is established before the

<sup>6</sup> This use of the word 'tinkering' derives from ethnographic studies of scientific practices such as Knorr (1979).

details are filled in, examples are tried, analogies are made, observations, discoveries and new lines of thought are discussed with others. The knowledge maker tries and tries, again and again (Polya, 1986:100). All of this occurs in a social context in which one mathematician is aware of the work of others and seeks to impress and convince these others of the validity and importance of their own ideas. Processes are established in the community to facilitate the dissemination and accreditation of new contributions (Goodman, 1986:82).

The descriptions given by Milly, one of the mathematicians I interviewed, give an impression of how mathematicians go about their work. Her descriptions are representative of the descriptions given by the other participants.

Usually [there is] something you would like to know the answer to, you know, what happens if you do this? You might understand something about it already. What happens if you change something, how is it changed and then you scrabble around and get all the bugs. [You] ask other people how they would do this and you look in the literature. Once you know what it is you want to prove there is a lot of time trying to find some way. You spend a lot of time fluffing around trying, seeing that it is not 'do-able' and trying something else. (Milly)

The development of new mathematical concepts and proofs requires much more than the completion of logical deductions from one step to the next. Tinkering and intuition are required to conceive what the next steps could be before the logic of the deduction from one step to the next is clarified.

### **Intuition**

In Enlightenment thought reason and intuition are represented as a dichotomy. Reason is the process of reaching a conclusion as a result of deductive logic and intuition is the process of “immediate apprehension by the mind without reasoning” (Allen, 1990:623). It is my contention that these two processes are not so distinct and actually inform one another. Intuition does not occur out of nowhere but builds on the insights gained or confirmed by reason and vice versa. In dichotomising reason and intuition, reason has been privileged and

associated with the masculine and intuition devalued and associated with the feminine, as in 'women's intuition'. It is a little surprising then to find mathematicians talking so much about intuition in their work practices. They 'know' something is 'true' before they 'prove' it. Reason then serves to confirm or discount this intuition for intuition can be deceptive (Kline, 1980:317). Becoming a mathematician, requires the aspirant to develop their mathematical intuition. Being able to manipulate the formal symbolic language of mathematics is not sufficient. What the mathematician seeks is an 'intuitive' understanding of mathematical concepts. A rigorous proof means nothing if the result doesn't make sense intuitively (Kline, 1980:315). Accounts of mathematics that privilege the rational over the intuitive, privilege the masculine over the feminine and shore up the power relations that operate within mathematics to exclude women and to suppress any connection to the 'feminine'.

### **Proof**

In defining reason and logic in opposition to emotion and intuition a certainty is given to proof that it does not deserve. The popular appreciation of proof is that one begins with undeniable axioms and proceeds step by step, with each step logically deduced from the previous one, to a conclusion which must inevitably be true, if the axioms were true. This is a popular belief about what mathematicians do, but it rarely if ever occurs in practice (de Millo et al, 1986:273). In other forms of mathematical practice such as university courses it is very common for students to spend a lot of time repeating the steps of important proofs but this is different from the practices of creative mathematicians.

What does happen is that the ideas of a proof are presented to other mathematicians who are in a position to understand them and they may suggest refinements. Then the theorem is submitted for publication and if accepted others gain access to it. Once accepted as probably true, others may use the theorem in their own work, they may internalise it and rework it in their own

terms. It gets used and if it does not lead to contradictions, belief in it will be strengthened. Engineers may plug physical values into it, further strengthening belief in the proof (de Millo et al, 1986:272-3). What is less likely to happen is for another mathematician to search the proof for errors. Kline (1980:312-3) describes this process clearly:

Mathematics grows through a series of great intuitive advances, which are later established not in one step but by a series of corrections of oversights and errors until the proof reaches the level of accepted proof for that time. No proof is final. New counterexamples undermine old proofs. The proofs are then revised and mistakenly considered proven for all time. But history tells us that this merely means that the time has not yet come for a critical examination of the proof. Such an examination is often wilfully delayed. Not only is there no glory in finding errors but the mathematician who could have reason to question the proof of a theorem may want to cite it on behalf of his own work. Mathematicians are far more concerned with establishing their own theorems than with finding flaws in existing results.

What is being established here is that there is no rigorous definition of proof. A proof is accepted if it receives the “endorsement of the leading specialists of the time or employs the principles that are fashionable at the moment” (Kline, 1980:315; Thom, 1986:72). The acceptance of a proof then, is very much dependent on the social relations of the mathematical community. If as de Millo et al (1986:268) claim 200,000 theorems are published every year and the ‘rigours’ of mathematical proof are not as rigorously defined as the popular view holds, then gatekeeping practices taking place within the mathematics community are part of the process by which a mathematical proof becomes accepted.

### **Communication**

Mathematicians’ habits of communication have been described as dysfunctional by Thurston (1994:165). One reason for this arises as a consequence of the intensification of specialisation in mathematics. Mathematicians in different specialities are often unable to communicate their mathematics to specialists in different areas (Griffiths, 1993:597). It is not uncommon for a speaker at a colloquium or seminar to continue to speak for fifty minutes although the vast

majority of the audience failed to understand the talk after the first five minutes. As one mathematician in the department where I worked while writing this thesis remarked “I could go to a seminar in any other discipline in the university and understand more of it than I do at most mathematics seminars I go to” (Carter, 1994). When I asked him why he and other mathematicians in the department bother going he replied “To provide an audience for a distinguished visitor or to show support for our graduate students or fellow staff members.” This reply highlights the complexity of social processes occurring in a mathematical community. The culture of mathematics is hierarchical and elitist but within that context individuals provide support and encouragement for each other and for their ‘apprentices’.

The intense specialisation occurring in mathematics is only one of the reasons for the common practice of mathematicians to talk without an expectation of everyone in the audience following the whole talk. Understanding implies trivia; mystification implies prestige and power. At the same time, mathematicians knowledgeable enough to understand multiple fields can enhance their prestige by knowing so much. They can also intimidate others and help to validate and maintain the system by making understanding appear to be possible for anybody. Communication practices in mathematics have the air of the ‘emperor’s new clothes’ about them with no one willing to publicly admit ‘I don’t know what you are talking about’.

Milly and Fiona’s reactions to this communication style are typical of the women interviewed.

If you go to a talk that is understandable, other mathematicians are very scathing about it. They presume if they understand it [and it is outside their specialist area] then it must be trivial. (Milly)

I think most mathematicians in different fields can explain to some extent if they really want to. If they don’t want the mystique in their power province. It makes you feel powerful doesn’t it, if you understand all this stuff. (Fiona)

The women I interviewed all deplored this practice and valued clear and understandable communication. Their responses corresponded with the stereotype that holds that women are 'better at communication and value it more highly'. I retain some degree of caution about being too ready to confirm such stereotypes while at the same time recognising that these practices within mathematics have gendered implications.

Given these communication problems and the pretence that power relations are not involved, what purpose do mathematical seminars and colloquia serve? Mathematicians, like many other groups, are driven by considerations of economics and status. To acquire and distribute this status and the resulting economic rewards, mathematicians are continually judging and being judged (Thurston, 1994:171). In such a fiercely competitive, elitist and hierarchical system, grades, seminars, conference papers, invitations to speak and visit, prizes and publications all serve as the desired currency of the system. Increasingly the ability to attract research funding is becoming part of that currency. This creates pressure to change some mathematical practices which I will address in greater detail later.

Mathematicians are under intense pressure to publish (Kline, 1980:282). This is the most important avenue for them to establish credentials for appointments, promotions and funding. This pressure is partly responsible for the high number of theorems published annually. Many of these theorems will never be taken up by anybody but mathematicians continue to chum them out. The pressure to publish also influences the kinds and directions of problems that mathematicians work on. Under the pressure mathematicians must ensure they are working on problems that are 'do-able' and will allow them to meet the goals set for them. One visiting mathematician (Chew, 1994) told me of the advice his Ph.D. supervisor had given him:

You have to have your feet in two camps. One foot is in the camp where you can get quick and regular publications and the other foot is where your mathematical heart lies. This is where the problems that *really* interest you are. But they will be difficult and important

problems and will take a very long time, perhaps years and years to solve. If you make a breakthrough you will receive much acclaim because others will recognise the difficulty of the problem you have solved or the new techniques you have developed. In the meantime you have to be publishing in a simpler area in case the big breakthrough is very slow or never comes. (Chew)

The women I interviewed were mostly aware of these strategic approaches but were reluctant to adopt them themselves. I will discuss this attitude at greater length in Chapters 7 and 8.

This same visitor told me about strategies for getting papers published:

First you have to identify journals likely to be interested in your topic. Then you identify the people most likely to be reviewing your work. Then you make sure you cite their work in your own paper. This will increase their enthusiasm for publishing your paper as it will increase their own citation ratings and flatter their egos. (Chew)

In many mathematics journals one-sided blind reviewing is common practice, that is the referee knows who wrote the paper but the author does not know the referee. (Except that they can often make a shrewd guess). Another way to increase your likelihood of being published which was suggested to me by a mathematician is to include the name of someone prestigious amongst the authors, with their permission but without expecting more from them than a cursory glance over the paper before it is submitted.

There is a hidden agenda of hierarchy and elitism. It is not just the merit of the mathematics that establishes its value. The prestige of the author(s) and their relationship with others who occupy high positions in the mathematical hierarchy also plays a part. Thurston (1994:171), Ernest (1994a:43) and Jaco (1994:426) all refer to the role of gatekeepers in examining Ph.D. theses and refereeing conference and journal papers.

Geller (1996a, 1996b)<sup>7</sup> undertook research on the acceptance rates for women mathematicians in mathematical journals published in the United States on behalf of the Joint Committee on Women in the Mathematical Sciences. The purpose of this research was to help the nine societies this committee reports to, to establish and maintain fairness and equity. One journal did not publish any papers written by women and this was found to be an intentional result of attitudes of the editor of that journal. Steps were taken to correct this problem. Apart from this one exception Geller reports:

[T]he journals had an overall higher rate of acceptance for women in numbers. In the premier journals, which had few papers by women, we found that few women sent them papers but that the acceptance rate was very much higher than that of males, but with such a small number of women, I did not think it appropriate to run significance tests. The overall higher rate held for both double blind and by author refereeing<sup>8</sup> with no discernible trend as to one being more favorable than the other. The truly amazing (to me) finding is that the rate of request for major revision was enormously higher in the males - in one journal only one female author in 3 years was asked to do a major revision while 32 male authors were, yet over 10% of the articles accepted in those three years were authored or co-authored by women. Even the request rate for minor revision was lower for women. We hypothesised that women spend more time polishing their papers, perhaps too much in the sense that they may be spending time over-polishing when they could be doing research, and that they had less confidence in the quality of their work so sometimes sent their papers to lower quality journals than the work deserved (Geller, 1996a)

Geller was also involved in research looking at other forms of communication:

As to other studies we did - rate of plenary speakers at international, national and regional meetings by gender, and the same for invited session organizers and invited sessions. The results were abysmal, but the (private) report had great consequences. We still have to remind the

<sup>7</sup> There are restrictions on what can be reported from Geller's study resulting from confidentiality agreements with the participating journals.

<sup>8</sup> In double blind refereeing both the author and the referees are unknown to each other. What Geller refers to as "by author refereeing" means that the author does not know who the referees are but the referees know who the author is.

organizations occasionally (esp. the international congress), but on the national level a small 'ahem' is all that is needed. Women are now routinely invited and we have gotten them past the position that there are only 3 women to ask but they will be often. It's now spread around (Geller, 1996b).

Geller's report shows mixed receptions to the publication and presentation of work written by women mathematicians. There was discrimination against women at the same time that women had higher acceptance rates. Geller's hypothesis about the much smaller need for women to do major revisions highlights the complexities involved in considering gender issues and any other discrimination issues. The situation is further complicated when the results of another study undertaken in 1979 are taken into account.

A study on citations showed that in mathematics 2.9% of articles classifiable by gender were written by women although 13% of the membership of professional associations were women and 7.6% of those doctorates in the mathematical sciences employed in educational institutions in 1979 were women (Billard, 1991:712).

Hopefully the more optimistic findings of Geller's research indicates an improvement over time. The behaviour of the groups thought to be discriminated against also has to be examined and understood. These studies show that the value of the mathematical contribution is not the sole determinant of the worth attributed to new results in mathematics.

A closer look at communication and publishing practices gives a different perspective on the mathematical community than that implied by the popular view of mathematics as objective and impersonal. The exclusion of all but a very few women is brought about by a complexity of political, cultural and material factors. The hierarchical and elitist culture of mathematics, the values pervading mathematics, communication and other work practices and the ways in which all of these are intertwined in our constructions of masculinity, combine in multiple and complex ways to distinguish between those who will and those who will not become insiders in mathematics

## Changes being imposed from outside mathematics

Mathematics is not hermetically sealed from the wider society within which it is situated and so changes occurring in the wider society impose and stimulate change within mathematics. Of particular interest to me are pressures on mathematical communities to change traditional practices as a result of pressure from changes in funding regimes, technological changes and the demands of historically marginalised groups for full participation in mathematics. In this section I will discuss the implications some of these changes could have for mathematics and the ways in which mathematics and gender are mutually constitutive.

A movement in politics to the right has resulted in changes in funding and status for universities. This has had the result of severely restricting the financial resources of universities and of the imposition of different kinds of accountability for expenditure on research amongst many other things. Universities are caught up in conflicts between discourses of ‘academic freedom’ which have previously dominated academia and discourses of ‘accountability’ which arise from the rational management discourses and practices of the New Right.

Discourses of ‘accountability’ played out in determining the allocation of research funding have potentially severe effects for pure mathematical research and for the practices of mathematicians. To gain research funding under regimes formed by discourses of ‘accountability’ requires two kinds of changes. It requires change in forms of practice that pure mathematicians in the past have prided themselves on *not* being involved in. Gaining status within their hierarchies has depended at least to some extent on not undertaking these practices. The first is linking developments in pure mathematics to ‘practical’ ‘real’ outcomes that have economic benefits. Under the new regime potential ‘economic benefits’ of research are a powerful device for obtaining funding. The kind of research that attracts funding will be where the resources in terms of staffing, facilities and money are to be found. This has the consequence of

determining where the jobs are and where the students, both graduate and undergraduate, will be attracted. Over time these areas become more prestigious.

Another pressure arising from the need to attract funding is the pressure to be able to communicate what it is you are doing. Mathematics has maintained its power and prestige in the past by not communicating with the uninitiated. It has retained power through its mysteriousness. But this is not such a viable strategy in the new regime. For the allocation of funds is not solely controlled by mathematicians themselves and therefore being able to communicate with outsiders about the meaning and value of a particular mathematical research project acquires more importance and threatens the traditional practices by which hierarchies within mathematics were established.

Technological changes, particularly in computer technology, also pose a threat to mathematics as it has been practised and understood. Developments in computer technology would have been impossible without the use of mathematics as “the enabling conceptual technology” (Rotman, 1994:77) but at the same time developments in computer technology are changing mathematics. New types of mathematics and ways of mathematical thinking have come into existence in areas such as chaos theory and fractal geometry. The nature of mathematical proof is being challenged by the power of computers (Rotman, 1994:84).

Previously a proof was supposed to be surveyable, that is, it could be checked by hand by verifying each inference was correct. The same condition cannot be applied to computer proofs. When a computer proof is so long that a hard copy would fill several rooms, the surveyable condition appears to be lost (Tymoczko, 1986:243 & 247).

Chaos theory and fractal geometry rely on computer-generated images that would otherwise be undrawable. These new developments in mathematics in combination with the potential of virtual reality could lead to the development of new mathematical practices. With a virtually realized mathematical structure,

a mathematician or student or any interested person could walk around it, move it, rearrange it, feel it and alter its shape. The basis for mathematical proof could be completely different. “A proof would no longer have to be an argument organized around a written ... sequence of logically connected symbols but could take on the character of an external, empirical verification” (Rotman, 1994:84). As Rotman (1994:84). says:

[S]uch a transformation of mathematical practice would have a revolutionary impact on how we conceptualize mathematics, on what we imagine a mathematical object to be, on what we consider ourselves to be doing when we carry out mathematical investigations and persuade ourselves that certain assertions, certain properties and features of mathematical objects, are to be accepted as ‘true’.

The third pressure for change I have identified as relevant to my project is the demand from traditionally marginalised groups for full participation in mathematics and all other aspects of society. Feminist demands have been of central concern in my project but there are related movements based on the demands of indigenous peoples and other ethnic minorities. Pressure to include such groups within the mathematics community leads to the questioning of the dominant histories of mathematics, definitions of what is and is not mathematics, and the elitist and hierarchical practices occurring within mathematics communities.

These different pressures intersect and interact with each other in complex ways. The participation of previously marginalised groups may be threatened by changes to funding regimes and technological developments. If the allocation of funding is influenced by discriminatory practices against women, then the status of women will be adversely affected and pressure to include more women may be countered. Access to technology is also influenced by gender, so access by women to new prestigious areas of mathematics may be restricted rather than enhanced.

Mathematics could look and be practised quite differently in the future. How it looks will be determined by a complex interaction of discourses, practices and material conditions all of which intersect with gender in a variety of ways.

## Conclusions

In this chapter I have attempted to show that mathematics is inextricably bound up in the social and in this binding there are implications for gender. The association of mathematics with its public face serves to reinforce the association of mathematics with masculinity both in terms of thinking about mathematics as a masculine domain and in reinforcing dominant definitions of masculinity. As the masculine is privileged in society this association shores up the power and prestige of mathematics. In the private world of mathematics different values and practices are operating, ones which are traditionally associated with the feminine but this private world is kept hidden and access to it is retained for the privileged few. Changes in the wider society are imposing changes on mathematics which could lead to shifts in the practices and power relations of mathematical culture.

In the next chapters I will move on to an examination of the experiences of some women mathematicians and how they make sense of the world of mathematics and their positions in it.

# Chapter 7

## The Experiences of Women Mathematicians

### Part One: Who Can be a Knower?

#### Introduction

In Chapter 2 I argued for a broader definition of epistemology that included questions about who could be an agent of knowledge, how credibility is established, connections between knowledge and power and the political nature of knowledge projects. In this chapter I relate the first of the questions raised in my arguments for feminist epistemology, that is who can be a knower? to the experiences of women mathematicians as knowers. In Chapter 3 I introduced the women mathematicians who participated in this project and gave some of their biographical details. Here their experiences serve as an illustration of the processes through which an individual passes in becoming a mathematician. These experiences serve to illustrate how the processes involved maintain a gendered group of knowers and in particular make women's inclusion problematic. For women to become mathematicians they have to negotiate contradictions and conflicts, and avoid or overcome exclusionary practices. These women's stories tell how they negotiated this tricky terrain.

In addressing the question of who can be a knower I make the assumption that these women are 'knowers in mathematics'. Their position as women in mathematics is problematic. They are not necessarily or always welcome. However they *are* knowers in that they develop/invent/create new mathematics and this mathematics receives acceptance and validation by the mathematical community. Seven of them have Ph.D.s in mathematics which in itself is a recognition that they have made an original contribution to the discipline. They have all made further contributions in published papers or reports.

In order for women to join this world, they may have barriers to overcome. The first of these is the prejudice that women have a problem with mathematics and that being mathematical is in some way incompatible with being feminine. They may face resistance or lack of support from their families when they express interest in entering a non-traditional field. They may receive poor quality career counselling that restricts rather than expands their possibilities. Some will find being outnumbered by male students alienating and isolating and drop out. Others may not receive the mentoring and introduction to scholarship and job opportunities their male peers receive. If experienced, sexual harassment can be another barrier to participation. Career breaks for childraising or other family responsibilities are often used to explain the lack of progress in women's mathematical careers (Barinaga et al, 1993; Billard, 1991; Birman, 1991; Bleier, 1986; Cole and Zuckerman, 1991; Epstein, 1991; Fee, 1983; Fox, 1991; Gray, 1995; Harrison, 1991; Henrion, 1991; Lewis, 1991; Rose, 1994; Yentsch and Sindermann, 1992; Zuckerman, 1991). Some examples of how the women in this research negotiated these barriers are presented here.

Also discussed in this chapter are the experiences of isolation these women often describe both within the male worlds of mathematics and in their interactions with other women outside mathematics. This isolation is not a constant in their lives but is felt more strongly at some times and in some circumstances by some individuals. The women have a variety of responses and ways of coming to terms with these contradictions. The same variety can be found in their attraction to mathematics itself and to the particular aspects of it with which they are involved.

In the next chapter I relate their experiences to the second of my epistemological questions about “the processes that determine and legitimate the practice and act of knowing” (Braidotti et al, 1994:34). This exposition not only illustrates how ‘knowing’ is legitimated in mathematics but illustrates how these processes are mediated by gendered discourses and practices.

Because I am trying to capture the complexities and contradictions in the women's experiences sometimes quotes are selected because they are typical of the responses of all the women. At other times an exceptional response is selected to illustrate the contradictions amongst even this small group of women. As I have a commitment to convey a sense of the individual voices of the women I have sometimes quoted from them at some length. On other occasions I judged a shorter quote to be sufficient to retain a sense of the participants as individuals and to depict the complexity of their responses.

### **Who can be a knower in mathematics?**

In considering this question of who can be a knower in mathematics, I have taken a qualitative approach as I outlined in Chapter 3. Quantitative analyses have highlighted the rarity of women mathematicians and have established some key issues that act as barriers to the participation of women. In my qualitative analysis I seek to illuminate the complexities and intricacies of how gendered processes and practices impact on these women mathematicians. In the process of gaining access to the private worlds of mathematics women encounter barriers and the women in this study are no exception. There are both differences and similarities in how they negotiated these barriers and the impact the obstacles had on them.

### **Transition from school to university**

I begin with the transition from school to university. As this transition is not the central focus of my investigations I focus only on prior academic achievement, family support and career counselling.

Intellectual ability and academic success are necessary prerequisites for any person pursuing the study of mathematics at this level but they are not sufficient, particularly for women. The women in this study did have the necessary intellectual abilities. Sarah, for example, was the second to top girl in

Scholarship in her year. She got 100% in Bursary mathematics<sup>1</sup>. They were not victims of some of the discursive practices (which I discussed in Chapter 4) that operate to exclude girls from achieving their potential in mathematics at school. Unfortunately further discussion of this lies outside the constraints of my thesis.

Although none of them received helpful careers advice from their school counsellors or careers officers, they did receive encouragement and support from their families. They did not have to overcome resistance by their families to their participation in non-traditional areas. Rebecca and Sarah's responses were representative of all the women.

When I first went to university, my mother said I should do maths because I was very unsure what I wanted to do and she felt that if I had that [mathematics] I could go [into] either science [or arts]. She is a scientist and I think they felt really regretful that I hadn't gone on in science. So if I did maths I could still have that avenue open to me. So I did maths somewhat reluctantly. (Rebecca)

I guess there was probably quite a lot of family pressure too, subtle but there, around achievement. My mother's brother was a Professor. There wasn't a lot of education in the family. I was one of the few of my generation on my father's side who had actually done university study. It was certainly the kind of ethos at home where you have to use all your talents. If you are a talented academic you really have to use it. (Sarah)

Although Imogen's family couldn't afford to support her at university so she had to bond herself to teaching in order to get government support, they did provide encouragement and moral support.

The women continued on with subjects they were interested in at school. They had enjoyed mathematics, they had done well at it and they carried on with it,

<sup>1</sup> At the end of the final year at high school New Zealand students intending to go on to university sit a nation-wide examination called Bursary, usually in five subjects. The most able students have the option of also sitting harder examinations commonly referred to as 'scholarship' because the winners receive scholarships for university. At the time Sarah sat scholarship, students sat five subjects and were ranked on their total marks.

without being introduced to other mathematical areas like engineering. Liz was an exception. She did an undergraduate engineering degree, unlike the others who majored in mathematics. She was influenced in this choice by her interest in mathematics and family connections to engineering through her father and brothers.

### **Transition to doctoral study**

Making the transition from graduate to doctoral study is often facilitated by the encouragement given by supervisors or professors. Suggesting to people that they 'have what it takes' assists the individual to make the decision to carry on to the next step. This does not happen for everyone, including male students, and certainly did not happen for all the women in this study. There is evidence from other accounts to show that this is not unusual for female students (Gray, 1995; Harrison, 1991; Jackson, 1991; Schafer, 1991).

Milly was unusual in that she received specific encouragement to go on to doctoral study although this did not extend to introductions to suitable supervisors:

There was a woman in physics. The maths department had no women. She encouraged me. She was the only one of all the physics people who said if you want to go to medical school, go to medical school. The others said 'Oh no, you must do physics.' She talked about doing a Ph.D. [She said] it was so hard that if you had any doubts about it you wouldn't be able to do it. So she was the opposite, she was supportive but she wasn't pushy.

*So you did masters and then did you get a scholarship to go to Oxbridge<sup>2</sup>?*

Yes. It was the next thing I did. I had always wanted, for a long time, I thought of going to Oxbridge, not for any other reason but if you live in New Zealand you have this idea about the mystery about it. In hindsight it might not have been the best thing, but once you are there of course [you got on with it]. (Milly)

<sup>2</sup> Italics in this context represent the interviewer was speaking.

Fiona on the other hand was more typical in that she did not receive such support:

*Did you have a lot of encouragement from here to go and do this?*

No, but I wouldn't say I wasn't encouraged either, I ..didn't talk about it a whole lot.

*At the time did you think it was unusual?*

I knew it was unusual, yes. I don't think it bothered me one way or the other, that was what I wanted to do so I did it. (Fiona)

Jane commented that this situation of women students not being personally encouraged to go on, had not changed much at her university since her days as a student:

I think that some of the very good women students in mathematics, the ones at the very top were not encouraged to go to graduate school like the boys were. None of them have gone on to Ph.D.s, none of them, and we have had some good ones. (Jane)

Another way in which students are eased through the transition from undergraduate and masterate study to doctoral study is the practice of supervisors or university teachers using their own networks to open up opportunities for their students. A student's superior can serve a 'gate-keeping' role by introducing their students to others they know who can provide supervision, facilities and/or funding for doctoral research. Of course this does not happen for all male students but it is significant how seldom it happened for these female students. Only Sarah had the experience of having a professor use his networks on her behalf to set up supervision for her Ph.D. The others tended to find their own way. They may have received helpful advice but otherwise they saw scholarships and jobs advertised and applied for them.

Sarah's supervisor, B, used his personal networks to set her up for a Ph.D.:

It seems a bit presumptuous but I guess I had always assumed that I'd go and do something like that. I was always good there was no doubt about that. I remember B sat me down part way through the honours year and said what are you thinking about doing next year and at that stage I didn't think I was going to get first class honours

because I didn't think I was working hard enough to get it. I knew I was capable of it but I wasn't with it enough to get it. I said, yeah, if I got honours I would probably go and do one, (Ph.D.) if I got some money. I knew I would have to leave New Zealand to do it in the kind of things I'd been doing in operations research. Yeah because B was about the only one who was doing it here and he was going off to Australia the following year. I knew I really needed to look outside to go anywhere and I knew to do that I had to get a scholarship and I knew to get that I had to get first class honours. So yes, I suppose I was half tapped on the shoulder and half, um, well, yeah, it was the kind of thing, if you are going through and doing academic stuff what do you do? You just keep going. (Sarah)

Rebecca acted more on her own initiative which was also typical of the other women:

When I did the honours year, I had got really interested in the philosophy of maths as well, but mainly I wanted to go with maths logic and I also didn't want to stay in New Zealand. Really I wanted to go to a bigger university where I could say study Aristotle for a bit in detail, study some of the sort of philosophy that I hadn't done and maths as well. It just so happened that on the notice board there was an ad for a department in Canada in [a university in Canada] setting out a philosophy of science programme within their Ph.D. in philosophy which allowed people from maths and physics to go straight into it without a background in philosophy. (Rebecca)

### **Difficulties as PhD students**

In a paper "Physics and mathematics, reality and language: dilemmas for feminists", Robyn Arianrhod (1992:45) relates feminist critiques to her own experiences as a feminist and a physicist. She points out some of the difficulties women face in participating in the social life of mathematics and science.

The irony, however, is that despite the way mathematics and physics seem to like to present themselves to the public, and perhaps also to undergraduate and school students - as rational, dichotomous and true - in reality, they are built on a very intuitive and communal process to which, in my experience, women have difficulty adjusting. The problems for women with the communal part of the process are not surprising because of the masculine social interactions that are part of it: in my experience feelings are rarely discussed; the relationships formed between collaborating researchers are not explored as we feminists- and women in general - are used to doing. So that unacknowledged tensions and nuances, which don't appear to worry the men, do worry us; and the fact that men hold almost all the positions of power in the faculty make it difficult for women to interact

socially or professionally without a sense of either inferiority or caution. Thus, although I have been encouraged by my (male) supervisor to join in the social life of our department, I have found this difficult to do. This has adversely affected my research because I have excluded myself from, and in turn, been excluded from much scientific discussion and networking.

The women in this study reported similar difficulties. I begin with a discussion of some of their experiences as PhD. students. For most, these difficulties continued later into their careers as I will describe in the following section.

Milly's experience shows the intertwining of the social with knowledge creation processes and how being a woman affected this. Although she said she could have joined in the social networking she did not feel comfortable about it and she attributed this at least partly to gender and partly to personality. Of course these are intimately connected. The arrival of another women in her group made a difference. This is a theme that several other women commented on in similar ways in different contexts. The arrival of another woman meant that she could 'reposition herself'. There is a shift here from attributing what she was experiencing to her own personality to attributing it to her gender.

*Did you ever feel like an impostor, that somebody was going to find out eventually that you didn't really belong?*

Yeah, I felt that right through. I suppose it depends on your personality I used to feel really, really uncomfortable, I don't know whether [I did] as a student here but when I was overseas, particularly as a student, but certainly overseas.

In Oxbridge anyway it is really alienating, the whole experience. Most people were foreigners living in a very strange country with strange customs, and if anything is going to make you feel worse then it is not a good thing. I think there were about 65 Ph.D. students in that department. There were about 5 women. And they were all in different groups. I didn't realise it was a problem until a woman postdoc in the same group came along and then I realised what a relief it was.

*Another woman arriving?*

Yeah, I don't know why. We would occasionally go, the only place we could go in that building was the women's loos. Occasionally we would go and have a gossip, it wasn't really a gossip, something

would happen, we would go and talk there with nobody else around but um, other than that I don't really know what it was about that group.

*Well, did you think that you were discriminated against?*

No, no I don't think so. ... Because so much of the research is tied up with social stuff. You know, everybody would go off to the pub after a seminar and talk more mathematics or they would go to lunch together and talk mathematics. So the work and the social stuff were so mixed up that if you were not really at any of the more social situations you don't have a peer group somehow.

*Were you able to be involved in that social side?*

I probably could have if I had, you know, if I had wanted to, but somehow it seemed like it wasn't natural. I don't know how much of that was just my personality and how much of that was being female, it didn't help anyway.

*Did you have experiences where the young men 'got the nod'?*

Not that I noticed. Certainly there were men around who [were] sort of more confident than they deserved to be. They would assume things that I would never have assumed but then again I don't know what is personality, and what is, how much is training that had gone on.

There was nobody really looking out for my interests, nobody mentoring. I am not sure that at Oxbridge the male students got much more of that but they did get it from each other. I didn't get that because I didn't hang out with them, if you make friends amongst them then you got stuff through that.

I found Oxbridge pretty hostile really. My supervisor was very difficult, he didn't [introduce me to his networks]. There was a real turkey [a student] who came after me. He [the supervisor] pushed him. That was one person who he did find contacts for. (Milly)

Rebecca also went overseas to do a Ph.D.<sup>3</sup>, in her case to Canada. There were 54 male students and her.

<sup>3</sup> Rebecca had to do course work as part of her Ph.D. programme. She did philosophy papers and then did a Ph.D. in the foundations of quantum mechanics. So for a time she was more

I was the first woman. It turned out to be a strong thing in the department, a strong feeling among some of the staff that you couldn't have women do philosophy. That it just wasn't something women did. (Rebecca)

Rebecca was subjected to sexual harassment although at the time the language was not available to describe her experiences in those terms. Her reaction to it then was to shrug it off and to minimise it. Talking about it now she continues to minimise the effect it had on her but the explanations she gives now have to be understood within the context of twenty years of hindsight. Rebecca herself raised the topic when asked about whether they had tried to get rid of her. She was the only person to do so.

(laughs) I had never seen anything like it. I mean in maths departments you get used to the men but honestly they were just like babies. Really, they fell in love one after the other. I fought off all the students and by then the staff had decided it was a good idea to try and I fought off all the staff. (laughs)

*And was it fighting them off?*

Basically it often was, yes. But in the nicest possible way because you had to work with them but yeah.

*But now would people call it harassment?*

Oh hell yeah, but I mean and they probably, oh yeah, I mean they sort of physically pounce on you apart from anything else but they would also set you up.

*Did you find that very off-putting?*

I know you're meant to be appalled and that but I didn't take it too seriously. Really it was just one more thing. In Canada it was much more always there, I suppose, but I put that down to the fact that they hadn't grown up. They were like a sort of, boys, especially the ones from the sciences.

Actually a lot of it was just, they weren't monsters or anything. They were just really unformed personalities and they'd had very little to do

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closely associated with the philosophy of science programme than mathematics, although they were in the same overall department.

with women, a lot of them. Especially the ones who had come up through physics and stuff and they actually didn't know how to behave. They were just undeveloped personalities. They hadn't developed a way of handling emotions they felt when women were around. You know, they were childish. They were transparent.

But they were nice as well. I mean, I actually got, you know, it got to be quite good. It was one more thing you had to hassle about and that was a drag but it wasn't a major impediment that made me feel all terribly unable to do anything at all. Because it was like a grown up (laughs) that I had to lead them through things, tell them that they weren't madly in love. They were just repressed or something. So try and lead them in different directions. But it was quite strange, you know, and it took me a while to realise you know. When I went into the common room for the first time and they were all guys and the conversation stopped, you know, because they were having conversations unfit for female ears, I suddenly realised, that's how they always had been. A lot of staff really liked having a woman in the department and after me there were some (more). By the time I left there were more women.

Well, what made it good was, that there were some really good staff there, that were really interested and didn't have so much bullshit. There was always a slight sort of sexual thing, you know, it was never, I was never a man exactly, but with a lot of them it wasn't a big deal. It was easy to handle and a lot of them had terrible personal problems and you ended up being told all of those.

I was angry about one of them who used to be, he'd say things like 'let's have a gang rape' when you went in and there was just you and a few other staff and I used to find that that made me angry. He was just a real horrible person and that was just his idea of making you uncomfortable. That was the most unpleasant. It never got more unpleasant than that. The silly people trying to grope you didn't bother me really but I found that nasty because it was intended to be very nasty, whereas the others were just silly. They didn't know their own feelings. (Rebecca)

Sexual harassment and the threat of sexual violence are a very powerful deterrent to women's participation and although Rebecca was able to complete her studies in this context, she has not gone on to do mathematics in an institutional setting. She did not attribute this choice to these experiences of sexual harassment.

Fiona's situation was different and led to a different kind of social isolation from her peers in mathematics. She was married with young children and did not have time to get involved socially with other Ph.D. students. Taking care of

her children was a higher priority for her. This priority was even higher at times when her childcare arrangements were disrupted such as when her principal babysitter moved away.

Imogen, on the other hand, did a Ph.D. at the university where she had been an undergraduate so she did not have the added stress of being isolated from home and family. She believes she was perceived by others as a student, and that being a woman wasn't important. It didn't affect anything. She didn't see any discrimination. She felt encouraged. It wasn't a problem.

I've always wanted to carry on with mathematics, I don't care if I'm a man or woman, it doesn't make a difference. There is a sense of achievement in being a woman. Almost the opposite of discrimination. (Imogen)

This contradiction is a constant theme in the discussion with Imogen. On the one hand she did not attribute any differences to gender and on the other she took some pride in being successful as a woman. In other aspects of the discussion she spoke at length about the difficulties of being a mother and a mathematician but she expressed no indication that she thought the institution or culture should change to accommodate her situation as a woman, a mother, in mathematics.

Sarah also went overseas to do her Ph.D. This compounded her isolation as a woman in a college that had only ten percent women in total. When Sarah realised that she was not really interested in her Ph.D. topic, her isolation compounded her inability to do anything about this problem.

I realised quite early on that what I had signed up for wasn't what I really wanted to do and I didn't know how to get out of it. I saw operations research as being able to have a window into using my undoubted logic talent, logic skills and make a difference I guess primarily in government and public service and that sort of thing. There was a lot of that going on in New Zealand in the early 70s, the time of the Labour Government and all sorts of things were going on and I realised when I got into doing a Ph.D. that I was doing computing and that it was totally unconnected to anything really and it wasn't what I wanted to do but I didn't know what on earth you would do to change at that point. I was out there in the UK on my own, nobody I knew, nothing like that. In retrospect I realise I could

have gone across to one of the other departments in the university.  
(Sarah)

Being caught up in a subject area she was not interested in has continued to dog Sarah until a few years ago when she switched to a new area of research.

Informal social networks involving peers can be a source of emotional support, information and advice. As can be seen from this discussion, isolation from these networks can affect an individual in a variety of ways.

### **Career issues**

Having survived the rigours of Ph.D. study, these women have embarked on careers as mathematicians in various capacities. Mathematical research is a vital aspect of their work. Being women in these positions is a crucial factor in their experiences and career progress and in how they position themselves as mathematicians in these contexts. In this section I include some very long accounts from particular women in order to explain some of the circumstances of their careers at the same time as retaining a sense of each woman's voice and individuality. The length is also a reflection of the diversity of their career paths and some of the similarities of their experiences within this diversity.

Liz worked as a research fellow in an engineering school for twelve years where she was involved in mathematical modelling. She did her Ph.D. as part of this work. She was currently on maternity leave and was unsure about her future. She thought at the time of the interview that she might not return to full time work until her baby went to school. For the first five or six years she had been the only woman on the academic staff.

*Did it make a difference to you when another woman came?*

It was nice having the company and she sort of got things going. She was quite a bit more up front than me. One of the things that was interesting was that things that I thought were because of who I am they had in common. Personality traits of mine were actually common to other women working in a very male dominated area.

Conversation in the tea room was never at all personal. They'd all be talking about the rugby or politics or something like that but never

about what their kids did at school or what they did in the weekend or something like that. You can talk for ages about politics or sport and never get to know someone at all. You might know their political views but that is about all. Well I really missed that.

*Were there other kinds of differences?*

Engineering school is a visually sterile place and I think that that is improving. Since they've had more women, that has helped improved that because other women said the same as me and it was nice to feel I wasn't such a freak as I actually noticed and didn't like it.

*You said on the phone<sup>4</sup> that you have a reluctance to encourage young women to go into the culture.*

Not because of the content of the work, because there is a lot of work and there's not much time to do much else. And engineering students together tend to behave a bit like boys in boys' schools do. They can be a bit thuggish, you know, stereotypes, I know some lovely engineers and some lovely engineering students but as a whole they do seem to conform to that thuggish stereotype and I mean I think in the workplace too. I wouldn't like to encourage anyone to do it who wasn't aware of what it could be like.

*How do you think being a woman has affected your progress?*

[It's a] bit like me saying when other women came I found that things I thought were me they had in common. I'm not a particularly competitive woman and I don't know whether that's because I am a woman or because I am me. Obviously having children has affected my progress and having a partner who works revolting long hours. [But even if I didn't have children] I think [it would make a difference], I'm not a very confident person I think that's a [problem].

*Would you like to be doing the same kind of work in a different environment?*

I think it would be quite different if I was working as a team or had more contact with people. I probably would have enjoyed it a lot more if it wasn't the engineering school. (Liz)

Sarah went to work in an engineering school after she had worked for some years at another university. She eventually moved out of the engineering school

<sup>4</sup> When I called to arrange the interview time.

into another area related to operations research. Although she had found the previous mathematics department to be quite nurturing, she did not have the same experience in the engineering school:<sup>5</sup>

I found them very very difficult to work with. I am sure D thought that I was going to come on board and be one of his little minions and get into publishing with him and that kind of stuff but I just wasn't interested in that kind of stuff. In a way that was doing more of the sorts of stuff I'd done for my Ph.D. and it just left me cold, the whole idea and I also didn't because it didn't seem to make sense. Well I knew I could make sense of it. I knew I had the capability but it was like, what's the point? what does it mean?

I've never really gone into a group and worked with a group.

*From choice, were you excluded?*

It kind of felt<sup>6</sup> like these guys got their rocks off on talking about all these intricacies of mathematics and I would think 2 things (1) what's the point? and (2) I can't contribute into that. I didn't feel like I could. I wanted to explore but I didn't feel like I could say anything because I would get laughed out of the house as it were. It would feel like I would have missed one of the things that were obvious or they would be able to quote a paper to me that I hadn't come across or something like that and I'd feel like I couldn't do it. So I tended to just shut up really and not talk out stuff at all and of course and that means that you don't really get [to] sort of develop, it is quite hard to develop because you are working in isolation like that. It's just like male = normal. It was quite a lonely kind of place but it's not something that you actually notice what it is. But it's like that feels like that's normal and you don't really have any other way of describing it. If that's the experience that you have then that's the experience. It's like that's how it is. It was quite an alienating place really.

*Is this a better environment for you to work in?*

<sup>5</sup> Although these two women worked in the engineering school they were working as mathematicians. The engineering science department where they worked was where the mathematics associated with engineering is done.

<sup>6</sup> She cried while talking about this.

Not particularly much better<sup>7</sup>. I actually very nearly just walked out the door. I just couldn't handle it. I don't think I've ever been so bruised in meetings before. People are very defensive and very private. We don't have a culture of talking to each other about what we are up to. There is one woman who has just joined.

[M]en are so prevalent here, men seem to have constructed the discipline and men have constructed what it is to be normal and it works mostly for how men operate and women don't happen to be men so we appear to be abnormal all the time. There is certainly an element of that. I look at the women who seem to be able to succeed in the system and I think I don't want to be like that and this affects how I feel. It feels like to be like that, I have to give up all the things that I think matter most about being in the university.

*Has it been a positive change as far as the interest in the subject is concerned?*

Oh yeah, yeah, no doubt about that. I feel like I'm more in contact with things that are actually happening and making a difference.

*Do you think it would be easier if there were more women in the department?*

I think it probably would. I know I have really enjoyed having E around. It is hard to say because I have not been in places where there have been women around. Where I have been working it feels more like that what matters is that there are people around who are sort of open or not into point scoring because that is criticism. I think one of the reasons I find the reviewing process so painful and so bruising is that it feels like they are saying I'm not OK. So what would be really good is to be able to have a group of 4 or 5 who had that openness and honesty with each other and we could actually build up a community of inquiry. Something where there are possibilities I think, of being able to be friends as well, is a thing that would really matter. I don't really feel like I would be able to establish friendships with any of the people here for example. Gender isn't just the sole discriminator or distinguisher. Gender does make a difference however in general terms. (Sarah)

Rebecca and her husband run a software company in which she does the marketing and the documentation and her husband does the programming.

<sup>7</sup> Somebody she had found very difficult at the engineering school had gained a position of responsibility between the engineering school and her new department.

Rebecca has never had an academic position or a position as a mathematical researcher. She said this is a choice she has made.

It's basically earning a living [her work in their company]. Actually the truth of the matter is that I found that really good because that doesn't interfere with my real, you know the sort of maths that I do. If it was more programming I think it would interfere more. It would start using up brain space that actually I've reserved for something else. So it's sort of low level stuff in a way. My academic type stuff is completely separate.

*Have you ever worked in a university?*

I taught in a university as I finished my doctorate and I could have got university jobs in the States at that stage but I really didn't want to. I found again, teaching, I really admire people who do a lot of teaching. I think it's tremendously energy consuming. I mean you're at that stage of your own work, like I finished my doctorate but there was a lot more I wanted to do. I was interested in quantum mechanics at that stage. That was what really interested me and if I'd gone into a university I would have been 3 or 4 years out while I really got my courses and stuff together and I just really didn't want to do that, because it is so time and energy consuming, teaching well, that I couldn't have done both. So I kind of retired and just did that. (Rebecca)

Rebecca was invited by the British Institute of Physics to write a book about her research. As a result she was invited to be a reviewer for *Zentralblatt für Mathematische*, a prestigious journal which reviews all papers published in all mathematical journals.

*Do you think not having been tied to an institution has hindered your progress much?*

No. I think I made the right decision. I mean it's certainly hindered my progress, if you look at progress in terms of a career path and stuff. Because I don't have, apart from doing this reviewing for *Zentralblatt*, I don't have a career but I just know enough about universities to know that if I had gone to an institution I would have had much less control over what I had spent my creative time with and I think the only way to really control that is not to work for an institution.

*And do you just think away about [your mathematics] on your own?*

Yeah, yeah, I think about it all the time. (laughs) So it's a drag not being able to talk to other people but I don't think it has hindered me greatly, because I'm just too interested and the reviewing job is very

good from that point of view. And I review on this very topic and they review every paper that comes out. So I sort of know that if something absolutely groundbreaking is done, it'll be sent to me eventually to review and I'll find out about it.

*So do you see yourself as carrying on the way you are indefinitely?*

Certainly at the moment. The kids take up a big part of my life and the business, but I still manage to keep up the other. Ideally it would be much nicer to have people that I could talk over things with, because I do miss that. Eventually I might change but it would have to be to suit me.

I think that [being outside the system] is an advantage because of all the bullshit in the system and because of the teaching load even if you are in a really good department and most of them are sort of not really good. But you are just being pulled by all these other considerations. If you're just doing it for your own interest on your own, your eye is on the ball, you are concentrating on the things that interest you, so I think you'll do better because you are not having to do all this other stuff. (Rebecca)

Although Rebecca sees her decision to opt out of institutions as a personal choice which has given her the space to work on her research as she chooses, her 'choice' can be read in the wider context of her experiences. She faced difficulties as a graduate student including sexual harassment and she has a strong commitment to meeting the needs of her five children.

There are also contradictions in Imogen's accounts of her professional life. In conversation Imogen talked at length about the difficulties of working full time as the mother of two very young pre-schoolers. She would have preferred to work part time but as her husband was a student she felt obliged to earn a full time salary. She had no expectation that the organisation within which she worked would adapt to her needs as a mother. She was the one who had to do the adapting. She would have preferred to have bigger networks amongst other mathematicians and computer scientists in her area but said she was held back by the ties of having children.

I get annoyed when people ask about it (women in mathematics). I have always worked with mostly men. Men have treated me as an equal. There is a slight advantage as they want to get women (more women staff members). The disadvantage is in being a token woman on committees and school trips. It would be nice to have more

women but it doesn't bother me. It is nice to talk to another woman about your children. It doesn't matter to me. (Imogen)

Annette works for a crown research institute as a research mathematician. At the time of the interview she was very concerned about being made redundant as her group had been unsuccessful in recent funding rounds. At her institution there are nine general managers, six of whom are science managers and a manager each of business development, finance and human resources. They are all men except for the manager of human resources. There are also 60 team leaders who are all men except the librarian.

*How has being a woman affected your progress?*

I'm not sure it has made a difference actually. [In dealing with customers] you get the sweet young thing syndrome. I always run into that. People think I am younger than I am. You know, the sweet young thing, what do you know?

*Does that make it difficult to work with them?*

It can, yeah, it can. I don't know whether I get so much of that these days.

*So you wouldn't see yourself as more vulnerable because you are a woman in this new environment?*

No, no. I wouldn't, not that there is much help from the managers. But my whole life has been in male dominated areas even doing science at school, there weren't many girls.

*How do you feel about that being in such a male environment?*

Well, it's always been like that. I guess I am just used to it. It's not like a big deal. I guess I get on better with men than women anyway so ... I guess I've always just been in it and I'm used to it. (Annette)

Jane had worked in universities in the United States before coming to New Zealand. She did not attribute any of her experiences to gender differences until she came to New Zealand. Being a woman may well have had powerful consequences for Jane as a mathematician in the US but what I am interested in is how Jane positions herself as a mathematician and a woman in this location. I

am particularly interested in the New Zealand context in order to compare her experiences with the other women. In New Zealand being a woman did make a difference for Jane. She attributed the development of her interest in alternative spiritual movements to these experiences.

I think this was the one case in my career, where I feel being a woman was [a factor]. It both got me here and caused [problems].

*Did he<sup>8</sup> tell you he employed you because you were a woman?*

Oh no, he didn't have to. I was the only woman in the department. Well, the whole department was like at a meeting, I would make, I might make a motion about something. I moved something and then someone would second that, and he would say 'who seconded that?' and so they realised that if they wanted to be on good terms with him, they should knock me around to please him.

*Did you find it quite unpleasant?*

Oh yeah. As a matter of fact, I went on long bicycle rides, I went for swims. I had to fight. I became vegetarian. I felt I had to stay healthy to be able to fight this situation. Yeah so. Yeah, yeah. I became involved with spiritualism.

*And you attribute those things to difficult work situations?*

And I'm grateful to him because he got me into these things.

*And you didn't feel supported by anybody else?*

No one, no one. Every other place that I'd been I always had friends. I had to be stronger.

*But at other places you hadn't felt isolated?*

Oh no, no.

*Did that make you feel quite lonely in the department?*

Oh no, it was a challenge, it was a challenge, and I had to stay strong to be able to combat it. They say wherever you are there are

<sup>8</sup> The head of department.

problems, just different kinds of problems. More recently they hired a young woman to be in statistics. She would probably be in her early 20s and she doesn't have her Ph.D. Most of them they hire do, but she doesn't. And one of the young men in the department said 'we've found your replacement now'. In other words because I'm a woman. I certainly had nothing to do with statistics<sup>9</sup>. But the thing is, that this young man assumed she is my replacement. But she is not my replacement because she doesn't teach what I taught. (Jane)

Milly and Fiona both work in university mathematics departments where they have found that the climate is not problematic.

I don't find the climate chilly. I don't think so, not in this department, and not in New Zealand really. I think it probably takes more effort but its quite good on the whole (Milly).

*Would you describe the climate as chilly?*

The department here has been brilliant.

I was certainly happy when maths and statistics started hiring women. It's been wonderful to have them around. I think it was partly the situation where you maybe didn't realise how badly off you were until you got better. You know what I mean.

I think maybe we talk together, maybe, a bit differently than I talk to the guys. It's certainly (better) on a practical level. There's more people to go on committees which think there should be a woman on (Fiona).

Both these women were called on to serve on committees to provide a gender balance. This had the advantage of allowing them to influence decision making and the disadvantage of taking up time which could have been spent on research. It also kept some attention focused on their gender.

Being women marks these mathematicians as different from the male norms that dominate. How this difference is played out in the individual experiences of these women differs with each individual woman and with the other

<sup>9</sup> Mathematics and statistics were in one department.

mathematicians with whom they come in contact. For some the difference does not present much difficulty because they are fortunate in the attitudes of those with whom they come in contact. Their experience of isolation is not so severe and their presence may be seen by their male co-workers as a positive contribution to their place of work. For others the difficulties are greater as they are more isolated and those they work with are more resistant to their presence. Those women who were lucky enough to work with people who appreciated their presence had fewer problems than the unlucky ones like Sarah, who struck colleagues who were not supportive of their difference. While 'luck' plays some part in this their comfort levels remain dependent on their acceptance by men whose values and practices continue to dominate in their work places.

### **Family constraints**

The constraints on the women's careers imposed by family ties and commitments is an underlying theme for most. Sarah, Annette and Jane were least affected by this as they did not have partners or children. Milly has the 'two body' problem to solve. Her partner has a postdoc at the same university but when that finishes they will have the problem of finding jobs for both of them in the same city.

Fiona's family ties have played a big role in her life. Her studies were interrupted as a result of her husband's being drafted and then her own career opportunities were constrained by her moving for her husband's career moves. When she separated from her husband she took a position as a tutor at a university in part because of the flexibility it allowed to combine her parenting role with full time work. She then worked herself into a position as a lecturer which includes a research component.

I didn't have a good research background cause I had effectively done no research but I did have teaching references. So once I got back in here I started trying to pick up research skills again. There was always the thought that I did want to go back full time. But I think research is such a huge component of a university job, a permanent job, it is such a huge component once you get to the point that you haven't done it for a while then it looms in your mind as something

harder and harder to actually get back into. I am sure there is an element of that. (Fiona)

Even now that her children have grown up her relationship with them is played out in her work choices. She takes study leaves in places that allow her to combine the study and spending time with her adult children.

Liz was on maternity leave with a young baby when I interviewed her. I asked her about her plans to return to work:

I really don't know I don't think I'll will go back to work until he goes to school. I can't imagine it. I don't want any more stress. I'm so busy I can't imagine doing anything. I find that a bit scary actually because I have done all my work in such a specialized area and I doubt whether I could get another job and I sort of don't feel very qualified for anything else so I try not to think too much about that. Obviously having children has affected my progress and having a partner who works revolting long hours. (Liz)

Rebecca has five children and places a high priority on meeting their needs and being involved in their day to day lives. Working outside institutional confines has given her some flexibility to do this. She was invited to write a book by the British Institute of Physics which she began about the time of the birth of her first child and tried to complete when she was pregnant with twins.

So that was a sort of nightmare, trying to finish it, knowing having had one child what twins were likely to be like, and because they were twins and they sort of always wanted to come into labour, they put me in the local hospital, which was a real Victorian institution. I had two weeks to try and finish the hardest chapter of it, before the twins were born. It was a sort of race between the book and them and the twins really won but at least I got the very difficult stuff out. I was madly trying to finish that before I was engulfed in the babies. But I think I just developed very good concentration skills. And when the kids were little if I just had twenty minutes when I didn't have to do anything I just went and worked on it. I just got so that I could pick it up at a moments notice.

I just got engulfed in kids. So yeah, I shut myself out of a lot of that I'm sure. (Rebecca)

Most of her mathematical work subsequent to the completion of her Ph.D. has been done around the needs of raising a family. I asked her about the effects of having children on her mathematical work and career.

So the children I don't think are quite the issue though maybe it's having a family and having, if you have kids there is no doubt where your priorities are in life. It is simply in that sense you are not looking for a reason to, I don't know, maybe there's some sort of psychological reason why when you have kids you are not so worried about whether you have got a great career because it's just not that important when families are much more important. Ego stuff. I'm just not interested in it really. I mean my ego doesn't require that I have a good title after my name.

*But do you see yourself as working back into it as the children get older?*

Maybe, but it would have to be to suit me. (Rebecca)

Family responsibilities are also very important in Imogen's life as she is the mother of two pre-school children. Imogen talked at great length about the difficulties of combining, as she put it, full time motherhood and full time lecturing. This made it very difficult to undertake her own research. She also said she would prefer to work part time in order to have more time for her children but she could not, as her husband is a full time Ph.D. student in computer science and she has to support the family. Her availability to attend conferences and develop networks with other mathematicians is constrained by her family responsibilities. She will face a further difficulty when her husband finishes his Ph.D. if he can not find a job in the same city.

Family responsibilities placed constraints on the career development of all the women who had such involvements.

### **Working with other women**

The women all experienced the isolation of working without other women colleagues at various stages and locations in their careers. They had all had the experience of being the only woman amongst much larger numbers of men and even when they were not the only woman there were only one or two others. All of those who had had the experience of being isolated and then being joined by another woman commented on the difference this made:

I didn't realise it was a problem until a woman postdoc in the same group came along and then I realised what a relief it was. I don't know why (Milly).

I was certainly happy when maths and statistics started hiring women. It's been wonderful to have them around. I think it was partly the situation where you maybe didn't realise how badly off you were until you got better (Fiona).

One of the things that was interesting when I first started and talking to other women there. Things that I thought were because of who I am they had in common, personality traits of mine were actually common to other women working in a very male dominated area (Liz).

I think it probably would [make a difference if another woman came]. I know I have really enjoyed having E [a woman] around (Sarah).

It would be nice to have more women but it doesn't bother me. It is nice to talk to another woman about your children. I have always worked with mostly men (Imogen).

It is noticeable in their responses to questions about working with other women, that they did not pinpoint the difference it made until other women came and even then they were unsure of exactly what had changed. The presence of other women not only meant they were not so individually marked as different in their work place but also their presence served a consciousness raising function for themselves. Liz for instance realised that things she had attributed to herself as an individual were common to other women. This enabled her to distance herself from some of the negative effects her isolation had had on her self-esteem.

### **Participation in other women's groups**

In their work place these women are isolated from other women. When they go to women's groups which are formed in recognition of the difficulties women experience in such workplaces, their specific needs are not always met. They can experience isolation in these groups as they are the only mathematicians. These experiences demonstrate some underlying ambivalences and

contradictions about being women and mathematicians and how they want to identify themselves.

For Milly and Liz, participation in these groups reinforced their feelings of being different.

I'll tell you what really pisses me off. When the academic women's group meet, they always assume that women there are from [the arts or social science]. It makes you feel like a bit of an oddity, [it means] you are really isolated from the women's groups.

I've been really identified as a woman here and to go into another group and be the only mathematician seems hopeless. It's the last straw. That is partly why I find it irritating. These are not supposed to be the enemy right? (laughs) You do get used to being [one of the only women] in this department (Milly).

I guess that contributes to the feeling that I'm a misfit. There's also that feeling if you're mathematical you're kind of heartless and cold. (laughs)

It's almost as if they are proud of their lack of ability at maths. It's kind of evidence of them being very philosophical or [of how feminine they are] (Liz).

Sarah highlighted the reluctance some women have to meet together in their workplace because it can increase their visibility and draw attention to the difference they carry when that is the very thing they are trying to keep quiet.

We had a group that we've met a few times together [here] but there's been problems with reluctance to come out and meet in a group like that somehow.

*Would it have repercussions?*

I think that's what people are afraid of. (Sarah)

Imogen's resistance to participation in women's groups was the most virulent as she is the one who most strongly attempts to position herself as 'mathematician' and not as 'woman mathematician'.

Cripes not feminists again. They're going over the top: trying to put men down. If women are talking together and a man arrives they

have to put the man down. I don't like people putting other people down. When things are a bit of a joke there is a double standard. It is OK for women but not for men. (Imogen)

Annette found participation in a group specifically for women scientists, was not inclusive of her and her particular needs and position. The emphasis appeared to her to be on women scientists who were also mothers and as she was not a mother she felt excluded. Her feelings of exclusion were heightened because she had always intended to become a mother rather than be a career woman but so far that had not eventuated for her. Without children she felt her success as a scientist did not count as such in this group.

*Why wouldn't you go to a meeting with the Women and Science thing?*

[There's] an attitude I ran into at the Women and Science Conference [which] was that to be a successful woman scientist you had to have kids as well. You have to successfully raise a family as well as being a great scientist if you are a woman scientist. Well, at different things, they said so and so was, um, but she never married or she never had children or like, you know if you are going to be a great scientist and you don't have kids, you have sacrificed something. It must be because you have sacrificed that, that you are successful. You are not a real woman if you don't have kids. So to be a really proper woman scientist you have to successfully raise children as well as have a successful science career, otherwise you sacrifice one for the other. I don't have kids. It's not because I want to be a career scientist. That's not the reason I don't have children. I found that irritating.

*So if you're not doing both, you don't have any needs as a woman?*

Well, something along those lines, yeah. (Annette)

Jane was resistant to participation in women's groups because she wants to avoid positioning herself as a 'woman mathematician'. She expressed an ambivalence about this because at the same time as she wanted to be identified as a 'mathematician' not a 'woman mathematician' she was aware that being a woman had made a difference to her as a mathematician .

They formed the Association of Women in Mathematics (in the US). I went to the initial meeting. I was at the first meeting of it but I wasn't particularly interested in it. I never joined.

*Why weren't you interested in it?*

Well, I think mathematicians are mathematicians and I don't like to feel I am a woman mathematician. I feel I am a, I like to do mathematics not because I am a woman or, but it is like, I don't think, I think of a sexless sort of society.

*But given that it isn't sexless?*

I don't know. I'm not sure. I have mixed reactions on this.

*Can you tell me more about it?*

Well, I think people are people. I like to think it's not because you are a woman that you should be interested in cooking or sewing or not be interested in mathematics. I think that as a human being. (Jane)

Those women who want to identify as 'mathematicians' rather than as 'women mathematicians' were most resistant to membership of women's groups. The others expressed some ambivalence about membership because contradictions between being women and mathematicians remained even in groups like this whose purpose was to support women.

### **Woman, mathematician, is there a contradiction?**

In answering questions about any contradictions they experienced between being women and being mathematicians two themes emerged. The first is their recognition that as women mathematicians, they did not fit a norm for women or mathematicians. The second theme is their rejection of a narrow essentialist concept of 'woman' defined in opposition to 'man'. Liz and Rebecca for example expressed the first theme in terms of feeling like an oddity or a misfit.

*How do you feel yourself about working as a woman in such a male area? About yourself?*

I feel a bit as an oddity. I suppose.

*An oddity as an engineer or an oddity as a woman or a bit of both?*

A bit of both. (Liz)

*Do you feel like a misfit?*

I probably am a bit of a misfit anyway, slightly eccentric in other ways, in the things that I did. So I have kind of got used to that. I think my interest in the subject is just too intense for the rest of it to matter and in a way, there are so few people in the area anyway that if they're interested, you don't care whether they are men or women (Rebecca).

Fiona rejected an essentialist concept of women and talks about belonging in several places.

*Some people say that because they work in such a male-dominated area, they ask themselves, 'Am I a real woman'?*

mm What's a real woman?

*Do I really belong here? Do I really belong in a group of women? Do I really belong in a group of mathematicians?*

Well, can't you belong several places? I think women have to, that's so much rot, that's just a self doubt thing and I think maybe their self image is worse than men's.

*So the only difference is a woman's self image?*

That's my feeling on the matter. (Fiona)

Fiona positioned and repositioned herself. She maintained that you can 'belong' in several places but the person who 'belongs' is not a unitary unified individual. Fiona can belong as a mathematician amongst mathematicians and a woman amongst women. The positions she takes up shift with the context.

Annette and Jane discussed the question in terms of a range of personality types rather than clearly delineated gender differences. They saw these types as cutting across gender boundaries rather than each gender having fixed essentialist types and meanings.

Well, I don't like to generalise about men and women like that. Again I think that is personality types that are different, the thinking, feeling or whatever, intuitive. Because not all men, not all women are alike

and I think there are more differences within them than across them. I did the Myers Biggs stuff and 2/3 of women are feelers and 2/3 of men are thinkers, and I think those kinds of things have more impact than whether you are male and female. I don't know why they have the personalities they do or why more women have one kind of personality and more men have another, but it doesn't mean all women have the same one. Probably you are doing mathematics because you don't think the same way as most women do, that you have that logical mind that men usually have, and women don't. Perhaps it's that kind of stuff. People do think about things differently. So yeah, I have trouble with differences between men and women because I am not sure what they are entirely based on, male or female. (Annette)

*So it didn't bother you [to be one of the very few women in mathematics]?*

Oh no, no. There are some males that have female personalities and some females that have male personalities. In some ways I have male interests but I'm not mechanically orientated or things like that. But I don't have female interests. I mean I'm not interested in cooking or sewing. Oh, I used to fight that all the time in school. I wasn't interested in any of those things.

I think it depends on how you are being guided, or what your basic motivation is, or what your basic philosophy is. As I say since I came here I became far more aware of these things, when I became involved in spiritualism and vegetarianism and theosophy. (Jane)

Imogen's position is different in that she strongly resisted feminist discourses that imply any discrimination against women.

I thought your question<sup>10</sup> about what it felt like to work in a male dominated area was biased. Does male dominated mean there are more men than women or does it mean the men dominate the women? If it is the former that is OK but if it is the latter that implies a prejudgement. It was badly worded. I just laugh at things like being the token woman. (Imogen)

<sup>10</sup> This was in the letter I sent telling the women in advance the kinds of things I would be asking them about. See Appendix 3.

For all of these women being a woman in mathematics presents some extra difficulties and obstacles to be negotiated, ignored or overcome. Even those who wish to ignore the effect of gender differences cannot avoid it. The ways in which they undertake this negotiation are diverse and complex.

### **Attraction to mathematics**

Responses to questions about what attracts these women to mathematics reflect the diversity existing within even this small group of women. An attraction to solving puzzles, the unfolding patterns and the orderliness of mathematics were common themes but within this theme there were differences. Some enjoyed the surprising and unexpected; others the precision. Nor was there a unified view about the applicability of mathematics. While some were attracted to the applied aspects of mathematics, others were not concerned with applications.

Fiona was not concerned with applications. She enjoyed the puzzle solving aspects and the combination of orderliness and the unexpected.

*Does the mathematics you do have applications?*

It does but that is not of huge interest to me. No, I enjoy it for what it is.

*Is it just sort of a puzzle?*

Yeah, it's a puzzle. Yes, I like puzzles. I like murder mysteries. I like crosswords.

*Is that what attracts you to mathematics?*

Partly and the order and what else? It has got a lot of the unexpected in it too.

*Things don't work out the way you expected them to?*

Yeah, I think mathematics research is difficult in the sense that there are not a lot of routine things you can do that you might just churn through and know there's going to be a result.

*mm and I'm interested that you don't care about the applications at all.*

No, I don't have time but I mean that's not ....I mean if I find any applications that is good.

*But you are not (interested in that. You are interested in) solving the next step in the problem.*

Yes, the abstract thing.

*Yeah and you enjoy that part of it.*

Yes. (Fiona)

Liz, Imogen and Annette all appreciated the patterns and orderliness.

*What attracts you to mathematics? What do you enjoy about the work?*

I think it is the pattern in it. I like looking for patterns and the order too.

It does what it's supposed too. (laughs and looks at the baby who made a lot of noise during the interview)

*Do you find it intellectually stimulating and challenging?*

Yes I do. Although I mean, a lot of my work was pretty routine. Particularly I noticed it when I was in Sydney. I'd lie in bed at night thinking about it (Liz).

Imogen's attraction to graph theory was an attraction to patterns, finding them and describing them and applying it to puzzles. She had always loved puzzles. She said "Something about puzzles appeals to me." She liked "the aesthetics of mathematics, a nice proof." She enjoyed mathematics because it is fun. There is a sense of achievement. She said "You can try different things out. There are open ended questions."

In addition to pattern and order, Annette enjoyed the precision and the usefulness. She had little interest in mathematics that was not directly applicable.

*What do you like about it?*

The precision of it. I like things to be cut and dried which doesn't always work but your model is like that, even if real life isn't like that. I like things being predictable.

*The orderliness?*

Yeah.

*The predictability?*

Yes. I guess I like differentiation and those sort of things and then you get down to something that was tidy at the end. That kind of thing. The challenge you get and the applying of rules that kind of ... you are mixing and matching them but the applications to problems that are out there, that are real.

*Do you like the application to real problems?*

Yeah, rather than artificial ones. I like things that are going to be useful, things that are going to be used. I don't like working with things that aren't. Real analysis was just the pits, by then it was getting a bit theoretical airy fairy. (Annette)

Milly and Sarah also preferred mathematics that was applicable.

*What about mathematics itself? Are there things about mathematics itself that you don't like?*

There's lots of questions in mathematics, you've got to think about them, nothing will happen ... that's only one example....it gets a bit irritating, when I am in a bad mood it is irritating, the way mathematicians go and look at things because they're there. They do new mathematics just because it's there, for no other good reason. Nobody will ever be interested in it, it's not applicable to anything but they just do it because it is there and in good moods that's fine it doesn't worry me but sometimes it does, I get the urge to do something that is relevant,..... Yeah, yeah, and that's what you think about in your good moods [ how a lot of things which aren't thought to be relevant, have become relevant later]. (Milly)

As Sarah was interested in making a difference to society, for example in government or public service, she disliked the lack of connection between the mathematics she had been doing and such concerns. Hence she described it as having a remoteness. At the same time she did like the precision and the logic.

*You have drifted into it but then realised that you didn't like it that much.*

There is a remoteness somehow about it.

*Would there be things about maths that you did like?*

The [way it's] sort of clean and clear about what it was, I suppose.

*Do you think it would have been more interesting if you had been able to approach it in the way you wanted to approach it?*

Oh yeah, (Sarah)

Jane's description of her relationship to her mathematical objects showed a similarity to the attitude of Barbara McClintock to her scientific objects which is described in "A Feeling for the Organism" (Keller, 1983). For Jane the separation of subject and object, reason and emotion has blurred in the affection she developed for her "mathematical creatures". She also enjoyed the patterns found in mathematics.

*What is it that attracts you about mathematics?*

Getting results, seeing pretty patterns develop, seeing pretty properties. These are like little creatures. Like you have children, these are creatures that have their own properties and their own, and they can do their own thing, so to speak.

*Are they surprising?*

Oh yeah, lots of surprises happen. You get these nice patterns developing, these nice properties.

*So you develop some affection for them?*

Oh definitely.

*Is what you do very abstract?*

No, you can see the pattern. It is not very abstract. They are functions. So the things I do they are definitely not undefined terms because they are functions. You know what they are, they are not abstract functions, they are definitely functions, they are concrete. So technically, it is part of applied mathematics as far as..

*Would a non mathematician think they were abstract?*

It depends what you mean by abstract.

*How does it come about, that what you are talking about, that that kind of thing that you are calling applied mathematics, actually applies in the concrete situation? Some mathematicians develop all this mathematics without a care in the world as to whether it applies to anything concrete or not.*

It is just pretty in its own way, like you paint a painting. (Jane)

I include a long quote from Rebecca because she described her attraction to mathematics quite differently from the other women. Her description also highlighted the inadequacies of traditional hierarchical dualisms to explain the position of women in mathematics.

Rebecca was not interested in the puzzle qualities. She valued mathematics as a tool for thinking and for its beautiful structural qualities. She did not express the applicability of mathematics in dichotomous terms in which mathematics either is or is not applicable. For her the attraction lay in the way in which mathematics is abstract but not merely speculative.

*What attracts you to mathematics?*

When I first got interested in it, was when I saw it as a tool for thinking. I think here we are sort of little creatures on the planet trying to make sense of everything. If you can actually make your own reasoning powers clearer, you can actually learn things that help you think more clearly. That's what I wanted above all as a serious undergraduate and maths did that, especially in the maths logic side of things. And you really did learn good analytic skills I think. Plus I just really liked the abstraction of it. I think I am a really, really abstract person. I was quite depressed by my 2nd or 3rd year and the pleasure to be got out of doing algebra couldn't be compared really with anything else so I think there's that side of it as well.

*Do you enjoy sort of working out puzzles?*

That's why I think I possibly don't fit in with people who would otherwise be mathematicians. I see it. It's like art. It's just a very beautiful sort of structural thing and it's that side of it that really attracts me. And when applied to questions like the foundations of physics you just can't beat it because it is so interesting and yet it is not purely speculative. There is a part of philosophy that doesn't

interest me, where it almost doesn't matter which way you go. It wouldn't be interesting, if you didn't know the theory worked.

*You mean worked in a real way?*

Yeah, in a sense of giving you predictions that actually gel with the answer. It wouldn't be an interesting problem if it weren't for the fact that these are the right ones. If they were just wrong then somebody hasn't looked carefully enough or done the science carefully enough. That's of no interest to me. I am not a scientist. I'm not interested in the science part of it but given that they do actually decide what goes on, albeit in my opinion not as well as could be done, why are they so different? So when you are actually applying the rigours and abstractions of mathematics to a very real problem, that's when I am really interested.

I feel quite sure that I am a very abstract mathematician by nature because I just really love that abstraction and it pains me when it has to be applied to things. And to work through boring problems when you are really interested in the structures. And I think maybe that's something that's in your personality, but I would feel quite sure that there are a lot of other women who would have been really interested if they had only had the chance to really meet this stuff. I feel it was only quite by chance that I found it. I could just as easily have been someone who failed slow learners maths 1 and felt that maths wasn't their subject. It was just by chance that I found a part of it that really interests me. (Rebecca)

Any dichotomy which might define mathematics is undermined in these women's descriptions of their attraction to mathematics. They do not present a picture of mathematics as either abstract or applied, as predictable or surprising. It is sometimes one, sometimes the other and sometimes both. Nor are they all aligned with a particular view of the practice of mathematics that coincides with a gender stereotyping. They do not support the association of usefulness or concreteness with women and abstraction with men when they describe their own relationships with their mathematics. By describing the aesthetic appeal of mathematics and its potential for beauty and elegance they contradict the view of mathematics as value-free without contradicting themselves. This undermining of a definition of mathematics based on dualisms is subverted further in a discussion of their work practices in the next chapter.

## Who can be a knower? Conclusions

I return now to the question of who can be a knower in mathematics and how this relates to the experiences of these women.

The women in this study were successful in overcoming the problems associated with girls' participation and achievement in mathematics at school as discussed in Chapter 4 and in making it through the education system to become mathematical knowers. However having got to the stage of doctoral study and beyond their gender did not 'drop out'. Being a woman makes differences for mathematicians. The social practices of mathematics serve to emphasise the 'differences' of these women although the mathematics itself is less of a problem. This is not entirely unexpected because women who did find difficulties in the clash between the mathematics and their own subjectivity would have turned away from mathematics long before the Ph.D. level. Sarah is an exception as she left mathematics eventually and attributes the 'remoteness' of the mathematics as being a factor in this decision. For a woman to establish herself as a mathematician, she has to cope with contradictions and conflicts between 'womanliness' and 'mathematics'. Some like Imogen do this by ignoring or holding the contradictions apart. Some like Jane, Annette, Fiona and Rebecca take up positions as women that incorporate the differences. Others like Liz and Milly continue to struggle to find a way through. Milly has begun to push the cultural constraints by deliberately choosing to work with some other women to develop a joint research programme.

What I have not seen in the experiences of these women is evidence of the social worlds and culture of mathematics changing or moving to incorporate the differences these women bring to mathematics. If women can find a way to negotiate mathematical worlds they can find ways to be included but the exclusionary practices that make this negotiation difficult remain almost completely intact.

A kind of serendipity also operates. Those women who had the good fortune to work with men who they could relate to, such as Fiona, Milly and Liz, were

able to negotiate their ways more easily. But those like Sarah and Jane who were unlucky in the sense that the men they most directly worked with, they found particularly difficult, had a much unhappier experience. It is men who determine whether women will or won't be able to participate. If the men are welcoming, women's participation is facilitated. If they are not, then women's experiences in the culture can be so unpleasant and conflictual that it is extremely difficult for them to remain.

Of the eight women in this study only Fiona's continued participation appears to be unambiguous. Milly, Annette and Imogen do not express an intention of leaving mathematics but have other difficulties to face in maintaining their careers. Milly's position depends to some extent on her partner's future prospects; Annette faces imminent redundancy; Imogen has expressed a preference for part time work although her circumstances make this a very unlikely option for her. She may face a further problem if her husband cannot find work in the same city upon completion of his Ph.D. The participation of the other women is more problematic. Liz is on maternity leave and is very ambivalent about returning to her previous position; Jane is retired but her experiences as a woman in mathematics were instrumental in her taking up alternative spiritual movements and lifestyles; Rebecca has never taken up a paid job within mathematics and continues to do mathematics as an outsider; Sarah has opted out of mathematics and moved into a different area of research and teaching. Even within this select group of women who have 'made it' there is some cause for concern about the continued presence of women as knowers in mathematics.

In the next chapter I will continue the discussion of the experiences of these women mathematicians but I will consider them in regard to the practices that determine and legitimate mathematical knowing. In this chapter I have illustrated the ways in which gender impacts on determining *who* can be a knower of mathematics.

# **Chapter 8**

## **The Experiences of Women Mathematicians**

### **Part Two: What Processes Determine and Legitimate the Act of Knowing in Mathematics?**

#### **Introduction**

This is the second chapter which specifically addresses the results of my research with women mathematicians. In the previous chapter I addressed the first of my epistemological questions, who can be a knower, through the experiences of women mathematicians. In this chapter I take up the second question of how knowing is determined and legitimated in mathematics. To do this I turn away from an emphasis on the individual as a knowing subject. Instead I look at some specific practices occurring within the culture of mathematics to gain insights into how mathematical knowing is legitimated and disseminated. In particular I am interested in how gender is implicated in these practices and processes.

The styles of knowing used in mathematics; the ways in which mathematicians go about their creative work; the presentation of this work for critique and validation; the networks mathematicians establish amongst themselves; the division of labour in mathematics according to gender; and issues arising from contestable funding regimes are discussed in this chapter. By approaching these issues through the experiences of the women mathematicians interviewed for this study, the effects of gender are illuminated.

## Separate and connected knowing

In “Women’s Ways of Knowing” Belenky et al (1986) develop a paradigm for stages in the development of knowing. Their work is based on Gilligan’s (1982) stages of moral development which she developed in response to Kohlberg’s theories which were grounded on all male samples. The initial stages of Belenky et al’s paradigm are not relevant to my discussion of women mathematicians’ ways of knowing because these women have established themselves as knowers in mathematics. It is Belenky et al’s use of the terms ‘separate’ and ‘connected’ knowing borrowed from Gilligan (1982) to distinguish between two different styles of knowing, which I have found useful in analysing the knowing practices of these women mathematicians.

Becker (1995:166-167) describes separate knowing as “the use of impersonal procedures to establish truths. ... It often takes an adversarial form which is particularly difficult for girls and women, and separate knowers often employ rhetoric as if playing a game.” On the other hand connected knowing “builds on personal experiences. It explores what actions and thoughts lead to the perception that something is known.” The separate knower justifies their knowledge claims by the use of deductive logic while the connected knower explains the circumstance that led to the conclusion.

Becker (1995:167), drawing on Gilligan (1982), identifies the following as characteristics of separate knowing:

logic; rigour; abstraction; rationality; axiomatics; certainty; deduction; completeness; absolute truth; power and control; algorithmic approach structure and formality.

The following characteristics are identified with connected knowing:

intuition; creativity; hypothesising; conjecture; experience; relativism; induction; incompleteness; personal process tied to cultural environment; context.

Belenky et al (1986:102-3) do not claim that separate and connected knowing are gender-specific although they may be gender-related. More women than

men may tip toward connected knowing and more men than women toward separate knowing. Nor are these modes of knowing mutually exclusive. Individuals may use different styles in different contexts. They may also integrate the two into a single more balanced style (Belenky et al, 1986:103). Using the concepts of separate and connected knowing is particularly useful in analysing differences in knowing styles because it avoids the problems of essentialism arising from directly attributing such differences to gender. The link between gender and knowing style is looser than attributing particulars like reason to men and emotion to women. It can allow for the diversity amongst women and amongst men.

The distinction between these two styles arises from differences in the relationship between the knower and the object of knowledge and between knowers. For ease of writing and reading I begin by treating these two aspects of knowing, that is the relationship between knower and object of knowledge and the relationships between knowers, separately and then discuss how they influence and are influenced by each other. It is not my intention to dichotomise the two as they are different manifestations of the same concepts.

First I will discuss the relationship between the knower and the object of knowledge. In separate knowing the traditional dichotomy between the subject and object is maintained. Separate knowers claim to suppress the self, their feelings and their personal beliefs and seek 'knowledge' through the application of impersonal procedures for establishing truth. This 'knowledge' implies mastery over the object of that knowledge. While Belenky et al (1986:109) suggest that this kind of knowing and objectivity are "most highly elaborated" in the sciences, I have argued throughout this thesis that this strict separation of knower and object and the suppression of feelings and beliefs is an incomplete account of mathematical knowing.

On the other hand the connected knower seeks knowledge through care in which caring represents a quest for understanding (Belenky et al, 1986:102). The equality between the self and the object of knowledge is maintained

(Belenky et al, 1986:101) and understanding is based on empathy. The 'truth' for the connected knower is personal, particular and grounded in first-hand experience (Belenky et al, 1986:113).

The public face of mathematics in which mathematics is presented as strictly procedural - follow the rules and the correct conclusion will follow - appears to fit neatly into the category of separate knowing. Any hint of personality or emotion is suppressed. Proofs and solutions are closely examined to ensure there are no errors of logical deduction and no counterexamples ignored. The mathematics speaks for itself.

If one were only familiar with the public face of mathematics it would be easy to draw the conclusion that to be a knower in mathematics requires separate knowing. Therefore one could explain women's relatively low participation rates in mathematics by their discomfort with this style. Becker (1995: 171) asks whether women in mathematics are more likely than non-mathematicians to be separate knowers because they perceive mathematics to be an objective discipline in which they can find absolute truth. However in the private world of mathematics, the distinction between separate and connected knowing is not so clear and so this question cannot be answered simply, for in the private world of mathematics intuition, feelings and informality are important parts of mathematical practice. A distinction between separate and connected knowing is intersected by the operation of the public/private in mathematics. In the mathematical knowing taking place behind the scenes connected knowing is also used. Sometimes separate, sometimes connected and sometimes a combination of both are in use. This is demonstrated in the experiences of the mathematicians participating in this study.

Annette's description is an example of separate knowing styles in mathematics. For her mathematical practice consists of the predictable and orderly application of rules.

*What do you like about it?*

The precision of it. I like things to be cut and dried which doesn't always work but your model is like that, even if real life isn't like that. I like things being predictable.

*The orderliness?*

Yeah.

*The predictability?*

Yes. I guess I like differentiation and those sort of things and then you get down to something that was tidy at the end. That kind of thing. The challenge you get and the applying of rules that kind of ... you are mixing and matching them but the applications to problems that are out there, that are real. (Annette)

In a quote I have discussed in a different context in Chapter 7, Jane described a connected style in which the subject and object of knowledge are connected in an emotional relationship with each other. She developed affection for her mathematical objects and revelled in their surprises and unpredictability.

*What is it that attracts you about mathematics?*

Getting results, seeing pretty patterns develop, seeing pretty properties. These are like little creatures. Like you have children, these are creatures that have their own properties and their own, and they can do their own thing, so to speak.

*Are they surprising?*

Oh yeah, lots of surprises happen. You get these nice patterns developing, these nice properties.

*So you develop some affection for them?*

Oh definitely. (Jane)

In Fiona's description of how she goes about her work any boundary between a separate and connected knowing style is blurred. While she attempted to work procedurally this did not always work. She got stuck and then exercised the patience and forbearance that Belenky et al (1986:117) describe as an aspect of a connected style. She relied on intuition and insight to suggest new avenues along which to proceed. This intuition and insight are informed by her extensive knowledge and understanding of the logical procedures of mathematics.

*What do you do when you are actually going to work on some mathematics?*

mmm Well I guess that some things that you could do is try out, depending on what it is you're trying to do, little examples and see if they work. If they don't work then you think of a counterexample. Basically what happens is that you get stuck, and then I do exactly what I tell students to do if they get stuck, is go for a walk. I mean your brain works on while you're not physically sitting there with a pencil and paper trying to do anything.

*And then you come back and try out your insight?*

Well, usually if you are trying to solve this problem, you've usually got a whole lot of steps. If I could solve this, if I could solve that. Right. OK I could solve that level if I could solve that level. So you have usually got sort of steps mapped out in your mind and you start and then you start by [starting] at the bottom trying to, but then quite often your [plan] runs amuck because you find something back down here turns out not to be true when you thought it might be. So obviously what was up here wasn't going to work, then you have to .... (Fiona)

A difference between Annette's work and Jane and Fiona's is that Jane and Fiona were in the process of developing new procedures whereas Annette was using procedures already developed elsewhere. Annette's task was to apply these procedures to new situations. While Jane and Fiona were very much

working in the private worlds of mathematics, Annette was working more in the public where the mathematics is already 'tidied up'. In mathematics the different knowing styles are more useful at different stages of the creative process. In the early stages prior to the development of clearly defined techniques or procedures, that is when those techniques are being developed a connected style is dominant. Subsequent to the development of the new technique or proof the tidying up process leads to the appearance of a logical deductive and objective procedure in which any trace of emotion or personality has been suppressed. Those who are only aware of this 'tidy' procedural stage may not be exposed to the connected knowing that has been involved in its development. As Rebecca said more women might be attracted to mathematics if they were exposed to the intuitive and abstract aspects of mathematics:

I would feel quite sure that there are a lot of other women who would have been really interested if they had only had the chance to really meet this stuff. I feel it was only quite by chance that I found it.  
(Rebecca)

Turkle and Papert (1990) develop a similar analysis of the relationship between the subject and object of knowledge in computer programming. They draw on the work of Belenky et al (1986) and Gilligan (1982) but use the terms "concrete thinking" and "formal thinking" rather than "separate" and "connected knowing". They identify some subjects (separate knowers) in computer programming as treating their computational objects like an abstract entity while other (connected knowers) treat them like physical objects (Turkle and Papert, 1990:145). These computational objects are on a boundary between the physical and the abstract. They can be seen, moved and placed on top of each other but they are mathematical constructions. The connected knowers in computer programming develop a closeness to their objects which favours contextual and associational styles of work while not excluding the possibility of using a hierarchical style. Separate knowers maintain a distanced relationship with their objects which supports an analytic, rule oriented style (Turkle and Papert, 1990:147). Turkle and Papert (1990:145) suggest that the

ambivalent nature of these computational objects may ease access into mathematics. They do not go further to argue as I have done that the objects of mathematics themselves also exhibit this ambivalence.

Now I turn to the other aspect of separate and connected knowing, the relationship between knowers. Separate knowing is based on adversarial methods and critical thinking. When new ideas are put forward the immediate reaction is to doubt their truth or value. Separate knowers look for what is wrong with the new idea - "a loophole, a factual error, a logical contradiction, the omission of contrary evidence" (Belenky et al, 1986:104). To participate in such projects the knower has to be "tough-minded" to withstand the attacks on their own ideas and to present their own supporting arguments. When separate knowers work together in groups they present their ideas as fully developed propositions which they attempt to sell to other participants. They don't need to know the other members of the group as individuals as these exchanges consist in taking up and defending positions and attacking positions different from their own (Belenky et al, 1986:118). Many women (and men too in all probability) experience these debates as a battering with words and reason which they find unpleasant and not conducive to the kind of knowing practices they would prefer to use. While the separate knower may argue that it is the position that is being debated not the person, many women are uncomfortable with this style of argument as they are concerned that some people, including themselves, may get hurt or relationships may be broken (Belenky et al, 1986:105). For those not attracted to this style of knowing the exchanges taking place appear to be a form of ceremonial combat. This kind of disinterested reason has the potential to lead to monotony and boredom on the part of the knowers as the aim is to win the argument rather than to establish the best answer to questions the knowers feel passionately about. Rhetoric is prized over 'truth' (Belenky et al, 1986:110).

When groups of connected knowers exchange new ideas they do so not through competitive arguments, not through attacking or defending fixed positions but through the presentation of incomplete thoughts which they

present for the other members to add to, and develop. As they are seeking nurturance for their new ideas, they need to know and trust the other members of the group in order to have the confidence to expose their tentative thoughts (Belenky et al, 1986:118). Rather than attempting to take away the effects of personalities, they attempt to stretch their own vision in order to empathise with and to share the views of other members. Personalities and their effects are taken into account as causal factors rather than suppressed.

Those women who worked in groups of other mathematicians in situations where a separate knowing style was predominant expressed dissatisfaction and discomfort with that approach. Sarah's descriptions exemplify this discomfort.

It kind of felt<sup>1</sup> like these guys got their rocks off on talking about all these intricacies of mathematics and I would think two things (1) what's the point? and (2) I can't contribute into that. I didn't feel like I could. I wanted to explore but I didn't feel like I could say anything because I would get laughed out of the house as it were. It would feel like I would have missed one of the things that were obvious or they would be able to quote a paper to me that I hadn't come across or something like that and I'd feel like I couldn't do it. So I tended to just shut up really and not talk out stuff at all and of course and that means that you don't really get [to] sort of develop, it is quite hard to develop because you are working in isolation like that. (Sarah)

Sarah would have preferred to work in a group that used a connected style that is where it was important to know the other people and trust them so that unfinished ideas could be shared and allowed to unfold and develop within the group. In this style positions do not have to be defended against attack from others.

<sup>1</sup> She cried while talking about this.

Where I have been working it feels more like that what matters is that there are people around who are sort of open or not into point scoring because that is criticism. I think one of the reasons I find the reviewing process so painful and so bruising is that it feels like they are saying I'm not OK and that's um and I have a feeling that's some of what's ... and that's how it comes out. So what would be really good is to be able to have a group of 4 or 5 who had that openness and honesty with each other and we could actually build up a community of inquiry. Something where there are possibilities I think, of being able to be friends as well, is a thing that would really matter. (Sarah)

Sarah alluded to another point made by Belenky et al (1986:105). Many women experience the adversarial nature of a separate style as personal criticism and feel battered and bruised by it.

On the other hand women, while preferring to do otherwise, can and do participate in such adversarial encounters. Belenky et al (1986:146) point out that there are also times when:

women may feel compelled to demonstrate that they can hold their own in a battle of ideas to prove to others that they, too, have the analytical powers and hard data to justify their claims. However, they usually resent the implicit pressure in male-dominated circles to toughen up and fight to get their ideas across.

Rebecca gave an example of this at a conference she attended in Germany. Although she could adapt to an adversarial style, this was not the manner of interaction she preferred.

I got to give my paper and have this discussion afterwards. And the thing was, they were so rude to each other. As soon as you start speaking, just take an example. You'd start speaking and someone who was terribly dignified and he'd get up and yell at him 'That's complete nonsense, this is complete crap. I don't want to come all this way and hear this sort of stuff.' They were incredibly rude to each other and part of the reason they called this [conference] was there

was a lot of strong feeling and difference of opinion on a lot of the foundation stuff. But they were so sort of, they wouldn't even let people get a proper hearing, and there was one other woman at that from X and she just found it really dreadful too.

I just thought, you know, I've got, myself. I said 'Be quiet. I don't want to hear anything. It's not fair if you don't let me say what I'm going to say and then you can be as rude as you like. If you don't let me tell you, you're never going to actually know what I'm trying to tell you.' And I just, and I found that sort of, it really was amazing. Mine was the only one where there was really sensible listening and discussion. I found it really rewarding. They came there to listen but they didn't actually. They didn't know what camp I was from, was part of the reason they got so sort of rude to start with. They all thought, 'Maybe she is really supporting that, in which case I better get in and flatten her before she starts.' (Rebecca)

In the relationship between knower and object there is a difference in knowing styles between the public and private domains. This same difference is not found in the relationship between knowers. In both the public and private worlds of mathematics, an adversarial separate style dominates. The dominance of this style contributes to the alienation of those who prefer a connected style. Many women are disadvantaged by this.

### **Work practices**

This discussion of work practices focuses on the relationship between the knower and the object of knowledge and concludes with a discussion of the similarities and differences in the relationships between the knower and the object of knowledge and the relationships between knowers. In the next section, legitimating practices, the relationship between different knowers is the focus.

A common theme in the accounts the women gave of their ways of working is that there is not a clear and distinct dichotomy between logical reason and

intuition in their work. They developed their mathematical knowledge through the interplay of reason and intuition and not through the use of one at the expense of the other. Initially they had to select a problem that is 'do-able'. Knowing whether it is 'do-able' or not comes from the intuitive feel for the topic and the logical understanding they have developed from past similar experiences. They have a 'feel' that something may work, they try it, sometimes it succeeds and sometimes it does not. They were sure it worked when they could assemble logical deductive steps for their proof or example. They moved between separate and connected styles and adapted them to suit particular contexts. Milly, Fiona and Jane's descriptions were representative of all the women interviewed.

*I want to ask you about how you go about doing your work?*

You spend a lot of time talking about what would be an interesting topic, and maybe thinking about a few that are not so interesting. Once you know what is an interesting problem you have to think about how to ask it in a tractable way. There are all sorts of, you can ask all sorts of interesting questions but you can't [always find a way of working them out], it is sort of moderating the interest.

Usually [there is] something you would like to know the answer to, you know, what happens if you do this? You might understand something about it already. What happens if you change something, how is it changed and then you scrabble around and get all the bugs.[You] ask other people how they would do this and you look in the literature. Once you know what it is you want to prove there is a lot of time trying to find some way.

You spend a lot of time fluffing around trying seeing that it is not 'do-able' and trying something else.

*Do you sit down in a room with all those other people<sup>2</sup> and talk about it?*

Yes, write on the white board and you get so far and then we say, this is no good let's stop and try again. Next time people come back and somebody usually has got another idea about how to approach it and have gone away and looked at a book and we spend quite a lot of time proving what we already know. So we know a result and we prove it three or four different ways, in the hope that one of these ways will [lead to something].

There comes a point where you just have to write something up. There are some problems that you, as you are thinking about that, are still not finished, it's difficult stuff . I still go back to [a problem like that], every so often but I still don't know if they are open ended ones if there will ever be [a solution] (Milly).

*How do you select a problem that you are going to work on?*

It might be a talk that you have gone to where somebody leads to something you know. You might read a book, they mention something that you think sounds interesting and go on with it.

Yeah, so that [finding something was trivial] wipes it out or if you've got yourself horribly, hopelessly stuck [so] that you couldn't finish, you spend several months trying to find [an answer] but you will eventually come up with something. You can't, you don't come to the office today and say I'm going to prove a theorem (Fiona).

*I want to ask you about how you do your maths.*

<sup>2</sup> A group of mathematicians and statisticians she was working on a project with.

Yes. I take pencil and paper and write a lot and see if patterns seem to develop or results seem to be happening.

*So would you sit down and just start doing something?*

If I think of something I might, yeah.

*Would you think about it a lot while you weren't actually sitting down with a piece of paper?*

Not necessarily.

*So you'd sit down start working something out and see what happens?*

I might wonder what would happen if this happens or..

*Would you often get to a point where you got stuck?*

Always.

*And then what would you do?*

Sometimes I would turn to something else and then I would come back to it.

*While you were doing something else would you think, 'Oh I'll try that'?*

Sometimes, or sometimes I would just go back to it and I don't like to read what I write either. So I start afresh and see what happens.

*Do you think intuition has a big part to play in this?*

It probably does. You have a feeling that something nice is going to come out of this.

*And then something nice comes out of it and you do the rigorous stuff afterwards?*

Yeah, right. Yes, I think that is a good way of stating it (Jane).

Often in the course of attempting a proof or solving a problem, the mathematician gets 'stuck'. They cannot think immediately of what to do next. The logical unfoldment of the solution is not obvious. They describe putting their work aside and doing something else. In this time they are not consciously working on the problem but allowing the subconscious or intuition to carry on below the surface.<sup>3</sup>

Other aspects of mathematics are routine and mechanical as Liz described when explaining her work in developing mathematical models. She distinguished between the routine and developmental processes. I discussed earlier in the chapter how connected knowing tends to coincide with the private and developmental stages of mathematical work.

A lot of it is extremely mechanical. I'll um, to a large extent, it is that they have huge amounts of [data. I will] try one set of, I'd slot in the results and see how they fitted in with past history and then [try] some more parameters and then maybe decide we needed to enlarge the model a bit to include another part of the field and, it would sort of be...

If it was routine stuff I'd forget about work when I came home but if it was development stuff I would often think about it when I was cooking tea or in bed or something (Liz).

<sup>3</sup> I do not want to be diverted here into a discussion about the nature of consciousness or intuition but to illustrate my point that reason and logic are not acting alone but are informed and intertwined with intuition and emotion in the creative work of mathematicians.

Jane and Rebecca went further in their discussions of their thinking processes. Jane had the belief, arising from her spiritual commitments that her thinking is 'guided' by a greater and external spiritual force.

Yeah, sometimes I say, I go through the stage sometimes, where I say I will give that up, and then I think about it again. Sometimes I say nothing will happen worth that and then I say I'll give it another go.

Yeah, I mean it might take a while, might take months, years. I feel very lucky but I don't think it is me actually I feel a sense of sort of guidance.

*And when you get in tune with that guidance you get good ideas?*

Oh well, it just happens. I mean, I don't feel I make decisions actually. We think we do, our ego makes us think we make decisions. It is all being guided. (Jane)

Rebecca has used self hypnosis techniques to access deeper levels of consciousness for thinking about her work:

I got really into self hypnosis at one stage when the problems got really difficult. I found it really useful to get skills that let me think much more deeply with my subconscious really. I'd pose a problem of whether something was a theorem or not. Often you would kind of know but sometimes I'd be really unsure whether that was the case or not and I found hypnosis for example, really helpful. So possibly I use my mind quite differently from some people anyway, partly through the fact that I've spent so many years now using it and trying to get the best out of it. (Rebecca)

When read together the following passages quoted from Fiona and Rebecca show the inadequacy of dichotomising abstraction, deduction and reason *and* connection, intuition and holism in order to capture the processes involved in developing mathematics.

Fiona described how she approaches her work:

Well, usually if you are trying to solve this problem, you've usually got a whole lot of steps. If I could solve this, if I could solve that. Right. OK I could solve that level if I could solve that level. So you have usually got sort of steps mapped out in your mind and you start and then you start by [starting] at the bottom trying to, but then quite often your (plan) runs amuck because you find something back down here turns out not to be true when you thought it might be. So obviously what was up here wasn't going to work, then you have to .... (Fiona)

Rebecca's description has similarities and differences:

I mean in, I know what ..say in the department and in my stuff, I just know that the way I saw it and the way I understood it and the way [I] felt my way to the end of it was just so different from all the blokes. I just felt I had a sort of overview and I could see the way in which things roughly went and then I'd find the maths to make the sort of sequence whereas I just don't think they approached things like that at all.

They were sort of going through the maths and if you wouldn't tell them what the next step was, they would never believe you in what the overview was, if you know what I mean. Well, it was very difficult because, oh it is hard to explain, I sort of had a feel for where the difference was, you know, and it has taken me maybe right up to writing this paper<sup>4</sup> to understand quite how that would come out in the maths but from the very beginning, I knew that was where roughly the solution was to found. (Rebecca)

<sup>4</sup> A paper she had recently submitted for publication in a journal.

Fiona presented a picture which might be associated with the left hand side of the binaries. She explained how she attempts to move logically through the steps required to solve the problem. A closer reading of her explanation however, illuminates the complex intertwining of the logical deductive processes and the intuitive overview. Somehow she had an overview of the steps which would be involved in solving the problem. This ‘somehow’ undermines the primacy of the deductive process. Some form of intuition is involved in this. She also pointed to the need for caution about the assumed inevitability of deductive processes in mathematics. In the public presentation of mathematics such as in school mathematics, mathematical processes often seem to assume an inevitability. If you start with for example  $2x+1=5$  then  $x$  must be 2. But in the private worlds of mathematicians where new insights into mathematics and its possibilities are being developed such inevitability cannot be counted on. As Fiona said sometimes things “run amuck” and something expected to be true is found not to be. The inevitable certainty of the process comes to the mathematician after the problem or theorem is complete and ‘tidied up’.

Rebecca attributed the ‘taking of an overview’ compared to ‘completing each step in sequence’ to a gender difference. It is tempting to subscribe to the same view but more reflection on the two accounts given here suggests that the differences are not so clear cut that such a conclusion could be well supported. Both Fiona and Rebecca developed an overview of their problem and how their solution would go and then filled in the necessary deductive steps subsequently. The two processes are inseparable. The difference Rebecca ascribed to gender could also be ascribed to a difference in the relationship between the subjects and objects of knowledge. In her area of expertise she is fully immersed in her mathematics. The boundary between the subject and object of knowledge is blurred. From this position she can develop a ‘feeling’ for the object. She ‘knows’ where her thinking is going to go. Her intuitive insights may be backed up in the logical deductive process she subsequently develops but as Fiona cautioned this is not always the case. For the outsider to this relationship

between subject and object, who in Rebecca's case had always been a male, the same blurring has not occurred. This other subject was not immersed in the object of knowledge and so had not developed the intuitive feel for what is going to happen next. Whether such a difference can be attributed to gender is difficult to substantiate. The comparison with Fiona's (another woman) explanation of her knowing practices partially supports and partially disturbs the establishment of such a gender difference. Analysing these differences in terms of separate and connected knowing reduces these difficulties. The difference then becomes one between a separate and connected style with women being more commonly but not exclusively associated with the latter.

Rebecca's comments also illustrate the intertwining of the relationship between the knower and object and between knowers. Rebecca could not 'connect' with other knowers because they did not share her overview of the problem. Rebecca's ability to see this overview is related to connection to her mathematical objects. Those who maintained a separation between subject and object adopted an adversarial stance with Rebecca and were unable to empathise with her thinking. They could not therefore understand or appreciate her approach.

I have argued here that the public face of mathematics is associated with a separate knowing style both in the relationship between knower and object and in the relationships between knowers. In the private worlds of mathematics, the separate knowing style dominates in the relationships between knowers. However in the relationship between knower and object the situation is even more complex. In the creation and development of new mathematics a connected style is very common. Even the claim made in the first sentence of this paragraph is an oversimplification of the situation as some students encountering the public face of mathematics in classrooms are able to make the mathematics 'their own' and connect with it. The association of these styles with gender is just as complex. There is some evidence in these women's accounts for claiming a preference by women for a connected relationship between knowers and a possible preference by men for a separate relationship.

A gendered relationship between knowing styles and the relationship between knower and object is more complex as mathematical knowing involves both, for women and for men.

### **Legitimizing practices**

In this discussion of legitimating practices the relationships between knowers are a central theme. Having developed new mathematics, mathematicians need to have their work accepted and legitimated by other mathematicians. I discussed in Chapter 6 how there is no absolute standard for mathematical proof and that what constitutes a proof is what mathematicians accept according to their standards of the day. This social nature of proof and verification indicates the potential for asking questions about how the social makeup of the group of 'mathematicians' can influence what is accepted and legitimated by that group. In this section I am going to discuss seminars, publications, networks amongst mathematicians, the gendered division of labour and the funding of research as determining and legitimating practices. I will consider these practices in relation to the experiences of the women mathematicians in my study in order to gain some understanding of the impact of gender in these practices. I will situate this discussion within a descriptive framework of some features of the culture of mathematics.

### **Culture**

The women identified competitiveness, elitism and the hierarchical social structures as features of the culture of mathematics. These imposed some constraints on their own work practices. In a competitive and elitist culture it is more difficult to explore new ideas co-operatively, that is to use a connected style. A separate knowing style dominates in the relationships between the knowers. The women's reluctance to engage in the strategies that other mathematicians use to establish their status means that they are less likely to reach positions high up in the hierarchy.

There is also an unworldliness about mathematical culture that is linked to its historical ties to theology and to commitments to 'purity'. This makes mathematics vulnerable to external challenges from changes in funding regimes and organisational structures. As a result of such challenges these women mathematicians shifted their positions in relation to mathematics. They distanced themselves from some of the competitive and elitist practices traditionally associated with masculinity but they repositioned themselves as mathematicians when facing challenges they were unprepared for, from new organisational and funding structures.

Milly's responses provide a clear picture of these elitist aspects of the culture and of her rejection of these values:

The people in the department (at a prestigious university in the US) think of themselves as very important, that comes through pretty strongly and it is pretty nauseating.

You get the impression that some people look through the journals and they, certainly graduate students, they look through and find what area is really hot and they move into that area, and that is always extremely repellent to me, the thought of doing that, because it is very high pressure, the lifestyle, you have to go where everybody else goes. I don't think you have got enough freedom to let your own [ideas develop].

There a few people in our department [in New Zealand] who have also been in places like that and they have those kinds of pretences and they will talk about 'this is the most important field' and the open questions in it. Mathematicians tend to be pretty unworldly I think, and so it doesn't happen as much as it can happen in other areas, because they are not, I mean, you only have to look at a bunch of mathematicians to realise that they are not very concerned about their image.

Teaching is perhaps the place that is easiest to describe. It's very elitist. You get the impression that you can't understand any mathematics until, you can't understand any original problems or do original work in mathematics, until you have done about eight years of study. That is the sort of impression and it's just completely false, it's just all wrong.

You go places and people will talk about the top twenty mathematicians in the world, and this just seems a ludicrous concept to me. It doesn't scan, it doesn't make any sense because how do you compare somebody that...it's like saying the best violinist in the world, it doesn't make any sense and they do spend a lot of time talking about that...this person is the best mathematician in New Zealand, I just find that completely repellent. (Milly)

The choosing of 'hot' topics which Milly alluded to is an example of the ways in which competitiveness and elitism are played out. Such values were repugnant to the women. None of them looked for 'hot' topics. They chose topics they were assigned by supervisors or in which they had a personal interest. Jane, Milly and Fiona's responses were typical.

Jane was encouraged to follow her own interests:

He [a professor she knew] said, find a topic you are interested in and work on it even if it is well known because your approach might lead to new results. So when Prof. L challenged me to write a thesis, I thought, well, what I liked was quaternions of Hamilton. I knew they were well known but quaternions are an extension of the complex numbers and I thought I will just see if I can extend the quaternions. It has probably been done but I will see what happens and it led to some very nice results. It led to my generalised powers and my Ph.D. thesis, all kinds of things, basically all my research. (Jane)

Milly and Fiona both followed their own interests rather than elite topics:

Well I tend to work not in those areas ['hot' areas] anyhow, because I think I work too slowly anyhow. Everybody else would have all their results published before me. So that is real disincentive.

... you have to choose something that is interesting. There's no point in choosing something boring (Milly).

All right there are hot topics and I really don't care about them. Really I want to do what interests me and what I feel I can do, so I don't follow up the hot topic of the month or anything (Fiona).

### **Seminars**

As I have argued elsewhere there are no absolute standards for legitimating mathematical rigour and proof, they are established by social processes of validation and legitimation. The presentation of new results in seminars is one such social process. The giving of seminars in mathematics serves a number of functions. New results, theorems, conjectures and proofs can be disseminated to a wider mathematical audience; the critical response of the audience can either support the legitimation of the work presented or discredit it; and the style of presentation serves to maintain the hierarchical, competitive and elitist aspects of mathematical culture.

As I discussed in Chapter 6 it is very common for those attending a mathematics seminar not to understand very much of the presentation. The presenter is often not concerned with explaining to a general mathematical audience but only to those who are specialists in the particular area of mathematics under consideration or a closely related topic. The women interviewed in this study clearly recognised this phenomena and saw it as an effect of the power relations existing in mathematics. These power relations are closely connected to the use of separate knowing and its associated group practices.

Milly and Fiona's reactions were typical:

*To me a phenomena of mathematics is summed up by somebody in my [mathematics] department who said that he could go to a seminar in any other department and understand more than he does at most maths seminars that he goes to.*

Yeah, that might be a slight exaggeration but ... well that is very common. I don't think, it is because the subject matter is...I think it is just that mathematicians (are bad) at giving talks. That's what I think. I mean I think it is absolutely appalling to have an audience of people who are not understanding.

*Are there people that can give a talk about their work that satisfies the specialist and the nonspecialist in the audience?*

I think so, I think it is possible. It's quite hard work, though it is much easier to talk to a specialist audience. I don't know how many seminars you have been to but, if you couldn't hear anything you can tell by looking at them that not much was going to get across because they stand at the blackboard, you write in minuscule writing with your back to the audience and mumble away and no effort is paid, overhead transparencies 25 lines to a page in minuscule writing, just no effort is paid at all.

*So it's not an important aspect of mathematical practice to communicate to people outside the area?*

People try, if you go to a talk that is understandable, other mathematicians are very scathing about it they presume if they understand it.

*It must be trivial.*

Yes, that is the really nasty thing about it all. Good speakers are always, people know who the good speakers are, but they are not

given enough praise, that everyone wants to be a good speaker.  
(Milly)

But I think that they would at least be able to explain it to other people in some ... I think most mathematicians [in different fields] can explain to some extent if they really want to. If they don't want the mystique in their power province....

*And you think some of them do want that?*

Definitely.

*As part of their own personal power?*

It makes you feel powerful doesn't it you understand all of this stuff.

*Do you find that part of it attractive?*

Oh no, I like to try to give it so that people can understand it at least the flavour of what's going on.

*And you think it would be possible for all of these specialist mathematicians to do that if they chose to and they developed the skills?*

Well it would depend what .... Well I think you structure your talk to different levels. If you are giving your talk to people in your specialist area then you are going to put it on a different level than if you are trying to present it to a general audience. But some people in presenting to a general audience still think they should present at the specialist level .

One thing that maths has, is a huge amount of terminology a huge amount of [definitions]. You say something is a group that

immediately means four conditions are satisfied and there are certainly far more complex structures than that. This is an algebra, so certainly somebody outside mathematics wouldn't understand that. If I went to a history talk I could at least follow part of it. (Fiona)

Jane expressed similar reactions which reflect her own preference for a connected style of interaction. She claimed that if male mathematicians were more connected to other people they would communicate better.

*One of the things I have found amazing is this phenomena in mathematics of people giving seminars and their peers going to them and not understanding them.*

Oh that happens all the time.

*Well, that doesn't happen in all disciplines, usually people try and communicate so the people can understand.*

But some of them feel good. No one understood. They feel superior. They are so brilliant. No one else can understand me because I am so brilliant.

No, no, I think some of, but maybe the men who are good communicators, it is a female trait within, what is called a female trait within them.

It is because they are more concerned about human beings and communicating.

But also it is the feeling of feeling insecure. If you feel insecure, you feel everyone knows so much and I don't know anything, and they do things and they are not really getting together. Whereas if they feel more secure, they have a better feeling about [it], they may be more interested in [communicating]. (Jane)

The highly specialised symbolic language of mathematics does present problems for mathematicians wishing to communicate with non-specialists but as these women have pointed out often the presenter is not seriously attempting to do this. When attempts *are* made they are often not valued very highly. The women in this study distanced themselves from the power relations functioning in this practice and the dominance of separate knowing. For them the giving of seminars was about communication and discussion and not about establishing a position in a hierarchy.

### **Publications**

Publications, especially papers published in refereed journals, are another way in which new findings are disseminated and are an aspect of the legitimisation process of new mathematical knowledge. Referees who determine whether a paper is publishable, are gatekeepers in determining the status of the mathematics presented in the paper. These publications do more than disseminate new results. They also serve as the currency of academic appointments and promotions. Those with the best publication records, which mean not only large numbers of publications but also publications in the prestigious journals, are the most likely to be appointed to academic positions and to reach high status within universities. Successful publication rates are also advantageous when applying for funding for further research.

I have discussed in Chapter 6 some research on women's publication rates in mathematical journals and here I report the responses of the women mathematicians in this project to questions about publishing.

Milly plans to publish so as to disseminate her findings and to meet the goals her position requires but she does not adopt strategies to ingratiate herself with potential reviewers.

*Are you trying to get lots of publications?*

No, you have to do a certain amount of that. There is no point in doing this work if nobody sees it but lots of people publish just for the

sake of publishing. They have one idea... I'd rather it was a good paper and I ....so I have what is regarded as a poor attitude to publishing. I mean, I do enough to get by. I do enough to get promoted and ... I feel an enormous sense of relief when a paper comes out, cause right now whatever I do for the rest of the year I don't have to worry about ...

*For you there is quite a distinction between the writing of the paper and doing the mathematics.*

Yes, it is partly because you have to, there are a whole lot of things that are not to do with mathematics, ....bureaucracy.

*Would you have trouble getting your work published?*

Not really, not because of, everybody has problems from time to time with certain bits of work, once you find the right journal, then that's fine. There are some problems, you have to choose the right journal. Often it will come back with a ... there might be some comment like... I don't know of a paper that was accepted without any corrections.  
(Milly)

Fiona also plans to publish regularly.

*Are you really driven to publish is this really important to you or? It's quite an important part of an academic career isn't it?*

Yeah, yeah, yeah, I guess I have goals and one of them is to publish periodically. Yeah, yeah I think you definitely plan to get out [a certain number] a year. (Fiona)

Sarah has had difficulties getting her work published. As she is a strong adherent of connected relationships, she found the rejection of her paper particularly difficult. She did not separate herself from her ideas or from those critiquing them. As a consequence she felt personally hurt and devastated by the criticism her paper received.

*When you were at [the other university] did you do much research?*

No, one thing [it] didn't do was to encourage me to do research. I put stuff in for publication from my Ph.D. and got really quite ratshit reviewing and got it turned down, and I just, and I didn't know how to handle it. I just put it away in a cupboard. It was quite a devastating feeling at that point. Yeah and what was even worse about it was when I looked at it later I realised the guy hadn't even refereed it properly. It was like, there were some holes in the paper, in the way it was constructed, um, but it felt like he thought it was a hick town in the back of nowhere, rubbish comes out of it and slammed the paper really. (Sarah)

Rebecca did reviews of papers published in her area for *Zentralblatt für Mathematische*, a prestigious German journal, which reviews every mathematical paper published. Reviewing these papers allows Rebecca to keep up to date with everything published in her field and means she knows the journals which will be most interested in her own work.

*It's pretty prestigious, isn't it, reviewing for Zentralblatt?*

Probably. You see, I'm right out of the academic world so I don't really know. But it certainly has served me well because I get to see... I saw one which was a total rip off of my stuff and I've actually said that. I wouldn't have minded if he had really understood it properly, but he didn't apply it properly.

*Now do you think which journals publish the best papers?*

I'm not the right person to ask. I don't read journals. I probably am a bit arrogant but I just know how much crap is published. Take something like this business of logic being nondistributive and isn't it 'wow you have to use this different logic when you want to think about really small things'. It either means nothing, you know, to say you use a different logic or it means you don't understand anything. And either way that's sort of the end of the story. (laughs) I'm just not

really interested in that as an answer but the mathematicians sort of picked up this whole thing. I don't know if you know much pure maths but a Boolean algebra is sort of the standard algebra you use for switching circuits and classical logic and it's got a sort of mystical status as this great algebra. And so in their sort of way, lots of people say what can we chuck out of the Boolean algebra to make it not classical, to suit quantum mechanics? So they chucked out the distributive law and I would say hundreds of papers every year are written on algebras that aren't Boolean, that are lacking the distributivity. The fact that these structures are really ugly like there's nothing, Boolean has a very inherent simplicity even though its highly structured. It's a kind of beautiful thing. These things they end up with, are just ghastly. There's no simple rule that has come out of the next one down if you get rid of the Boolean structure. There is no other algebra that has arisen out of this lovely structure but isn't quite Boolean. They have just blasted ahead with no concern at what they are really saying, which is that you can't think distributively, but never mind let's just look at the algebraic structures, something that isn't distributive, which I think is a pretty unimpressive approach really. Secondly they haven't bothered about the fact that the maths is completely gruesome. I mean it really is revolting. There's no simple rules that come out. There's these ghastly complicated things, no obvious applications, no obvious sort of simplicity in their structure, that should have warned that they are going up the creek. And so there are literally thousands. Then they do it in all these different ways and I just find it a real mindless approach. I think a lot of what goes on in maths is basically quite mindless. It picks on little things.

*A lot of it is about establishing publishing records and*

I suppose it is. I got out of all that and that's partly why I got out, because I think if all that stuff is burdening you, the chances of doing good work are just going down rather than up. You [are] also having to think about...

And it's not just publications. It's those dreadful meetings where they all sort of spar against each other. I find that very uninteresting. I am quite serious about, really, I've only got one life time, I don't want to stuff around doing that.

*And the aspect of disseminating your own work isn't that important to you?*

I guess it isn't really. It's more important to me to get the stuff written down and I'm not sure yet whether I've really done what I hoped I did of making it clear enough, general enough and completely convincing enough. I mean it is to me but whether I've really done that for someone else I don't know but I have had my best shot at it.

(Rebecca)

Rebecca drew attention to another consequence of the need to publish to acquire credibility. This is that many trivial results are published. With over two hundred thousand theorems being published per year, many relatively insignificant findings must be being reported (Davis and Hersh, 1980:21). Having opted out of the academic system Rebecca can and does distance herself from the use of publication records to establish status and hierarchy. None of the women took a strategic approach to publishing in the sense of developing tactics to ensure they were published in the most strategic areas although several of them did have goals to publish regularly. Those working in universities were aware of the need to publish regularly but were not driven to publish purely for the sake of it.

### **Networking**

The saying 'it's not what you know, it's who you know' applies in mathematics just as it does anywhere else. Knowing the 'right' people can open up opportunities and enhance the credibility of one's knowledge claims. If the high status people in a field endorse an individual or their work, then it is easier for that individual's work to gain recognition. Women are often excluded from

such informal networks and thus do not have that advantage when seeking recognition for their work.

There are a variety of ways in which gender impacted on the networking of these women. It should be noted that none of these women had achieved a status sufficiently high to cause others to seek them out as individuals whose influence was worth courting.

Milly's experiences as a Ph.D. student demonstrate some ways in which gender impacts on the networking processes. As a Ph.D. student she was the only female student in her particular area and this affected her establishment amongst a network of peers.

[S]o much of the research is tied up with social stuff. You know everybody would go off to the pub after a seminar and talk more mathematics or they would go to lunch together and talk mathematics. So the work and the social stuff were so mixed up that if you were not really at any of the more social situations you don't have a peer group somehow.

*Were you able to be involved in that social side?*

I probably could have if I had, you know, if I had wanted to, but somehow it seemed like .... it wasn't natural...I don't know how much of that was just my personality and how much of that was being female, it didn't help anyway (Milly).

Milly has since had the opportunity to build up a network amongst women mathematicians through women she met while working as a postdoc in the United States. Gender continues to impact on networking practices here but in this example women were using their commonalities to support each other. None of the other women have had this opportunity or experience.

This woman was at C. She had the right personality to get herself established so through her I met a lot of people.

We got on well, we thought ... it was quite natural that we work together, we spent a lot of time trying to think of something we could work on, by ourselves without [any men] and this happened with a couple of women (Milly).

Fiona and Imogen's experiences illustrate another difficulty with establishing networks women can face when they are also responsible for children. As a Ph.D. student Fiona had two small children so did most of her work at home and did not have much time to spend socialising with her peers. Imogen said she would prefer to have bigger networks but the ties of small children restricted her opportunities to do that.

Not all of their networking had difficulties associated with it. Both Fiona and Jane discussed connections they had made with other mathematicians and then followed up on study leaves. Fiona was fortunate when looking to work with someone who lived near her children, so that she could visit them at the same time. She has maintained a happy working relationship with this man for several years, although it was by chance that this was the case.

If I was going to stay a long enough time I wanted to go see my other children in the States so I ..., so I just looked through the NSF<sup>5</sup> files to see who at the university was or might be doing work in the same area and found this person and I wrote to him and ..... No, it was a total shot in the dark. I couldn't find anybody who had actually met him but I heard some people who had read some of the things he had done in slightly different areas and thought it was good work so I just went and met him and it worked out just fine. In fact he is coming out here the week after next.

*You had no idea about his personality or what it would be like working with him?*

<sup>5</sup> National Science Foundation of the United States of America

No. I suppose it sounds a bit reckless (laughs) (Fiona).

Jane has had similar fortunate experiences through contacting people whose mathematical work interested her.

Oh I visit, I went all over the world. I went all over the States and I went to England and France. In combinatorics they are interested. They have some interest in what I have done but they don't do it. I have given talks on what I have done.

*So how did you choose where to go on those sabbaticals?*

Well, I worked on special functions based on things in combinatorics and so I know these famous people in combinatorics and I write to them and they invite me.

*Right, and that hasn't been a problem for you?*

Oh no, no. It's good. I had two sabbaticals and they were both great.

*And it wasn't difficult to find places to go?*

Not at all, no. I just meet people through, well if I liked something they wrote or something, I would write to them. (Jane)

Jane and Fiona's approach is in marked contrast with a former member of the mathematics department where I was working, who explained to me that when he went to international conferences he spent an evening working out who were the prestigious people he should talk to (Vogel, 1994). Milly expressed irritation with that kind of networking:

I don't think they [mathematicians who do that] do more interesting mathematics. That's how I value...

*But would their mathematics get a better audience? or they get more acclaim for it?*

Possibly, yeah, certainly I can think of people who get more acclaim than the quality of their mathematics would entitle them to expect. Some people are very good at promoting themselves, and if you are into promoting yourself then that is probably what you should do. It gets irritating when you see people like that, when people come up and .....occasionally that happens but not very often because I am not the right person but people come up and ... rather than because they are interested in what you've got to say or you might be interested in what they've got to say, ... [they are interested in promoting themselves by talking to you]. (Milly)

The kinds of relationships formed between individuals in these networks do not necessarily have anything to do with the kind of emotional and intimate connections described in a connected knowing style. They are more likely to be about establishing a position in the hierarchy.

### **Gendered division of labour**

The practice of dividing and assigning work according to gender impacts on women in the workforce. As women are most often assigned the lowest status and lowest paid work, these practices have an enormous impact. However they have less impact for these particular women mathematicians because in achieving their present positions, they have avoided the full impact of this gendered division. Women in mathematics as in other areas are assigned the work that is most closely associated with caring and domestic work. In mathematics this is played out for women in their being teachers of mathematics or specialising in mathematics education rather than mathematical research itself. Although the women in this study have broken through that invisible barrier this gendered division still has some effects. For example many of the women have the experiences of being 'token' women on committees and selection panels. This is a double edged sword as on the one hand it allows them access to decision making processes they might not otherwise have. On the other hand it can take up their time on administrative work at the expense of time spent doing research which is what is most important for promotion.

All but Jane had been involved in programmes of various kinds to attract more girls and young women into mathematics.

Amongst the women in this study I could find no evidence of a gendered division in research areas. Their range of research interests includes: nonlinear geometry and dynamical systems; graph theory; geothermal modelling; foundations of quantum theory; operations research and management; the combinatorial aspects of computer science; and combinatorics and special functions. They include both pure and applied topics and greater or lesser use of computer technology.

The gendered division of labour also impacts on relationships between family and work. Women continue to be expected (and often want) to be responsible for their children as well as their paid work. Men can usually expect somebody else to be responsible for the care of their children. Such family responsibilities were very influential in the careers of those with children, Fiona, Liz, Rebecca and Imogen. Many of their choices were made to take account of their need to be able to care for their children.

Fiona's career path is an interesting example of this. Her experience is atypical of this group of women as she is the only one who has children and is old enough to have had this experience. During the years she was the primary caregiver of her children, she was out of the main stream of mathematical research and lost contact with her mathematical research as a working body of knowledge. It is often claimed that women who take time out for child raising cannot catch up again and that this is why there are so few women mathematicians. Fiona's experiences show that this is not inevitable. She was able to take up a new area of mathematical research that had developed during the time she spent with her children.

*When you came back into doing research again did you pick up in the same kind of area where you had been?*

No, I totally changed area. One of the staff members here said one day “I reckon we could do something in this,” which was in graph theory.

*Was it just through involvement with one other person?*

No, I had been going to some of the seminars and things and that looked like a nice area to be in. At this first point I had forgotten pretty much all the mathematics I knew or any stuff that I had worked with anyhow. In terms of it being a working body of knowledge it had simply gone, so I was sort of wide open for [something new].

*Did you have to start at the very beginning?*

No. I sort of managed to do everything upside down. I sort of started. You know, I regard maths as a very much of a building block operation to some extent and you really need to start here and as you know and come up but I sort of started here and every time I didn't know something I stepped down and tried to find out about it but it wasn't the ideal way to do things but it sort of worked for me.

*When you moved into this research area was it just that it looked interesting or did you assess that there were good possibilities for research or good people to work with?*

Yeah, there were good people to work with. It seemed to be interesting and it seemed to be something that you could think about some of the problems in it without having to have a huge background knowledge. (Fiona)

Fiona's comment that “there were good people to work with” demonstrates the importance to her of connections between knowers.

## Funding

For most of the women getting funding was not a big issue because they did not have high costs. Those working in universities had not had their career prospects affected by the ability to attract external funding but they did want some money particularly for travel and computers.

Milly and Fiona's responses were typical of all the women except Annette.

I need money to go overseas a little bit and I need money to go to conferences and I need money to buy computers and I need money for graduate students. If I didn't have any of that money I could still do my research. It would be hard without it certainly. (Milly)

Mostly what you want money for is to go other places, to talk to people; you want money to go to conferences and sometimes depending on what area you are in, you want money to get a computer. (Fiona)

In Chapter 6 I discussed the potential of changes in research funding regimes to change the power relations and practices in mathematics. Of all the women interviewed Annette was the one at the forefront of these changes. On the day before the interview her team had heard that none of their funding bids had been successful. For Annette this meant that she was facing redundancy. Her experiences illustrate the ways in which traditional practice in mathematics has made mathematicians vulnerable under these new regimes. As I argued in Chapter 6 the 'purity' of mathematics and communication practices in mathematics have become dysfunctional in the new funding regimes. Most funding is awarded to projects that will have significant and immediate, practical and economic outcomes. Maintaining 'purity' at the expense of a concern with practical applications and communicating to establish power and status rather than communicating the significance of mathematical research to a

nonspecialist audience are not likely to be successful strategies in contested funding rounds.

A mathematician like Annette who has been educated in the traditional culture of mathematics is faced with many difficult challenges in the new regime. First, she has to be able to find projects that match the desired outcomes. This involves working with industries and manufacturers to find out what they need which she may be able to provide.

Yeah and also we don't really have enough experience in manufacturing to know what to offer or what's the best thing to look at. It's such a big problem that you don't know where to start. We really don't have the background yet.

I'm really not a research leader and that's kind of the position I've been pushed into. [I have to] come up with the new ideas and that kind of thing which is quite hard. I'd rather do the work when it was there, rather than come up with the bright new ideas. And of course in this current system, it's every year come up with a bright new idea and the next year come up with another bright new idea. So that's been quite hard. (Annette)

She also has to be able to successfully implement the results in the practical setting. Mathematicians in the past have not been concerned with this. They have left that to the people who have picked up the applications of their work. In the following example the project failed because it did not meet the client's needs and nobody ensured the implementation was going to work.

We ended up working on one firm in W. We tried to explain what we were doing and get what the problem was. We'd go back to them with what we had come up with, to see if it suited them and then we'd find they had things they hadn't told you. So you would go back and put them in next and you go back and find something else they hadn't told you. They just didn't notice what they do or they do but they don't tell you. I thought so at the time. They did seem quite happy with it. Then I went overseas for two months and they had

some problems with the things they hadn't told us. And in the end they decided it wasn't any more useful than what they'd got which I think was a shame because I don't think it was true. But by the time I got back, it was a bit late and by then you had no money, no funding to do it with. (Annette)

The changing economic pressures on mathematicians resulting in their need to attract funding from business sources impacts on the skills and work practices mathematicians need to develop. In order to continue to attract such funding mathematicians need the skills to communicate with clients to ascertain their needs and circumstances and to ensure their projects are successfully implemented.

The short term and insecure nature of this kind of research funding leads to an increasing casualisation of many positions. Jobs are made temporary or part time depending on funding. Women are most likely to be appointed to such positions where they lose the benefits not only of job security but also of provisions such as maternity leave and study leave. Newcomers to the area are less likely to be employed because they do not have a track record in attracting funding.

## Conclusions

The acceptance of new results in mathematics depends on *both* the mathematics itself *and* the social processes by which mathematics is validated and legitimated. The mathematics itself must be correct according to the standards of the time *and* the work has to pass through mathematics' gatekeeping processes. Gender impacts on these processes of validation and legitimation. They occur within a culture that is elitist, competitive and hierarchical and in which knowledge is established by means of adversarial interactions. The women whose experiences are reported here, often found these aspects of mathematical culture repellent or at least uninteresting. As a consequence they maintained a distance between themselves and their whole-hearted immersion in these processes. For some this influenced a withdrawal

from full participation in mathematical worlds. Others maintain a distance or ambivalence between themselves as women and themselves as mathematicians. They have entered the private worlds of mathematics where the practices of mathematicians going about their mathematical work are not always based on the binaries of reason and logic versus intuition and emotion but often on the interplay between them. In their private worlds mathematicians often use connected knowing styles which many women feel comfortable with but in the public world of mathematics separate knowing and the adversarial practices associated with it continue to dominate and cause many women discomfort and even unhappiness. Although in mathematics, qualities/values/attributes/knowing styles associated with the feminine are an integral part of everyday practice, being a woman continues to make a difference.

## Chapter 9

# A Feminist Epistemology for Mathematics

### Introduction

The boundaries surrounding mathematics are under threat from economic changes in society and the development of new technologies as well as the clamour of previously marginalised voices who demand to be heard within mathematics. Feminist pressures for increasing the participation of girls and women, and for the addressing of questions arising from women's experiences are a vital part of this threat. Together with the new developments in the philosophy and sociology of mathematics which take the social nature of mathematics into account, these challenges have led to the opening up of the rhetorical space in which to ask different questions about mathematics. The development of a feminist epistemology for mathematics not only challenges the boundaries of mathematics but also the boundaries of epistemology and feminist theory. The feminist epistemology for mathematics developed here does not consist merely of the addition of women or feminism stirred into the existing definitions of epistemology but is a reconceptualisation of the epistemological project.

Members of marginalised groups including women, voice a different kind of scepticism about mathematics than that raised in traditional mathematical epistemology. They are concerned with the impact of mathematics on their lives; the relationship between their own experiences and mathematics; and their own mathematising of the world. They are concerned with access to mathematics and with the use of mathematics for their own purposes.

An underlying theme of this thesis is the question of whether mathematics would be different if more women were involved. Questions about the nature of mathematical knowledge emerge out of this theme but this represents a very different approach from that of traditional epistemology. Traditional

epistemology has been more concerned with answering questions about the nature and possibility of mathematical knowledge and establishing the certainty of the foundations upon which mathematics is built. The relationship of mathematical knowledge to its exponents has not been addressed in this tradition. Any such relationship has been disguised by ideologies of objectivity and rationality so that such a question does not 'make sense' in that context. The rhetorical space and the necessary choral support for the discussion of such questions (Code, 1995:ix-x) has not been found within the confines of traditional epistemology.

In my discussions of feminist epistemology, the gender mathematics and education debates, the feminist science debates, the philosophy and sociology of mathematics and my empirical work with women mathematicians I have opened up the rhetorical space in which to discuss such questions and to move towards developing a feminist epistemology for mathematics.

In this chapter I am going to draw together the threads developed in the different chapters of my thesis to present a feminist epistemology for mathematics. This epistemology addresses the three questions I have identified as essential to such a project. I begin with brief summaries of the major themes of my thesis and identify within them the rhetorical space for asking whether mathematics would be different if more women were involved. I then discuss Burton's paper as her work is ground breaking in that she addresses the epistemology issues that other writers (Fennema, 1995) have identified as important but have so far not taken up themselves. Then I present my own epistemology addressing each of my epistemological questions in turn specifically in relationship to mathematics.

### **Feminist epistemology**

In feminist epistemology the question of who can know is central. Acknowledging the social character of knowledge leads to an interest in the politics of knowledge and the connections between knowledge and power. This means that the following questions are all vital concerns of feminist

epistemology: how a knower establishes credibility and status; whose experiences count as evidence; how the agendas for knowledge projects are formed; the kinds of questions deemed worthy of investigation; and the relationships between knowers and the objects of knowledge. Within this context the question of whether increasing women's participation could make a difference seems particularly relevant and has a high probability of receiving 'choral support'. This support comes from feminist epistemologists and does not imply a transformation in the interests of traditional epistemologists. As well as a concern with the social character of knowledge feminist epistemologists retain an interest in the relationship between knowledge and reality and coherence between knowledge claims.

### **The gender mathematics and education debates**

The philosophy of mathematics expounded in mathematics education; the role of mathematics as a critical filter to both prestigious education and professions; the gender imbalances in participation in mathematics education; and the lack of recognition given to girls' achievement in mathematics not only mutually reinforce each other but also point to questions about the intertwining of discourses of mathematics and gender. This intertwining is played out in the privileging of masculinity. These debates support the rhetorical space to speculate about the effects of recognising and valuing the feminine in mathematics.

### **The feminist science debates**

Although there are differences between science and mathematics, particularly the empirical nature of science and the analytical nature of mathematics, there is also much overlap and coincidence. Mathematics has its quasi-empirical aspects and science has its analytical aspects so arguments established in the feminist science debates are relevant to feminist debates about mathematics.

Both science and mathematics are associated with masculinity and in our societies the masculine is privileged over the feminine and thus anything associated with masculinity is privileged. As I have argued in Chapter 5 this

privileging is reflected in scientific practices; in the language and metaphors of science; in the stories told of what science is; and in the epistemological values such as objectivity and reason that are used to justify the truth claims of science. Applying similar analysis to mathematics illuminates the rhetorical space in which it is possible to examine the impact of gender on mathematics.

### **The philosophy and sociology of mathematics**

The failure of foundationalist epistemologies to achieve certainty for mathematical knowledge and their inability to account for recent developments in mathematics fosters the asking of different questions about the nature of mathematics and how we know it. Questions about the culture of mathematics; its history and values; the relationships between this culture and that of the wider society; and the interests served and power relations produced are all considered relevant in these new approaches to mathematical philosophy. Although questions about the interrelationships between mathematics and gender have seldom been addressed within this context, such questions arise from consideration of the social and cultural as gender intersects and constitutes them.

Awareness of the importance of values associated with the feminine in mathematics and mathematics education is hidden in the private worlds of mathematics. The acceptance of the social nature of proof leads to an examination of the processes and practices involved in establishing a proof and how these processes and practices serve the exclusion of women. Claims to purity have been crucial in establishing the status of mathematics and have also served to exclude women and the feminine as purity has been defined by hierarchical dualisms which associate women with sexual excess and the body and so with impurity. The association of mathematics with masculinity has served to enhance the status of mathematics but realisation of this association makes questions about gender particularly relevant. While a recognition of the social nature of mathematics has gained more support amongst philosophers of mathematics, it would be premature to say that the rhetorical space is now available for questions about the implications of gender in this social nature to

find ‘choral support’ amongst such philosophers. My work here is an attempt to provide arguments that will lead to the achievement of such support.

### **The experiences of women mathematicians**

The experiences of women mathematicians demonstrate the complexities involved in asking whether mathematics would be different if more women were involved. The diversity present in even such a small group of women shows that simplistic definitive answers are unlikely. These women have much in common with their fellow mathematicians at the same time as they face contradictions as women in the world of mathematics. Their experiences in the ‘apprenticeship’ processes where they were largely left to find their own way and their rejection of the elitist practices occurring within mathematical circles, are evidence of some gender disparities. Their knowing styles and their descriptions of how they go about their work, reveal the inadequacies of philosophies based on binaries to explain mathematics and the presence/absence of women. Although any answers are necessarily complex, the experiences of these women provide further choral support for the asking of questions about the impact of gender on mathematics.

### **Rhetorical space**

The association of mathematics with rationality and objectivity makes the question of whether mathematics might be different if more women were involved appear nonsensical. Reason and objectivity are supposed to be beyond the influences of the social/cultural and individual particularities and prejudices. However there is a contradiction within this association between mathematics, objectivity and rationality because mathematics is also closely aligned with masculinity. To think mathematically is to ‘think like a man’. If objectivity and rationality really were above and beyond the social this association would appear overtly contradictory but this is not the case. In societies in which masculinity is privileged and knowledge systems are intertwined within power relations this contradiction is not transparent. The establishment of this association of mathematics with masculinity is mutually reinforcing as the high

status of knowledge which is said to be objective reinforces the high status of masculinity.

Opening up the rhetorical space in which to ask questions about these power relations and the ways in which they operate to exclude women from participation in mathematics poses a threat to the status and power of mathematics and the culture within which it is developed. If anybody and everybody had access to mathematical knowledge then mathematics would lose its mystery and the private interiors of mathematics would be exposed to the public gaze. This would uncover the intuitive, creative, conjectural aspects of mathematics, that is, the feminine side. This would pose a threat not only to the association of mathematics with masculinity but also to mathematicians' access to the resources necessary for the production of mathematics and the ability of mathematicians to pursue the intellectual and material rewards of their privileged profession without regard to the social, economic and environmental consequences.

### ***A feminist epistemology***

If it is to be called feminist, a feminist epistemology has to address the status of women, women's knowledge and experience, and the feminine. No matter what kind of knowledge, no matter how tenuous the link between a particular field of knowledge and gender appears to be, a feminist epistemology retains links with the diverse political projects of feminism. In the development of a feminist epistemology both feminism and epistemology are mutually challenged and reconstructed. Feminist theory challenges the constitutive values of epistemology such as rationality and objectivity. Epistemology challenges feminisms which have been constructed on an adherence to traditional feminine values and commitments such as a preference for the emotional and intuitive. For example Rose (1986:72) argues for a feminist epistemology which "emphasises holism, harmony, and complexity rather than reductionism, domination and linearity." I have argued throughout this thesis that such a

position is inadequate to provide the basis for a feminist epistemology for mathematics.

A feminist epistemology requires a reconstruction of the pivotal ideas and ideals of epistemology because these ideals such as objectivity, impartiality and universality are themselves derived androcentrically (Code, 1991:314). They are defined in terms of binaries in which the feminine is denigrated. To adopt them as the basis for a feminist epistemology would entail the permeation of this epistemological position by the very denigration of the female subjects of knowledge, traditional female knowledges and female experiences, which feminists are seeking to eradicate. What is required is not only a redefinition of the defining values of epistemology but an expansion of the agenda of epistemology to include different kinds of questions for epistemology. This requires taking different factors influential in the determining of knowledge claims into account, including social and cultural factors both within and outside mathematical communities.

A central question to be addressed in a feminist epistemology is “whose knowledge are we talking about?” (Code, 1991:114). This involves asking “who can be a knower?” (Braidotti et al, 1994:34; Harding, 1987:3) and by what processes of exclusion and inclusion one can achieve this status. The implicit assumption in this question, that the knower is an individual independent of social ties, is also interrogated as is the notion of the Cartesian self which underpins this concept of the individual. Knowledge creation occurs and is legitimated within communities of knowers who are themselves shifting position within and between discourses. The criteria for knowledge claims to be accepted and the processes by which this happens are another concern and lead to questioning whose observations and experiences count as evidence; how and by whom the political agendas for knowledge making are drawn up; and what kinds of things we want to know about (Code, 1991:7-8). The third set of questions relate to the objects of knowledge, the kinds of things that can be known and the relationship between such knowledge claims and the ‘real’ world. Such questions have been a fundamental consideration in traditional

epistemologies but again a wider perspective is considered. The relationship between the subject and object of knowledge is reconfigured and responsibility to the objects of knowledge is considered where appropriate. In mathematical epistemology the status of mathematical objects has long been a central concern and this is no different in a feminist epistemology. In attempting to explain these objects and their relationship to 'reality' this feminist epistemology rejects a dualistic approach which leads to nature/culture mind/body dichotomies in favour of an interactive dynamic approach.

### **Burton's epistemology**

Leone Burton (1995) in "Moving towards a feminist epistemology for mathematics" emphasises a hermeneutic, pluralist approach. Her aim is to develop an inclusive and accessible approach which encompasses "as wide a range of styles of understanding and doing mathematics as possible rather than reducible to those styles currently validated by the powerful." She claims that "knowing in mathematics cannot be differentiated from the knower"(Burton, 1995:286). She proposes "defining knowing in mathematics" (Burton, 1995:287) in relation to five categories:

- \* its person- and cultural/social-relatedness;
- \* the aesthetics of mathematical thinking it invokes;
- \* its nurturing of intuition and insight;
- \* its recognition and celebration of different approaches particularly in styles of thinking;
- \* the globality of its applications.

Knowing mathematics would, under this definition, be a function of who is claiming to know, related to which community, how that knowing is presented, what explanations are given for how that knowing was achieved, and the connections demonstrated between it and other knowings (applications) (Burton, 1995:287).

Although Burton (1995:287) claims that this epistemology "would displace dualisms such as the relativist/absolutist dichotomy" such a displacement has not been fully achieved through the five categories she has identified. In

mainstream epistemology intuition and insight have been defined as one side of dualism which include reason and logical deduction on the other. An epistemology which privileges the “nurturing of intuition and insight” (Burton, 1995:287) without including the nurturing of reason, logical deduction and abstraction, is in danger of reproducing the dualisms we wish to displace by privileging the other side. This other side has been defined in terms of the very dualisms we wish to displace.

The emphasis on the “person- and cultural/social-relatedness” of this approach is a valuable contribution to the development of such an epistemology. However the approach is limited by consideration of a narrow range of epistemological questions. An epistemology of mathematics also requires consideration of the relationship between mathematics and ‘reality’ and the nature of the subject of knowledge.

In developing a feminist epistemology for mathematics, I will now consider each of these sets of questions: who can be a knower? what are the processes which determine and legitimate the act of knowing? and what kinds of things can be known?

### **Who can be a knower?**

A feminist epistemology overtly links the political and the epistemological with the purpose of transforming the status of women as knowers. In this feminist epistemology for mathematics this transformation involves improvements in the participation and achievement of women in mathematics, changes in the practices and concerns of mathematics, changes in the stories we tell of what mathematics is and a revaluing of the feminine in mathematics. More indirectly this leads to a transformation of gender categories, changes in mathematics itself and changes in feminist theory and how we theorise both female subjects of knowledge and the feminine.

There is a tension in developing this feminist epistemology for mathematics, between defining this epistemology in terms of mathematics as it is currently

practised and mathematics as it would be after such a feminist transformation. Rather than establishing this tension as a binary between now and the (possible) future, I prefer to allow the tension to remain unresolved while acknowledging the inadequacy of traditional mathematical epistemology to account for mathematics as we know it, and in particular its rejection and suppression of the feminine. I also acknowledge within this tension, the relationship between any future developments for mathematics and the historical development of mathematics. A feminist mathematics will not arise out of nowhere but develops from the contradictions, conflicts and successes of 'current' mathematics. It is both constrained and enabled by its history.

Another aspect of this unresolved tension lies in the definition of epistemology. Is it a *description* of mathematics and its practices or a *prescription* of what mathematics can and should be? Both aspects are crucial to an epistemological understanding of mathematics, that is of knowing how we know. Describing the practices of mathematicians as I have done in the empirical parts of this thesis, is pertinent to the establishment of an epistemology for mathematics that reflects mathematics in practice, that is, is recognisable to practising mathematicians. In my research the experiences of women mathematicians and their mathematical practices give rise to questions about the public and private sides of mathematics and thus to an undermining of the binaries upon which traditional epistemology is built. Their experiences illustrate the intersection of gendered practices with mathematical practices. This *description* illuminates some of the ways in which the knower in mathematics has been *prescribed* to be male. Experience provides a grounding for epistemological questions and women's experiences in mathematics provide such a grounding for feminist epistemological questions.

A *feminist* epistemology raises the question of the epistemological significance of gender in knowledge creation. Claiming an epistemological significance for gender is replete with traps and difficulties. There are dangers associated with assuming essentialised gender categories; claiming subjectivity as a source of truth; or swinging to another extreme in which gender is deconstructed right

out of the analysis and thus losing the focus on the 'real' problems women face as knowers of mathematics.

In Chapter 2 I discussed the question of whether there is knowledge that only women or only men can have and argued that there is not. Even knowledge/experience based on biological differences can be communicated by hermeneutic means such as poetry, music or art. However women have been denied access to some kinds of knowledge including mathematics. The positioning of subjects within gendered discourses influences 'who can know what' in a context of asymmetric power relations.

As this is a *feminist* epistemology an impetus for social change is implied. This change is not only for women but also for other marginalised people, environmental concerns and consequently for men who are members of dominant groups in society. This impetus for change signals a disruption of traditional definitions of the subject of mathematical epistemology while retaining a commitment to the possibility of mathematical knowledge. This commitment includes the possibility, indeed the desire, for new visions for mathematical knowledge, knowledge projects and the place of mathematics within the power relations in society.

The subject of a feminist epistemology for mathematics transcends the dichotomies which have traditionally defined the subject. This feminist subject is both objective and subjective; rational and emotional; logical and intuitive; and capable of both abstraction and caring.

The traditional subject of mathematical knowledge, the rational Cartesian knower, is defined through the privileging of one side of the hierarchical dualisms discussed throughout this thesis, that is, objective/subjective, reason/emotion, rational/intuitive, mind/body. The definition of a new subject of knowledge through the privileging of the other side of these dichotomies is just as problematic for a number of reasons briefly reiterated here. The categories on the right-hand side of these binaries while associated with the feminine are defined in opposition to the male side and thus are defined in ways

oppressive to women. Privileging this other side does not extricate the feminine from the oppressive definitions which are inherent in these binaries but promotes and reinforces the precarious and oxymoronic position of women mathematicians. Women mathematicians cannot be explained by this radical feminist definition of the subject as they (women mathematicians) embody aspects of the left hand side of the binaries. They would remain aberrations in this move.

To be a mathematician is not to take up a fixed position such as the Archimedean point of the Cartesian knower but to move between and among positions defined and constructed within contradictory discourses and between such discourses. A 'woman mathematician' moves between and among discourses of mathematics and the feminine. She is positioned as both rational and logical *and* intuitive and emotional. Amongst mathematicians she may be marked 'feminine' and amongst women she may be marked 'mathematician' but she is both/and. This movement defines a subject who is "an unstable constellation of unconscious desires, fears, phobias, and conflicting linguistic, social and political forces" (Hawkesworth, 1989:550).

Soper (1990:146) describes this subject:

I am the site of intersection of a multiplicity of social discourses and practices which have made me who I am. .... I am not an autonomous subject, but relating and deciding, feeling and reacting only through a grid of discourse and practice which I myself have not created.

The woman mathematician, the female subject of mathematical knowledge, who positions and repositions herself and is positioned and repositioned within discourses of femininity and mathematics, may find contradictions and overlaps between these positions. Sometimes she experiences contradictions, sometimes she shrugs them off as she provides a challenge to the boundaries and definitions of these discourses. Sometimes she acknowledges the contradictions, sometimes she does not. Her experiences of the suppressed feminine in mathematics enable the reconciliation and resolution of some contradictions. Often the contradictions exist more for the outsider gazing at

her than for the woman mathematician herself. She can revel in the abstract, the rational, the logical, the work of the mind without giving up the pleasures and conflicts of the emotional, the intuitive, the caring and the body while others are denying this possibility. This leads to challenges to dominant discourses of femininity and mathematics.

There is a tension between locating the subject of knowledge in the individual or in the social group, the community of knowers. The individual subject cannot 'know' in isolation from the community of knowers of which they are a member. Knowing involves social processes and practices of criticism, evaluation, acknowledgement and communication which occur within a community of knowers and within that community in relation to other closely aligned communities and the wider society. Both the individual subject and the group are essential to knowledge creation. 'Thinking' occurs within individual minds but the individual and their thought processes are constructed within the group and operate within the discursive frameworks which function within that group.

The kinds of individuals making up the group influence those processes and practices; the critiques, evaluations and acknowledgement; the knowing and communication styles; and the relationships between individuals; which are sanctioned within the community of knowers. The individual and the community of knowers function in a complex and dynamic interaction with each other. As I have established in this thesis the dominance by men of the group 'mathematicians', together with discourses of gender and the privileging of the masculine, has led to the prevalence of particular processes and practices and accounts of mathematics which are based in and reinforce this privileging of the masculine.

In this feminist epistemology the membership of the community of mathematical knowers is challenged to include diversity but such a challenge meets resistance. It is not a matter of outsiders merely choosing to take up a position as a mathematical knower.

As I have discussed in Chapter 4, the use of mathematics as a critical filter in education serves to exclude many girls and women and to denigrate their achievements when they overcome this exclusion. The female mathematics student is constructed as inferior. Those who break through these exclusionary barriers find themselves in a precarious position. Not only through the contradictions between the 'regime of truth' in which to be mathematical is to think like a man, but in their experiences within the mathematical community as I discussed in Chapters 7 and 8. A gender division of labour within mathematics may see them channelled off into related but not mainstream areas of knowledge creation in mathematics, such as mathematics education. Those who overcome this can experience isolation and alienation as they are the only one or one of a very few women in a men's world. This world may be welcoming or tolerant to one or two 'special' women who occupy a 'special' place but strongly resistant to any challenges to their established practices and culture. Thus women mathematicians may find some difficulties with the climate. In a hierarchical and elitist environment they may feel compelled to reluctantly adopt the dominant practices or to accept the limitations imposed on them through resistance. The social relations within the group and the interaction styles may be exclusionary. Combining family responsibilities and relationships with a mathematical career in a culture which does not allow for these demands presents another barrier to full participation. The discourse of 'purity' in mathematics reinforces the exclusion of women from positions as knowers in mathematics, through the association of women with impurity, the sexual and the body. Notions of purity reinforce the association of mathematics with masculinity.

**Conclusions: In this feminist epistemology who can be a knower?**

To be a knower in this feminist epistemology for mathematics, the subject in dynamic interaction with the community of mathematical knowers positions and repositions themselves, and is positioned and repositioned within contradictory discourses and practices of mathematics, gender and other social/cultural commitments and values. These shifts and movements provide

challenges to traditional constructions of the knower and support the transformation of traditional gender categories. For to be a knower in this epistemology requires practices of reason and intuition; the rational and emotional; the subjective and objective. The very categories that have traditionally defined the knower are themselves transformed. This opens the way for an appreciation of the diversity of potential knowers of mathematics and the possibilities such diversity has to contribute to the creation of mathematical knowledge.

A transformation of the defining values of mathematical epistemology is not equivalent to their devaluation. Reason, logical deduction and abstraction are fundamental to mathematical knowledge and are not discarded. But to achieve stronger objectivity mathematicians must acknowledge and reflect on the situatedness of their knowledge. Within mathematical practice there must be space for the development of critical reflexivity in which mathematicians disentangle themselves, their prior commitments and the dominant values and practices of their social worlds from the knowledge they create. This can only be a partial process because the mathematicians themselves are caught up in the very processes they are being called to reflect upon. However a discourse of purity cannot excuse mathematicians from reflection on how mathematics serves to empower some and disempower others; to include some and exclude others; to legitimate some arguments because they can be expressed mathematically or quantitatively and to delegitimise others. Pure mathematicians who pursue their research independently of any connections to applications cannot be expected to anticipate all the uses others may make of their work. Sometimes a hundred years can go by before a particular piece of pure mathematics is found to have applications. But they can reflect on how it is they have the resources to pursue such work independently of direct applications. Many applied mathematicians are in a different situation. Those employed in research in the military, surveillance, biomathematics and the modelling of environmental processes and structures are in a position to critically reflect on the social and environmental consequences of their work.

The subject of a feminist epistemology for mathematics is caught up in political projects of change; change in the categories and values and practices defining what it is to be a mathematician, a woman or man, and the nature, concerns and consequences of mathematics itself.

### **What are the processes that determine and legitimate the practice and act of knowing?**

The tension between mathematics as it is currently practised and feminist visions for mathematics in the future underlie the discussion of the question addressed here. It is out of such tensions brought about by challenges to the status quo that new approaches to epistemology and mathematical practices develop. Feminist changes occur out of the muck and mire of lived experience and are not the result of a clean disjuncture between the present and the future.

Mathematics consists of multiple practices and overlapping structures only one aspect of which is under scrutiny here. Mathematical research, the creation of new mathematical knowledge, which is usually undertaken in academic institutions is the focus. Even within this subset of mathematics, there are multiplicities, intersections and overlaps.

It has been well established in this thesis and elsewhere that traditional epistemologies of mathematics have provided only a limited understanding of mathematical knowledge and how it is secured and that this limited understanding can be expanded by accounts of the social nature of mathematical knowledge. In order to expand this understanding the definitions and concerns of epistemology have to be widened to include the social. But social explanations in themselves are also insufficient to completely explain mathematics because mathematics is based on symbolic language, ways of thinking, and values in a combination which is unique to mathematics. Mathematical knowledge also has a relationship to the real world it often seeks to explain. It attempts to describe/explain/understand/predict/control the patterns and rhythms of the natural world and its phenomena.

Addressing the question of the ‘processes that determine and legitimate the practice and act of knowing’ requires consideration of both these aspects of mathematics and their interaction: the epistemological values underpinning mathematical knowledge and the social processes by which mathematical knowledge is produced and accepted. There is not a split between the two for they are intimately intertwined and mutually inform each other.

Accounts of knowing in mathematics have been based in partial accounts of knowing practices and values which reflect the power relations of the societies in which mathematics is developed. Traditional accounts have emphasised “objectivity, logic, rigor, abstraction, rationality, impersonality, axiomatics, formalism, lack of applications, exactitude, certainty, completeness, absolute truth, power and control” (Burton in Mura, 1987:7). Feminist challenges to these accounts developed in opposition to the traditional accounts characterise mathematical knowing by “intuition, creativity, incompleteness, conjecture and relativism” (Burton in Mura, 1987:7). There are problems with both accounts.

The scope of feminist theorising based on an opposition to traditional theories can be confined to a debate defined by the concepts being rejected rather than the debate being expanded to take feminist theoretical concepts into account. The possibilities for new theories are then limited. A feminist epistemology for mathematics must build on a transformation of such polarities as both poles are implicated in the establishment of mathematical knowledge. The traditional values of epistemology such as abstraction and objectivity are intrinsic to mathematics but their social construction in ways which reflect the gendered commitments of their definers limits their usefulness to the answering of the questions being addressed here.

Hawkesworth (1989:551) points out the pitfalls of privileging some knowing practices at the expense of others and captures much of the diversity of these practices in this list:

Perception, intuition, conceptualization, inference, representation, reflection, imagination, remembrance, conjecture, rationalization, argumentation, justification, contemplation, ratiocination, speculation,

meditation, validation, deliberation - even a partial listing of the many dimensions of knowing suggests that it is a grave error to attempt to reduce this multiplicity to a unitary model.

With the addition of deduction and abstraction which Hawkesworth has left out, all of these practices are recognisable as relevant to knowing mathematics, although not all are included in the 'public' stories of mathematics. Only some of these practices are crucial to the legitimation of mathematical knowledge. For example the products of intuition, imagination and meditation are not legitimated unless and until they are subjected to validation processes that include meeting accepted standards of justification. These include rationalization and logical deduction. If a claim to mathematical knowledge does not meet the standards of logical deduction then it remains at the level of speculation. A knowledge claim achieves the higher status of 'conjecture' if there is judged to be sufficient other evidence in terms of numerical evidence or it's 'fit' with other proven knowledge claims. Until it meets the criteria of logical deduction from one step to the next a conjecture is not legitimated as a theorem. While intuition, imagination and creativity are all vital practices in mathematics, logic, rigour and exactitude are essential for 'something' to be included in the body of knowledge mathematics.

There is a limitation in our epistemological thinking which I claim arises from the pervasive influence of positivism. It is the 'positive' metaphor of positivism that pervades this thinking. Mathematics not only involves the creative and intuitive, the abstract and rational. It also involves the making of mistakes; false starts; discovering that what looked like an interesting question turns out to be trivial; the tedious repetitiveness of some problem solving; the frustration of not being able to work out the next step. Some conclusions or conjectures are established as mistakes, as incorrect, as false. In rejecting the stories of mathematics which portray it as the inevitable unfolding of each step towards one correct answer, accounts of mathematical knowing will be made richer by the inclusion of the 'negative' as well as the 'positive'.

The aesthetics of mathematical thinking (Burton, 1995:287) also play a part in determining the course of development of mathematics. Mathematicians favour simplicity and elegance in their proofs and solutions.

Simple, attractive theorems are the ones most likely to be heard, read, internalized and used. Mathematicians use simplicity as the first test of a proof. Only if it looks interesting at first glance will they consider it in detail. Mathematicians are not altruistic masochists. On the contrary, the history of mathematics is one long search for ease and pleasure and elegance- in the realm of symbols of course (de Millo et al, 1986:274).

The 'processes that determine and legitimate the practice and act of knowing in mathematics' in a feminist epistemology for mathematics are marked by their multiplicity and diversity. These multiple and diverse processes include accounts of the social *and* of the defining values and commitments of mathematics. There is no mathematics without its defining values such as logic, rigour and abstraction but what feminist epistemology has been successful in identifying is that these values are themselves defined within their social context. Feminist epistemology has also brought into the public gaze knowing practices that have always been vital to mathematics but which have been confined to the private sphere.

### **How is mathematical knowledge established in a feminist epistemology?**

In this feminist epistemology for mathematics the knower is an individual subject in dynamic interaction with a community of knowers. This knower is constructed by/within discourses such as those of gender, race, and class, and as such brings different experiences, questions and values to the processes of knowledge creation. The question being addressed now is how mathematical knowledge is established as knowledge. There is an assumption here that there is(are) such a thing(s) as mathematical knowledge. The nature of that knowledge will be elaborated further in the next section.

Although establishing mathematical knowledge is an ongoing process built on and in opposition to mathematical knowledge built up over a very long history, I will begin with the selection of topics considered worthy of the attention of

mathematicians. In doing so I recognise this long history and emphasise that there is no ‘beginning’ as the selection of topics is determined in part by the state of mathematical knowledge at a particular historical moment. Some questions can only be imagined after other developments have taken place and some require the development of other new techniques before they become tractable.

### **Topic selection**

Ask a mathematician why they selected a particular topic and their answer is likely to give no hint of the social forces and power relations behind the setting of mathematical agendas. A mathematician is likely to say ‘because it looked interesting’ or ‘because I thought I could solve it’ or ‘because I needed to do that before I could get on to the question I was really interested in’. What makes a question ‘interesting’ in the sense implied here could be any or all of the following: an appreciation of what is required to solve it; the significance of that question for other mathematical developments; and an understanding of the prestige and status awarded to a mathematician who makes a significant breakthrough. Often mathematicians know that a particular problem cannot be solved with existing mathematical knowledge and so the problem is interesting because its solution would imply that new techniques had been developed (Vogel, 1994). The prestige awarded to a mathematician making a significant breakthrough and the ambition to do so are entangled with the motivation and creative desire to solve difficult and significant problems.

The power and prestige of mathematics interspersed with a discourse of purity and the privileging of the masculine has allowed for the rhetorical space within mathematics in which mathematical questions are pursued for the reason that ‘they are there’. The motivation for gaining the resulting status and prestige is hidden behind this discourse of purity. One consequence of mathematics being described as pure is that mathematicians too are associated with such purity and an ‘unworldliness’ that supposedly puts them above such ambition. Such a view of mathematics and mathematicians is at odds with the culture of mathematical communities which is generally both hierarchical and elitist. But

this image of unworldliness has served a political purpose in the relationship between mathematicians and the politics of the wider society as I discussed in Chapter 6.

Mathematics also develops out of practical applications; out of connections to the real world. Such connections have stimulated mathematical advancements. In the elaboration of mathematical models of real world phenomena, new mathematical techniques and methods are developed which in turn lead to new theorems and conjectures.

In a feminist epistemology for mathematics the stimulus for this kind of development includes questions arising from the experiences and concerns of diverse marginalised groups including women. This quest for knowledge is based on a desire for understanding rather than solely a desire for prediction, control and domination. Contextualist and reductionist approaches are valued. Notions of strong objectivity in which the relationship between subject and object of knowledge is reflected upon critically are part of the quest. Complex dynamic interactive models will often be preferred over linear reductionist ones.

The development of new computer technology provides further stimulus for such new agendas. Not only does it facilitate the use of different methods, but mathematicians' interest is stimulated by the availability of such new 'toys'. The emphasis shifts from a concern with existential problems in traditional mathematics to an interest in constructional problems. Whereas traditional mathematics has been used to prove the existence of mathematical objects, computer technology facilitates an interest in the construction of such objects. Computational methods rather than traditional analytic proofs are used to 'prove' a theorem with the consequence that the status of such computational proofs is presenting new philosophical problems for mathematics. The possibility that these technological developments will lead to asking questions arising from women's experiences is caught up not only in the gender and power relations in mathematics but also those operating in the world of computer technology. Given that women's design and use of computer

technology is at least as problematic as women's involvement in mathematics (Dain, 1991; Griffiths, 1988; Kramer and Lehman, 1990; Spender, 1995; Turkle and Papert, 1990), the possibility of addressing questions of interest to women in this arena does not seem very certain at this historical moment.

Changes to funding regimes for universities and research institutions in the context of a political shift to the new right also influence the setting of mathematical research agendas. As these new funding regimes require outputs of 'economic benefit' the 'purity' of mathematical research is threatened. The possibilities for feminist research agendas emerging from these changes is entangled with the operation of gendered power relations in these new political environments.

Mathematicians select topics in a context of power relations within mathematics. Some select 'hot' topics in which research success will ensure status and prestige. At the same time often these 'hot' topics are 'hot' because they are exciting and moving quickly so that there is a great deal of stimulation and interest in them. For a feminist epistemology for mathematics this represents something of an unresolved conflict because as the women I interviewed said, they were not interested in the selection of topics because the topics were 'hot' but because they were 'interesting'. For them 'interesting' can mean 'fascinating' or 'challenging', or it could mean a topic they knew they could 'connect' with. In a feminist epistemology for mathematics which challenges the existing hierarchical elitism of mathematical culture, I want to retain a commitment to the vigorous pursuit of new and exciting developments in mathematical knowledge. At the same time the critically self-reflective subject of mathematical knowledge, in relationship with the mathematical community, reflects on the agendas for mathematical research and considers where possible their potential social, economic and environmental consequences.

### **Work practices**

A feminist epistemology for mathematics is enriched by an examination of the actual practices of mathematicians developing mathematical knowledge. This examination shows that there are a multiplicity of practices and styles of knowing in the creation of mathematics. Public accounts of mathematical practice which have become the dominant means of mathematical exposition in education represent only one aspect of these practices.

The pursuit of new discoveries involves tinkering: trying out intuitive hunches; testing examples; searching for counterexamples; getting stuck in dead ends; finding out potential lines of inquiry prove to be trivial; getting frustrated; the flash of creative insight; and the use of logical deduction. The tidy algorithms of school mathematics come after the 'ideas' of a proof or solution have been developed. They are a consequence rather than a cause of such development.

Both separate and connected knowing styles, both contextualist and reductionist approaches to developing mathematics should be included in an epistemology for mathematics. For mathematics is created by a multiplicity of styles that breach the boundaries of such binaries. To reject reductionist approaches as some feminists do, would result in the exclusion of much mathematical knowledge which is already well established. Reductionist approaches have been very useful in making many advances but they cannot be used to understand everything. Contextualist approaches are also useful and stimulate different kinds of mathematical developments that involve complexity, dynamic interaction and interdependence. But such complex approaches do not always give rise to 'do-able' problems. One of the ways in which mathematics advances is through the retreat to simpler, easier to solve problems where complex ones prove too difficult (McNabb, 1994). Once these models are solved, the mathematician attempts to build back up to more complex models for the problem. Contextual and reductionist models are best used in conjunction with each other and not when the use of one is privileged at the expense of the other.

### **Community acceptance of knowledge claims**

A new conjecture, proof or solution in mathematics is subjected to social processes of criticism and acknowledgement before it is accepted and incorporated into the body of mathematical knowledge. There have been no standards of proof guaranteeing absolute certainty for mathematical knowledge established by mathematical epistemology. The standards accepted are contingent and depend on what mathematicians, those who are “adequately educated and prepared to understand it” (Thom, 1986:72) accept as proof. As I argued in Chapter 6 the membership of this group reflects the dominant social relations of the wider society within which mathematics is situated.

A feminist epistemology implies change in and challenge to those social relations so that the constitution of the community of those “adequately educated and prepared to understand” (Thom, 1986:72) mathematics is challenged. In a feminist epistemology the mathematical community is marked by its diversity and inclusiveness while retaining the commitment to knowledge claims being adjudicated by those who have the necessary knowledge of mathematics. In such a diverse community a wider range of questions is validated. A stronger concept of objectivity underpins the process as the status and identity of knowledge claimants is reflected upon as part of the accreditation process. Present standards of objectivity are insufficient to eliminate the social values, interests, and agendas (Harding, 1993b:52) of dominant groups in mathematics. A stronger concept will not automatically eliminate such values either but calls for critical reflection on what they might be and how they might influence the knowledge claims under consideration.

In a feminist epistemology where diversity is privileged over hierarchy, there remains a commitment to ‘getting the mathematics right’ but this is assured not by the status of the claimant nor by the forms of ‘ceremonial combat’ associated with a separate style but through critical reflection on the situatedness of knowledge, the nurturance of new possibilities and questions *and* the close examination of the logical deductive steps in the mathematics presented.

The process of legitimating new mathematical knowledge occurs through the practices of peer review and communication in seminars, conference papers and publications. In these practices a separate knowing style has predominated. Claims are judged in an adversarial style that aims to eliminate the inadequate rather than nurture promising new developments. This style fosters the exclusion of those whose preferred style is 'connected', that is those who prefer an empathetic style to an adversarial one. A connected style is valued in a feminist epistemology.

Although the processes by which mathematical knowledge is developed involve the intuitive apprehension of new insights, the processes of logical deduction determine and legitimate new knowledge claims. The lack of logical progress from one step to another implies a problem with the proof. There may, for instance, be a need for tighter constraints or a body of previously assumed results may have been left out but for whatever reason such a failure of logical deduction signals the need for further investigation and contemplation. In a feminist epistemology such a need cannot be discarded in the interests of 'feminine' sympathies (which I have disregarded as essentialist) but remains a vital part of the determining and legitimating processes by which mathematics is established as a body of knowledge.

Although de Millo et al (1986:273) claim that mathematicians in practice do not demonstrate their proofs by formal deductive logic this claim is an exaggeration or perhaps results from a different more formal understanding of deductive logic. The individual and their community may not do so immediately. The processes by which a proof is validated which were described in Chapter 6 may be sufficient to achieve its acceptance. But mathematics classrooms in universities throughout the world are full of students duplicating the comprehensive and intricate steps of the proofs of major theorems. If such a proof could never be duplicated then the 'proof' would remain the cause of considerable contention and interest.

Mathematics is not only the result of particular kinds of social relations and power structures. It is a body of knowledge distinguished by the abstraction of properties of number, quantity and space from structures and patterns occurring in the natural world and from the world of mathematical objects themselves. This body of knowledge has permeable boundaries between itself and related disciplines and is marked by the utility of its concepts to explain and predict phenomena and concepts across the boundaries of many disciplines.

In establishing the ‘processes that determine and legitimate the act of knowing in mathematics’ a feminist epistemology for mathematics has to include reflexive processes that account for intuition, creativity, incompleteness, and the social relations and processes in the mathematical community. This is in addition to and not at the expense of developing criteria for objectivity, logic, rigour, abstraction, axiomatics, exactitude, and formalism which will entail the redefinition of some of these concepts. Mathematics in practice involves the manipulation of symbolic language according to rules and definitions and accepted (although contested) standards of proof and this cannot be ignored in a feminist epistemology.

In the next section questions about the kinds of things that can be known in mathematics and the relationship between the knower and the objects of knowledge are addressed more specifically.

**What can be ‘known’, that is to say, what factors affect the establishment of adequate objects of knowledge? What kinds of things can be known?**

Questions about the existence and nature of mathematical objects, the relationship of mathematical knowledge to ‘reality’ and its applicability are perennial questions in the philosophy of mathematics (Rav, 1993:87). These retain their relevance in a feminist epistemology for mathematics.

I am assuming the existence of a reality that is “independent of our taking cognizance of it” (Rav, 1993:88). This reality has its “regularities” (Rav,

1993:88) or “order” (Keller, 1985:134). Mathematics is a means for understanding this order through the elucidation and abstraction of patterns found within it. As I argued in Chapter 5 the use of a concept of order “allows for nature to be generative and resourceful, complex and abundant. Nature is seen as an active partner in a reciprocal relationship to the equally active observer fostering a relationship between mind and nature” (Keller, 1985:134). Through the abstraction of patterns and structural features in this order and their translation into the symbolic language of mathematics, mathematicians have developed a means to understand, describe, predict and control aspects of this reality.

From this abstraction of patterns and their translation into mathematical language are built further abstractions upon abstractions and the discernment of patterns within the mathematics itself. In their turn these mathematical abstractions come to be seen as ‘objects’ and are found to have applications in other aspects of reality. The intensification of the abstractions and the applicability they are often found to have in unexpected places gives rise to fundamental philosophical questions about the nature of these mathematical objects and how this applicability is possible.

A range of possible theories have been expounded in attempting to explain the nature of mathematical objects. I am taking a position that disrupts binaries and is defined within the complexities of the interaction of the ‘real world’, the biological, the social and the intellectual. This position is not completely resolved and may never be. It does however offer more potentially fruitful lines of inquiry than the dualistic approaches that are the alternatives. Most of these have involved taking up a position on either side of the binaries mind/body or nature/culture.

Explanations of mathematical objects tend to fall into two very broad camps aligned to the mind/body binary. There are those who argue that mathematical objects are mental constructs, the product of ‘pure’ thought. This explanation is unable to explain the applicability of mathematical objects in previously

unforeseen situations. It does however allow for the possibility of social and cultural influences on mathematical objects but only to the extent that the mental is seen to be influenced by the social. It implies that there is a realm of mathematical objects and a different one of physical objects.

The association of mathematical objects with the mind and pure thought is problematic for feminist epistemology as accepting this position forces feminists to take up one or the other side of the binary. If feminists accept the association of women with the body then women's exclusion from mathematics as a realm of pure thought is reinforced. If they take up the alternative position and claim women's right to an association with the mind, then women are equated with men and their differences are suppressed. What is required is a disruption of the mind/body dualism. Such a disruption precludes the possibility of defining mathematical objects as purely mental constructs because it denies the possibility of the existence of such an object. There is no mind without body, they are interdependent and inseparably intertwined.

Other explanations fall into the category of quasi-empiricism. Mathematical objects are abstracted from physical phenomena and experience. It is this origin in physical phenomena that is supposed to explain the applicability of mathematical objects that are derived from abstraction upon abstraction upon abstraction. Such an explanation is useful in some areas of mathematical practice where there is a close link between observable physical phenomena and the mathematical abstraction but this linkage is not so clear in many instances of mathematical practice. Rav (1993:88) argues that this argument only displaces the problem as it doesn't explain how the process of abstraction actually works. He continues:

Besides, it is not the elementary part of mathematics that plays a fundamental role in the elaboration of scientific theories; rather, it is the totality of mathematics, with its most abstract concepts, that serves as a *pool* from which the scientist draws *conceptual schemes* for the elaboration of scientific theories (Rav, 1993:88).

Any explanation of mathematical objects that relies on a distinction between mathematical and physical objects runs into difficulties from recent developments in knowledge creation such as quantum mechanics and virtual reality. In quantum mechanics “the very concept of a physical object became more problematic than any mathematical concept” (Rav, 1993:82). Mathematical objects are needed to be able to even speak about the objects of these physical theories (Rav, 1993:101). Developments in virtual reality also call any distinction between mathematical objects and physical objects into question as virtual reality calls our fundamental notions of ‘physical reality’ itself into question. Virtual reality is dependent on mathematics for its enabling technology at the same time as it transforms the nature of mathematical objects. Virtual reality allows for the possibility of immersing ourselves in mathematical structures, walking around them, rearranging them, altering them and feeling them (Rotman, 1994:84). Are the objects in virtual reality physical objects or mathematical objects, or yet another kind of reality? As Rav (1993:82) says “It *was* an interesting question to compare mathematical ‘objects’ with physical objects as long as the latter concept was believed to be unambiguous.”

Another explanation for mathematical objects is that they are human creations (Rav, 1993:99) and as such their construction is influenced by social and cultural factors in which I include gender. Rav (1993:99) raises an interesting question about the possibility of human biological factors being influential in the creation of mathematical objects. He questions whether biological cognitive mechanisms which have evolved under environmental pressure and become genetically fixed could be involved in the logico-operational component of mathematics (Rav, 1993:89). In the past feminists have been cautious about attributing cause to biological factors as they have analysed the impacts of biological determinism on women. This approach by feminists is no longer useful as it privileges only one side (culture) of the binary nature/culture. Deconstruction of this binary allows for the pursuit by feminists of interesting questions about possible relationships between biological mechanisms and the development of our mathematical thinking.

Restivo (1991:168) attributes the process of increasing abstraction to the specialization occurring within the mathematics community. As a result of this specialization mathematicians work more and more within mathematics and forget their history. The idea that mathematical objects are purely mental objects becomes more plausible in this context.

In Chapter 6 I quoted from Appelbaum (1995:11) that an epistemological approach to mathematics requires “a focus on the study of processes rather than remote origins: on multiple rather than single causes”. My understanding of mathematical objects is based on an appreciation of such multiplicity and complexity. Mathematical objects are formed through the interaction of physical reality; the quasi-empirical interactions of mathematicians with that reality; the construction and constraints of the symbolic language of mathematics; the discerning and imposing of patterns; the interrelationship of scientific and mathematical knowledges; the interdependence of mathematics and technology; and the social and cultural influences and power relations both internal and external to the mathematical community. The impact of human biology requires further explication. While I am assuming an objective reality of which humans are a part, and that this reality has regularities, I am not assuming that these regularities function according to mathematical laws which mathematicians are in the process of discovering. Mathematics is a framework, a language, a conceptualisation of the abstractions we make from the regularities of our reality and which we in turn impose upon that reality. This imposition allows us to understand some aspects of that reality but that understanding remains provisional as our mathematics is challenged by the unforeseen and unexplained. It is out of the interaction of nature and culture and the changes each imposes upon the other that mathematics is developed. One is neither privileged over nor prior to the other.

### **Feminist perspectives**

In a feminist epistemology for mathematics gender relations are a factor affecting ‘the establishment of adequate objects of knowledge’. Questions

arising from women's lives and experiences in all their diversity are considered worthy of attention and form the basis of new developments in mathematics. Any claims to how much difference this would make to the body of mathematical knowledge can only be speculative at this historical moment. Their impact is limited by the extent of the empirical nature of mathematics. Mathematics is more analytical than empirical so that empirical questions such as those beginning in women's lives are unlikely to completely transform mathematics.

Strong arguments have been made for feminist concerns leading to a preference for complex dynamic interactive models rather than hierarchical models of static systems (Keller, 1985:134). Such a movement is already well established in mathematics facilitated by developments in computer technology. Changes in gender relations are themselves caught up in the interaction of the complexities of these other changes in society.

Throughout this feminist epistemology the hierarchical dualisms upon which traditional epistemological arguments have been based have been deconstructed. Rather than taking up a position on one side or the other I have argued that the very dualisms themselves are inadequate to explain the establishment of mathematical knowledge. This is also the case in the relationship between the knower and the object of knowledge, between mathematicians and mathematical objects. Traditional epistemology supports a depiction of objectivity that is based on the separation of subject and object. I have made a different argument. I retain a commitment to objectivity in the sense that it is vital to know to the greatest extent possible the consequences of our locatedness and commitments on our knowledge claims. Rather than claiming that the knower can step aside from such claims I have argued for the importance of the knower reflecting on their position, and attempting to disentangle their commitments from their knowledge claims and attempting to see from the perspectives of 'others'.

In mathematics too connections are formed between the mathematician and mathematical objects. Jane (see Chapter 8) described the affection she developed for her mathematical objects and the surprises they presented to her. While it may be difficult to contemplate mathematical objects responding to the mathematician in the ways we have come to expect human respondents in social research to do, mathematical objects do behave in unexpected ways and mathematicians develop feelings for these objects. Reflecting on these relationships is an aspect of the process of establishing ‘strong objectivity’.

### **Summing up**

A feminist epistemology for mathematics makes explicit the links between the social, political and epistemological. An examination of who knows, what and how we know in mathematics reveals these linkages. A feminist epistemology implies commitments to changing these linkages so that women are included as knowers, questions arising from women’s experiences are asked and the feminine in mathematics and mathematical practices is brought out into the public arena.

A feminist epistemology for mathematics depends on the transformation of the binaries which inform the epistemological values and the knowing practice of mathematics. This transformation does not consist of merely valorising the previously disprivileged side of these binaries in favour of the feminine but of redefining them in terms of multiplicity rather than hierarchies. In mathematics the logical and intuitive for example, mutually inform and support each other. Diversity and multiplicity are fundamental to this epistemology, for in this epistemology, mathematics is marked by: the diversity of its knowers and the contribution this makes to mathematics through the asking of different questions; the valuing of a wider range of knowing practices and an understanding of how these can be used in conjunction with each other; a stronger objectivity as more perspectives are available in the process of critical reflection on the situatedness of all knowledge claims; a more inclusive culture that values ‘connected’ processes and practices in critiquing and

acknowledging knowledge claims; a broader metaphorical base on which new concepts and approaches can be established; an understanding of the dynamic interaction of nature and culture in the establishment of mathematical objects; the exposure of the private side of mathematics to the public; a commitment to abstraction and logical deduction but not in isolation from other legitimating practices; a responsibility for the consequences of mathematical developments; and a transformation of the categories 'female' and 'male'. These processes occur in a complex interaction with the wider society and are influenced by economic and technological changes occurring inside and outside mathematics.

### **Further work**

I began research in this area because of my political commitment to increasing the participation of women in mathematics and mathematically related careers. There is much work still to be done in both mathematics education and mathematical epistemology. Mathematics education has presented the public face of mathematics to students and for many women (and others) this public face has been unattractive. Exposure to the private worlds of mathematics may be more successful in attracting women students but insufficient is known about these private worlds. More research is needed on the actual processes and practices of creative mathematicians, male or female. Detailed ethnographic studies of these areas would be valuable for both mathematics educators and epistemologists who want to locate their epistemology in mathematical practice. Knowing more about how mathematicians create mathematics and adapting and adopting those practices for classroom mathematics is a potentially valuable area of research.

Feminist analysis of the relationships between mathematical objects and reality or nature is another area of research which promises to be fruitful. The traditional concerns of mathematical epistemology take on a new significance when a feminist analysis is applied to them.

The processes of cognition including their biological aspects and the effects of these processes on how we think and make sense of the world is another area which would benefit from feminist approaches.

The symbolic language of mathematics and mathematical rhetoric and how these structure mathematical thinking would also be a valuable avenue to follow.

In this thesis I have focused, with some regret, on gender as a dominant axis of oppression. Others have looked at ethnicity and race. Further work needs to be done that considers the intersection of mathematics and all axes of domination and oppression.

Academic research is the area of mathematical practice which has been investigated here but gender issues in the mathematics and the mathematising of our everyday lives is another research area worthy of greater attention.

Feminist theorists and researchers from diverse backgrounds and disciplines will find that there are many worthwhile areas of investigation in mathematics.

### **Concluding thoughts**

My interest in this project arose from my own experiences as a high school mathematics teacher and my political commitment to encouraging more girls and women into mathematical, scientific, engineering and technology careers. Mathematics is a filter for entry into these careers as achievement in mathematics determines those who will or will not participate further. My interest was further stimulated by interest in the experiences of women who *do* mathematics, the rational and emotional binary and questions about the consequences for mathematics itself, of its gendered traditions and history. Most of the research on women and mathematics is concerned with women who do not achieve or participate but I was interested in what could be learned from those who do. In the feminist literature there is considerable discussion about the rational/emotional dualism. Reason and emotion are discussed as

mutually exclusive opposites. As a woman with a background in mathematics and mathematics education I originally found this difficult to come to terms with as I would have described myself as both rational and emotional. Further reflection and discussion with other women with a background in mathematics led me to appreciate the power of this dichotomy. Studying women mathematicians appeared to be and has proven to be a fruitful site for exploring its implications.

I have made contributions to a number of areas in this thesis. In feminist theory and epistemology I have developed a previously neglected area of analysis, mathematics. I have extended the feminist science debates to take mathematics into account.

In epistemology I have used feminist epistemological perspectives to extend the boundaries of epistemology, to ask epistemological questions which have not been considered relevant to traditional epistemology. When they are raised they shed light on crucial epistemological issues. Epistemological values have been redefined here in ways which disrupt hierarchical, gendered dichotomies. Taking the practices of mathematicians into account in epistemology exposes the public/private split in mathematics and enriches our understanding of how we come to know mathematics.

The new directions in the philosophy of mathematics have highlighted the importance of the social and cultural bases of mathematics but they have rarely taken gender into account. Gender cuts across the social and cultural and is therefore intertwined in the construction of mathematics.

In mathematics education research, gender issues have been given considerable attention but often this agenda has been limited by prior commitments arising from the dominant gender relations and commitments of the wider society in which mathematics is situated. Often this research has reinforced the very positions it was attempting to displace in which girls and women are constructed as inferior to an unproblematised male norm.

Although this thesis is now finished there is still much work to be done to ensure that girls and women and all marginalised groups gain their rightful place in the worlds of mathematics. We all have the right to appreciate and participate in the creation of humanity's "supreme intellectual achievement" (Kline, 1980:352). I hope this thesis will be another step towards making this possible.

# Appendix 1

## Initial Letter to Participants

Dear \_\_\_\_\_,

I am writing to invite you to participate in my Ph.D. research on the topic 'Women who work as creative mathematicians'. As this title suggests I am interested in women who do mathematics and who contribute to new developments and research in mathematics. I am particularly interested in the experiences of such women, their approaches to their mathematical work and the challenges, rewards and contradictions they experience working in such a male dominated area.

This is a qualitative research project involving indepth interviews with 8-10 women. It is being supervised by Dr Gillian Thornley, Dept. of Mathematics, Massey University and Dr Lynne Alice, Director of Women's Studies, Massey University. My own background is in the teaching of mathematics in high schools. My first degree is in mathematics and I have subsequently undertaken postgraduate study in women's studies.

Taking part in this project would involve you in two interviews of one and a half hours each. I am hoping to do the first of these in late April-early May and after analysing the results of this first round, conduct a second interview towards the end of the year.

If you indicate that you are interested in participating, I will then ask you to sign a consent form as required by the Massey University ethics committee, arrange the time and place for the first interview and send you more details of the kinds of questions I will be discussing with you.

If you have any questions about this project please do not hesitate to raise these with me at any time. You can contact me by phone, letter, email or fax as in the details above.

I look forward to hearing from you and meeting you in the near future.

Yours faithfully,

Mary Day.

## Appendix 2

# Participant Information Sheet and Consent Form

### PARTICIPANT INFORMATION SHEET

**Research project:** Women who work as creative mathematicians.

**Researcher:** Mary Day  
Department of Mathematics  
Massey University  
Palmerston North

**Supervisors:** Dr Gillian Thornley  
Department of Mathematics  
Massey University

Dr Lynne Alice  
Director of Women's Studies  
Massey University

### PURPOSE OF THE RESEARCH

The purpose of the research is to find out about your experiences as a woman mathematician. Of particular interest is:

- (a) how you became a mathematician.
- (b) your mathematical research.
- (c) any conflicts you experience working as a woman in such a male dominated discipline.
- (d) how your gender may have affected your mathematics.

### YOUR INVOLVEMENT IN THE RESEARCH

The research will involve you in two interviews of approximately one and a half hours. These interviews will be held four - five months apart. Prior to the interviews you will be sent a brief outline of the topics to be covered in the interview.

At any time during or between the interviews you are welcome to ask questions about the research or to make comments you find relevant but which have not been directly raised by the researcher.

The interviews will be held at a time and place that is convenient to you. At any time you may tell the researcher that it is not convenient to see her.

### **CONFIDENTIALITY**

The information provided for this study will be kept confidential. This confidentiality will be maintained by:

(a) Changing your name and the name of your institution that could lead to your identification.

(b) The interview tapes will only be listened to by the researcher Mary Day, and possibly by a secretary. Such a secretary will be required to make the same guarantees as the researcher to keep confidentiality.

While stringent steps will be taken to ensure the greatest possible degree of confidentiality, the small number of women mathematicians in this country may make it possible for readers of reports on the research to believe that they can identify a participant but they will be unable to confirm their suspicion with the researcher.

You will be free to withdraw from the study or to not answer any questions or to retract any information previously provided at any time. On request you will be provided with a copy of a transcript of your interviews which you may then amend if you wish to do so. All participants will be given a report on the findings and analysis resulting from the research on completion of the project.

This project has been approved by the Human Ethics Research Committee of Massey University.

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**CONSENT FORM FOR RESEARCH PROJECT:  
WOMEN WHO WORK AS CREATIVE MATHEMATICIANS.**

I have read the Information Sheet for this study and have had the details explained to me. My questions about the study have been answered to my satisfaction, and I understand that I may ask further questions at any time.

I also understand that I am free to withdraw from the study at any time or to decline to answer any particular questions in the study. I agree to provide information to the researcher on the understanding that it is confidential.

I agree to participate in this study under the conditions set out on the Information Sheet.

I agree/do not agree to the interview being taped.

Signed: \_\_\_\_\_

Name: \_\_\_\_\_

Date: \_\_\_\_\_

## Appendix 3

# Letter to Participants Outlining the Interview Questions

Dear Participant,

Once again thank you for agreeing to participate in my research. I am looking forward to meeting you. Arranging the interviews has been a much more straightforward process than I had imagined but only because of your kindness and cooperation. I approached eleven women; I could not find one as she had left her previous place of employment; one has not responded and the other nine have agreed to participate. For a qualitative study such as this that is an excellent response rate. As promised I am now sending you more information about the kinds of questions I will be asking.

Not all of the questions are applicable to all of the participants, so don't be concerned if you find that some questions are not relevant to your situation. This is a guide only, and the actual interview may well develop in different directions from that originally intended as unforeseen information comes to light. The purpose of the second interview later in the year, is to follow up any areas missed and any unforeseen areas that have arisen in the first round.

I will ask you some questions about your own career. Particularly about how and why you became a mathematician, the mathematical work you do and how you got involved in that area. Those women who have moved or are moving out of mathematics will be asked about that.

I am also interested in your work practices i.e. how you choose problems to work on and get the necessary resources and how you get credit for your results. I am particularly interested how you go about doing your mathematics itself and to find out will ask you questions like: Do you start by tossing around lots of ideas and see what gels; do you spend a lot of time thinking and then get sudden inspirations?

I also want to ask you about what attracts you to mathematics and how you think about mathematics. How would you describe mathematics? What is it?

The final topic is related to the impact of gender on mathematics and the mathematical community. I am interested here in the gender issues you have faced in your own career and also questions about whether you think women might do or think about mathematics differently.

There is a lot more I would love to ask you but one and a half hours will go really quickly. I am getting really excited about beginning this stage of the project.

Feel free to contact me with any questions or problems at any time.  
Regards,

Mary Day

## Appendix 4

### Interview Schedule

#### **Career:**

How and why did you become a mathematician?

What kinds of mathematical work do you do? How did you get involved in these areas?

How do you make progress in a career as a mathematician?

#### **Mathematical Practices:**

Can you describe how you go about doing your mathematics?

How do you choose problems to work on, get the resources you need and get credit for your results?

Are you involved in networks with other mathematicians?

#### **Mathematics:**

What attracts you to mathematics?

How would you describe mathematics?

#### **Mathematics and gender:**

How has being a woman affected your progress as a mathematician?

Do you or have you experienced personal internal conflicts between being a woman and a mathematician particularly as you are working in such a male dominated and male defined area?

Do you or have you worked in a climate that is 'chilly' for women?

Do you think it is possible that women might do mathematics differently or think about it differently?

Why have the numbers of women in mathematics not increased as quickly as they have in some other areas e.g. medicine?

In asking these central questions I will use the following as prompts where necessary.

### **Career:**

#### **How and why did you become a mathematician?**

Do you have to be a certain kind of person? Did you choose into mathematics or away from something else? Do you intend staying in mathematics?

#### **What kinds of mathematical work do you do? How did you get involved in these areas?**

Do you have responsibilities in the mathematical community other than your own mathematics? How did you come to specialize in your particular area of mathematics? Was it something you chose to go into or was it an opportunity that arose and you took it? Did you choose it because it was at the 'cutting edge'? Could you change now if you wanted to?

#### **How do you make progress in a career as a mathematician?**

How important are qualifications? subject area? personal networks? brilliant breakthroughs? ability? the leader in the field? good luck?

### **Mathematical Practices:**

#### **Can you describe how you go about doing your mathematics?**

Can you describe the process? Do you throw ideas around with a group until something crystallizes? Do you tinker away trying out things until something works and then formalize it?

#### **How do you choose problems to work on, get the resources you need and get credit for your results?**

Do you have any control over the areas you work on? Do you have access to the funding, resources and training you need? How do you go about getting these? Are you involved in networks with other mathematicians? How important are these for disseminating results and publishing? Is publishing results important for you? Do you get to hear about other people's breakthroughs through your networks? Do you review other people's work? Do you know who the reviewers of your own work will be? Do you write your papers to suit particular reviewers? Do you deliberately cite them? How are papers selected for publication? What is the importance of the author's status? What is the importance of networking? Do you know who controls the publication decisions in your area? How do these people get that authority and status? Is all good work published? Is all published work 'good'? Is some work rejected for reasons other than the merit of the work itself? What determines the worth of a paper? Could contrary opinions and voices be excluded by power interests within/out the group? Can the reviewers act as gatekeepers?

## **Mathematics:**

### **What attracts you to mathematics?**

Are certain types of people attracted to mathematics? e.g. those with an emotional need for power and control? those with a need for cool and objective remove? those who enjoy an adversarial pursuit of knowledge? those who can't write essays? those who don't like labs? those who think mathematics doesn't involve politics?

### **How would you describe mathematics?**

Is it an arbitrary game? What is the relationship between mathematics and the 'real' world, the 'natural' world? Is it 'socially constructed'? Is it objective? logical? rigorous? abstract? intuitive? creative? incomplete? relative? 'as cold as steel'? either true or false? Do you have any interest in or opinions about disputes about what is and what isn't mathematics? What are the 'hot' new topics or areas for research?

## **Mathematics and gender:**

### **How has being a woman affected your progress as a mathematician?**

Have you benefited from being a 'token' woman? Have you been discriminated against? Have you experienced any difficulties in establishing credibility with other mathematicians? Do you have problems getting included in mathematical networks? Do you have to become 'one of the boys'? Do you have to keep quiet about being a woman? Have you ever been subject to harassment at your workplace? Have any other women? If you have how has this affected your work and your career? How did you handle it?

### **Do you or have you experienced personal internal conflicts between being a woman and a mathematician?**

Do you feel 'special' being a woman in such a male dominated world? How do you feel about telling people what you do? Do you ever want to avoid it? Do you ever enjoy being able to drop it in to 'score a few points'? How do you feel in situations with women when it is assumed by everybody else that it is normal for women not to be able to do mathematics? Some women in non traditional fields describe feeling like an 'impostor' do you ever feel like that? Do you feel like you 'belong'? Do you think these are silly questions? Do you feel isolated because of the small number of women mathematicians? Would you advise other young women to go into mathematics?

### **Do you or have you worked in a climate that is 'chilly' for women?**

Is the climate in your workplace sexualized? Is there a lot of gender joking? Has sexual harassment been a problem? Are tasks assigned on the basis of gender? Are you the token woman who gets put on lots of committees and/or is expected to speak for all women?

**Do you think it is possible that women might do mathematics differently or approach it differently?**

In applying mathematics and/or building mathematical models do you think women might take different approaches and take different things into account?

**Why have the numbers of women in mathematics not increased as quickly as they have in some other areas e.g. medicine?**

## Appendix 5

# Bibliography of Research on Gender, Mathematics and Education

- Anderson, Johnston. (1989). "Sex-related differences on objective tests among undergraduates." in *Educational Studies in Mathematics*, 20: 165-177.
- Armstrong, Jane. (1982). "Correlates and predictors of women's mathematics participation." in *Journal for Research in Mathematics Education*, 13(2): 99-109.
- Baker, Robyn. (1994). "Including girls in mathematics and science." in *Samepapers*, 40-55.
- Barnes, Mary and Mary Coupland. (1990). "Humanizing calculus: a case study in curriculum development." in *Gender and mathematics*, Leone Burton (ed). 72- 79. London: Cassell Education.
- Barnes, Mary. (1988). "Mathematics: a barrier for women?" in *Crossing boundaries: feminisms and the critique of knowledges*, Barbara Caine, E. A. Grosz and Marie de Lepervanche (eds). 28-42. Sydney: Allen and Unwin.
- Barr, Jean and Lynda Birke. (1994). "Women, science, and adult education: toward a feminist curriculum." in *Women's Studies International Forum*, 17(5): 473-483.
- Becker, Douglas F and Robert A. Forsyth. (1994). "Gender differences in mathematics problem solving and science: a longitudinal analysis." in *International Journal of Educational Research*, 21: 407-416.
- Becker, Joanne and Mary Barnes. (1985). "Report on women and mathematics topic area at ICME 5." in *International Organisation of Women and Mathematics Education Newsletter*, 1(1): 7-13.
- Becker, Joanne Rossi. (1990) "Graduate education in the mathematical sciences: factors influencing women and men." in *Gender and mathematics*, Leone Burton (ed). 119-130. London: Cassell Education.
- Birenbaum, Menucha and Roberta Kraemer. (1995). "Gender and ethnic-group differences in causal attributions for success and failure in mathematics and language examinations." in *Journal of Cross-cultural Psychology*, 26(3): 342-359.

- Blum, Lenore. (1991). "A brief history of the association for women in mathematics: the presidents' perspectives." in *Notices of the American Mathematical Society*, 38(7): 738- 753.
- Boekaerts, Monique, Gerard Seegers and Harriet Vermeer. (1995). "Solving math problems: where and why does the solution process go astray?" in *Educational Studies in Mathematics*, 28: 241-262.
- Bohlin, Carol Fry. (1994). "Learning style factors and mathematics performance: sex related differences." in *International Journal of Educational Research*, 21: 387-397.
- Borasi, Raffaella. (1992). "Rethinking gender issues in mathematics education." in *Learning mathematics through inquiry*. Raffaella Borasi (author). 184-188. Portsmouth, NH: Heinemann Educational Books.
- Bridgeman, Brent and Cathy Wendler. (1991). "Gender differences in predictors of college mathematics performance and in college mathematics course grades." in *Journal of Educational Psychology*, 83(2): 275-284.
- Brusselmans-Dehairs, Christine and Georges F. Henry. (1994). "Gender and mathematics." in *International Journal for Educational Research*, 21: 351-438.
- Buerk, Dorothy. (1985). "The voices of women making meaning in mathematics." in *Journal of Education*, 167(3): 59-70.
- Burton, Leone. (1990). *Gender and mathematics*. London: Cassell Education.
- Byrne, Eileen. (1993). "Women, science and the snark syndrome: myths out, policy in." in *Celebrating women in science: proceedings of the Women's Suffrage Centennial Science Conference*, Mary Cresswell (ed). 18-28. Wellington: The New Zealand Association for Women in the Sciences.
- Campbell, James Reed and Rosalind Wu. (1994). "Gifted Chinese girls get the best mix of family processes to bolster their math achievement." in *International Journal of Educational Research*, 21(7): 685-695.
- Campbell, James Reed and Yasuhiro Uto. (1994). "Educated fathers and mothers have differential effects on overseas Japanese boys' and girls' math achievement." in *International Journal of Educational Research*; 21(7): 697.
- Casey, M Beth, Ronald Nuttall, Elizabeth Pezaris, and Camilla Persson Benbow. (1993). "The influence of spatial ability on gender differences in mathematics college entrance test scores across diverse samples." in *Developmental Psychology*, 31(4): 697-705.

- Catsambis, Sophia. (1994). "The path to math: gender and racial-ethnic differences in mathematics participation from middle school to high school." in *Sociology of Education*, 67: 199-215.
- Cheung, K. C. (1989). "Gender differences in the junior secondary mathematics curriculum in Hong Kong." in *Educational Studies in Mathematics Education*, 20: 97-103.
- Chipman, Susan F, David H Krantz and Rae Silver. (1992). "Mathematics anxiety and science careers among able college women." in *Psychological Science*, 3(5): 292-295.
- Damarin, Suzanne K. (1990). "Teaching mathematics: a feminist perspective." in *Teaching and learning mathematics in the 1990s*. Thomas J Cooney (ed). 144-151. Virginia: National Council of Teachers of Mathematics.
- Damarin, Suzanne K. (1995). "Gender and mathematics education: some implications from feminist science." in *Gender and mathematics education: an ICMI study*. Barbro Grevholm and Gila Hanna (eds). 129-136. Lund: Lund University Press.
- Day, Mary. (1996). "Women mathematicians: eight women's experiences." in *Journal for Research on Women and Minorities in Science and Engineering*. 3(1): 37-51.
- Druva-Roush, Cynthia Ann. (1994). "Gender differences in comprehension skills used in mathematical problem-solving by math-anxious and non-math-anxious students." in *International Journal of Educational Research*, 21: 300-406.
- Dugard, Pat. (1992/3). "Women in mathematics." in *Mathematical Spectrum*, 25(4): 97-105.
- Eccles, Jacquelynne S. and Janis E Jacobs. (1986). "Social forces shape math attitudes and performance." in *Signs: Journal of women in culture and society*, 11(2): 367-380.
- Engelhard Jr, George. (1990). "Gender differences in performance on mathematics items: evidence from the United States and Thailand." in *Contemporary Educational Psychology*, 15: 13- 26.
- Engelhard Jr, George. (1990). "Math anxiety, mother's education, and the mathematics performance of adolescent boys and girls: evidence from the United States and Thailand." in *Journal of Psychology*, 124(3): 289-298.
- Entwisle, Doris R, Karl L Alexander and Linda Stefel Olson. (1994). "The gender gap in math: its possible origins in neighborhood effects." *American Sociological Review*, 59: 822-838.

- Ethington, Corinna A. (1992). "Gender differences in a psychological model of mathematics achievement." in *Journal for Research in Mathematics Education*. 23(2): 166-181.
- Evans, Jeff. (1995). "Gender and mathematical thinking: myths, discourse and context as positioning in practices." in *Gender and mathematics education: an ICMI study*. Barbro Grevholm and Gila Hanna, (eds). 149-157. Lund: Lund University Press.
- Fellows, Michael, Ann Hibner Koblitz, and Neal Koblitz. (1994). "Cultural aspects of mathematics education reform." in *Notices of the American Mathematical Society*, 41(1): 5-9.
- Felson, Richard B and Lisa Trudeau. (1991). "Gender differences in mathematics performance." in *Social Psychology Quarterly*, 54(2): 113-126.
- Fennema, Elizabeth and Gilah Leder. (1990). *Mathematics and gender*. New York: Teachers College Press.
- Fennema, Elizabeth, Herbert Walberg and Cora Marrett. (1985). "Explaining sex-related differences in mathematics: theoretical models." in *Educational Studies in Mathematics*, 16: 303-320.
- Fennema, Elizabeth. (1990). "Justice, equity and mathematics education." in *Mathematics and gender*. Elizabeth Fennema and Gilah Leder (eds). 1-9. New York: Columbia.
- Fennema, Elizabeth. (1995). "Feminist perspectives on gender and mathematics." in *Gender and mathematics education: an ICMI study*. Barbro Grevholm and Gila Hanna (eds). 377-392. Lund: Lund University Press,;
- Fenster, Della Dumbaugh and Karen Hunger Parshall. (1993). "Women in the American mathematical community: 1891-1906." in *The history of modern mathematics*. Eberhard Knobloch and David Rowe (eds). 229-262. London: Academic Press.
- Ferrini-Mundy, Joan. (1987). "Spatial training for calculus students: sex differences in achievement and in visualization ability." in *Journal for Research in Mathematics Education*, 18(2): 126-140.
- Forgasz, Helen J. (1995). "Gender and the relationship between affective beliefs and perceptions of grade 7 mathematics classroom learning environments." in *Educational Studies in Mathematics*, 28: 219-239.
- Friedman, Lynn. (1989). "Mathematics and the gender gap: a meta-analysis of recent studies on sex differences in mathematical tasks." in *Review of Educational Research*, 59(2): 185-213.

- Friedman, Lynn. (1995). "The space factor in mathematics: gender differences." in *Review of educational research*, 65(1): 22- 50.
- Frost, Laurie A, Janet S Hyde and Elizabeth Fennema. (1994). "Gender, mathematics performance, and mathematics-related attitudes and affect: a meta-analytic synthesis." in *International Journal of Educational Research*, 21: 373-385.
- Furinghetti, Fulvia. (1993). "Images of mathematics outside the community of mathematicians: evidence and explanations." in *For the learning of mathematics*, 13(2): 33-38.
- Gallagher, Ann M and Richard De Lisi. (1994). "Gender differences in scholastic aptitude test -mathematics problem solving among high-ability students." in *Journal of Educational Psychology*, 86(2): 204-211.
- Gray, Mary W. (1991). "The association for women in mathematics - a personal view." in *The Mathematical Intelligencer*, 13(4): 6-11.
- Hall, Cathy, and Cynthia Hoff. (1988). "Gender differences in mathematical performance." in *Educational Studies in Mathematics*; 19: 395-401.
- Hanna, Gila and Gilah Leder. (1990). "Research background on gender differences in mathematics achievement." in *International Organisation of Women and Mathematics Education Newsletter*, 6(1).
- Hanna, Gila. (1994). "Cross-cultural gender differences in mathematics education." in *International Journal of Educational Research*, 21: 417-426.
- Hanna, Gila. (1994). "Should girls and boys be taught differently?" in *Didactics of mathematics as a scientific discipline*. R. Biehler, R. Scholz, R. Strasser, and B. Winkelmann (eds). 303-314. Dordrecht: Kluwer Academic.
- Hart, Laurie E. (1989). "Classroom processes, sex of student, and confidence in learning mathematics." in *Journal for Research in Mathematics Education*, 20(3): 242-260.
- Hembree, Ray. (1990). "The nature, effects and relief of mathematics anxiety." in *Journal for Research in Mathematics Education*, 21(1): 33-46.
- International Organisation of Women and Mathematics Education. (1992). "Gender and mathematics education: key issues and questions." in *International Organisation of Women and Mathematics Education Newsletter*, 8(2): 5-11.
- Isaacson, Zelda. (1990). " 'They look at you in absolute horror': women writing and talking about mathematics." in *Gender and mathematics*. Leone Burton (ed). 20-28. London: Cassell Education.

- Jackson, Allyn and James C. Turner Jr. (1994). "Perspectives on the underrepresentation of minorities in mathematics." in *Notices of the American Mathematical Society*, 41: 448-450.
- Jackson, Allyn. (1989). "Feminist critiques of science." in *Notices of the American Mathematical Society*, 36(6): 669-672.
- Jackson, Linda A, Ruth E. Fleury, Jennifer L. Girvin and Donna A. Gerard. (1995). "The numbers game: gender and attention to numerical information." in *Sex roles*, 33(7/8): 559-569.
- Jacobs, Janis E. (1991). "Influence of gender stereotypes on parent and child mathematics attitudes." in *Journal of Educational Psychology*, 83(4): 518-527.
- Jones, Alison and Susan Jacka. (1995). "Discourse of disadvantage: girls' school achievement." in *New Zealand Journal of Educational Studies*, 30(1&2): 165-175.
- Jones, Lesley and Teresa Smart. (1995). "Confidence and mathematics: a gender issue?" in *Gender and education*, 7(2): 157-166.
- Jones, Lyle. (1987). "The influence on mathematics test scores by ethnicity and sex, of prior achievement and high school mathematics courses." in *Journal for Research in Mathematics Education*, 18(3): 180-186.
- Jungwirth, Helga. (1986). "Women mathematicians and mathematics." in *International Organisation of Women and Mathematics Education Newsletter*, 2(2): 13.
- Jungwirth, Helga. (1991). "Interaction and gender - findings of a microethnographical approach to classroom discourse." in *Educational Studies in Mathematics*, 22: 263-284.
- Kaeley, G. S. (1988). "Sex differences in the learning of post- secondary mathematics in a neo-literate society." in *Educational Studies in Mathematics*, 19: 435-457.
- Kaiser-Messmer, Gabriele. (1993). "Results of an empirical study into gender differences in attitudes towards mathematics." in *Educational Studies in Mathematics*, 25: 209-233.
- Kaur, Berinderjeet. (1990). "Girls and mathematics in Singapore: the case of GCE 'O' level mathematics." in *Gender and mathematics*. Leone Burton (ed). 98- 112. London: Cassell Education.
- Kloostermann, Peter. (1990). "Attributions, performance following failure and motivation in mathematics." in *Mathematics and gender*. Elizabeth Fennema and Gilah Leder (eds). 96-127. New York: Columbia.

- Kwiatkowski, Erica, Richard Dammer, Jon K Mills, and Chwan-Shyang Jih. (1993). "Gender differences in attitudes towards mathematics among undergraduate college students: the role of environmental variables." in *Perceptual and motor skills*, 77: 79-82.
- Leder, Gilah and Elizabeth Fennema. (1990). "Gender differences in mathematics: a synthesis." in *Mathematics and gender*. Elizabeth Fennema and Gilah Leder (eds). 188-199. New York: Columbia.
- Leder, Gilah. (1986). "Gender linked differences in mathematics learning." in *International Organisation of Women and Mathematics Education Newsletter*, 2(2): 9-10.
- Linn, Marcia and Steven Pulos. (1983). "Aptitude and experience influences on proportional reasoning during adolescence: focus on male-female differences." in *Journal for Research in Mathematics Education*, 14(1): 30-46.
- Mallam, Winifred A. (1993). "Impact of school-type and sex of the teacher on female students' attitudes toward mathematics in Nigerian secondary schools." in *Educational Studies in Mathematics*, 24: 223-229.
- Marr, Beth and Sue Helme. (1990). "Women and maths in Australia: a confidence building experience for teachers and students." in *Gender and mathematics*. Leone Burton, (ed). 80-86. London: Cassell education.
- Marrett, Cory and Harold Gates. (1983). "Male-female enrollment across mathematics tracks in predominantly black high schools." in *Journal for Research in Mathematics Education*, 14(2):113-118.
- Marsh, Herbert W. (1989). "Sex differences in the development of verbal and mathematical constructs: the high school and beyond study." in *American Educational Research Journal*, 26(2):191-225.
- McBride, Maggie. (1989). "A foucaldian analysis of mathematical discourse." in *For the Learning of Mathematics*, 9(1):40- 47.
- Midkiff Jr, Robert M., Joy Patricia Burke, and Gerald C. Helmstadter. (1989). "A causal model of mathematics performance in early adolescence: the role of sex." in *Psychological Reports*, 64:167-176.
- Mura, Roberta. (1993). "Images of mathematics held by university teachers of mathematical sciences." in *Educational Studies in Mathematics*, 25:375-385.
- Oakes, Jeannie. (1990). "Opportunities, achievement, and choice: women and minority students in science and mathematics." in *Review of Research in Education*, 16:153- 222.

- Pollina, Ann. (1995). "Gender balance: lessons from girls in science and mathematics." in *Educational Leadership*, 53(1):30-31.
- Randhawa, Bikkar S. and Jason S. Randhawa. (1993). "Understanding sex differences in the components of mathematics achievement." in *Psychological Reports*, 73:435- 444.
- Reilly, B., I. Reilly, J. Pemberton and A. Lee. (1987). "Gender differences in performance in bursary pure mathematics." in *The New Zealand Mathematics Magazine*, 24(1):19-33.
- Reilly, B., I. Reilly, J. Pemberton, A. Lee and M. Morton. (1988). "Is the gender gap in bursary mathematics with calculus narrowing?" in *The New Zealand Mathematics Magazine*, 26(4):3-21.
- Rodgers, Maire. (1990). "Mathematics: pleasure or pain." in *Gender and mathematics*, Leone Burton (ed). 29-37. London: Cassell Education.
- Rogers, Pat. (1990). "Thoughts on power and pedagogy." in *Gender and mathematics*, Leone Burton (ed). 38-46. London: Cassell Education.
- Rosser, Sue V. (1990). *Female friendly science: applying women's studies methods and theories to attract students*. New York: Pergamon Press.
- Seegers, Gerard and Monique Boekarts. (1996). "Gender-related differences in self-referenced cognitions in relation to mathematics." in *Journal for Research in Mathematics Education*, 27(2):215-240.
- Skaalvik, Einar M. and Richard J. Rankin. (1994). "Gender differences in mathematics and verbal achievement, self- perception and motivation." in *British Journal of Educational Psychology*, 64:419-428.
- Solar, Claudie. (1995). "An inclusive pedagogy in mathematics education." in *Educational Studies in Mathematics*, 28:311- 333.
- Stage, Elizabeth. (1986). "Biological sex differences in mathematics ability." in *International Organisation of Women and Mathematics Education Newsletter*, 2(2):12.
- Stipek, Deborah J. and J. Heidi Galinski. (1991). "Gender differences in children's achievement-related beliefs and emotional responses to success and failure in mathematics." in *Journal of Educational Psychology*, 83(3):361-371.
- Taal, Margot. (1994). "How do mathematical experiences contribute to the choice of mathematics." in *Sex roles*, 31(11/12):757-769.
- Taole, James K., Marlies Zonneveld and Lebohng Letsie-Taole. (1995). "Gender interaction in mathematics classrooms: reflection and transformation." in *Educational Studies in Mathematics*, 28:263-274.

- Tartre, Lindsay Anne and Elizabeth Fennema. (1995). "Mathematics achievement and gender: a longitudinal study of selected cognitive and affective variables [grades 6-12]." in *Educational Studies in Mathematics*, 28:199-217.
- Tartre, Lindsay. (1990). "Spatial skills, gender and mathematics." in *Mathematics and gender*, Elizabeth Fennema and Gilah Leder (eds). 27-59. New York: Columbia.
- Taylor, Lyn. (1990). "American female and male university professors' mathematical attitudes and life histories." in *Gender and mathematics*, Leone Burton (ed). 47-59. London: Cassell Education.
- Tee, G. J. (1993). "Mathematics and statistics." in *New Zealand Mathematics Society Newsletter*, 57(43).
- Thomas, David A. (1992). *Teenagers, teachers, and mathematics*. Massachusetts: Allyn & Bacon.
- Tocci, Cynthia M. and George Engelhard Jr. (1991). "Achievement, parental support, and gender differences in attitudes toward mathematics." in *Journal of Educational Research*, 84(5):280-286.
- Tressou-Milonas, Evangelie. (1990). "True or false: primary school girls do badly at maths." in *Gender and mathematics*, Leone Burton (ed). 113-118. London: Cassell Education.
- Tyrrell, Jackie, Constance Brown, Jill Ellis, Robyn Fox, Rachel Kinley and Barbara Reilly. (1994). "Gender and mathematics: equal access to successful learning." in *Mathematics education: a handbook for teachers vol. 1*, Jim Neyland (ed). 330-345. Wellington: Wellington College of Education.
- Van Blerkom, Malcolm L. (1988). "Field dependence, sex role self-perceptions, and mathematics achievement in college students: a closer examination." in *Contemporary Educational Psychology*, 13:339-347.
- Verhage, Heleen. (1990). "Curriculum development and gender." in *Gender and mathematics*, Leone Burton (ed). 60-71. London: Cassell Education.
- Volman, Monique, Edith Van Eck and Geert Ten Dam. (1995). "Girls in science and technology: the development of a discourse." in *Gender and Education*, 7(3):283-292.
- Wainer, Howard and Linda S. Steinberg. (1992). "Sex differences in performance on the mathematics section of the scholastic aptitude test: a bidirectional validity study." in *Harvard Educational Review*, 62(3):323-336.

- Walkerdine, Valerie. (1988). *The mastery of reason: cognitive development and the production of rationality*. New York: Routledge.
- Willis, Sue. (1995). "Mathematics: from constructing privilege to deconstructing myths." in *Gender informs curriculum*, Jane Gaskell and John Willinsky. (eds). 262-284. New York: Teachers College Press.
- Willis, Sue. (1996). "Gender justice and the mathematics curriculum: four perspectives." in *Gender, science and mathematics: shortening the shadow*, Lesley Parker; Leonie Rennie and Barry Fraser (eds). 41-51. Dordrecht: Kluwer Academic Publishers.
- Wilson, Kenneth L. and Janet P. Boldizar. (1990). "Gender segregation in higher education: effects of aspirations, mathematics achievement, and income." in *Sociology of Education*, 63:62-74.
- Wily, Helen M. (1988). *Gender and mathematics in New Zealand. A bibliography*. Christchurch: International Organisation of Women and Mathematics education, NZ chapter.
- Wily, Helen. (1986). "Women in mathematics: some gender differences from the IEA survey in New Zealand." in *The New Zealand Mathematics Magazine*, 23(2):39-39.

## Bibliography

- Acker, Joan, Kate Barry and Johanna Esseveld. (1991). "Objectivity and truth: problems doing feminist research." in *Beyond methodology: feminist scholarship as lived research*, Mary Margaret Fonow and Judith A. Cook (eds). 133-153. Bloomington: Indiana University Press.
- Alcoff, Linda. (1994). "Cultural feminism versus post-structuralism: the identity crisis in feminist theory." in *Culture/Power/History: a reader in contemporary social theory*, Nicholas B. Dirks, Geoff Eley and Sherry B Ortner (eds). 96-122. New Jersey: Princeton University Press.
- Allen, Robert E. (1990). *The Concise Oxford dictionary*. Oxford: Clarendon Press.
- Antony, Louise. (1996). Email to Society for Women in Philosophy information and discussion list. *SWIP-L* 20 August.
- Appelbaum, Peter M. (1995). *Popular culture, educational discourse, and mathematics*. Albany: State University of New York Press.
- Arianrhod, Robyn. (1992). "Physics and mathematics, reality and language. Dilemmas for feminists." in *The knowledge explosion: generations of feminist scholarship*, Cheris Kramarae and Dale Spender (eds). 41-53. New York: Teachers College.
- Armstrong, J. E. (1910). "Coeducation in high school: Is it a failure?" in *Good Housekeeping*, 57, 491-495. in Gilah C. Leder, (1992). "Mathematics and gender: changing perspectives." in *Handbook of research on mathematics teaching and learning*, Douglas A. Grouws (ed). 597-622. New York: MacMillan.
- Armstrong, Jane and Richard Price. (1982). "Correlates and predictors of women's mathematics participation." in *Journal for Research in Mathematics Education*, 13(2): 99-109.
- Atweh, Bill and Tom Cooper. (1995). "The construction of gender, social class and mathematics in the classroom." in *Educational Studies in Mathematics*, 28: 293-310.
- Barinaga, Marcia, Ann Gibbons, Toomas Koppel, Elizabeth Culotta, Joe Alper, Patricia Kahn and Virginia Morell. (1993). "Gender and the culture of science." in *Science*, 260: 383-430.
- Battista, Michael. (1990). "Spatial visualization and gender differences in high school geometry." in *Journal for Research in Mathematics Education*, 21(1): 47-60.

- Becker, Joanne Rossi. (1995). "Women's ways of knowing in mathematics." in *Equity in mathematics education*, Pat Rogers and Gabriele Kaiser (eds). 163-174. London: Falmer Press.
- Belenky, Mary Field, Blythe McVicker Clinchy, Nancy Rule Goldberger and Jill Mattuck Tarule. (1986). *Women's ways of knowing: the development of self, voice and mind*. USA: Basic books
- Billard, Lynne. (1991). "The past, present and future of academic women in the mathematical sciences." in *Notices of the American Mathematical Society*, 38(7):707-714.
- Birman, Joan S. (1991). "In her own words: six mathematicians comment on their lives and careers." in *Notices of the American Mathematical Society*, 38(7):703-706.
- Bishop, Alan J. (1988). *Mathematical enculturation: a cultural perspective on mathematics education*. Dordrecht: Kluwer Academic Publishers.
- Bleier, Ruth. (1986). *Feminist Approaches to Science*. New York: Pergamon Press.
- Blithe, Thora, Sharleen Forbes, Megan Clark, Elizabeth Robinson and Kate Whitwell. (1994). "Gender differences in New Zealand mathematics performance at the secondary-tertiary interface." in *International Journal of Educational Research*, 21: 427-438.
- Bordo, Susan. (1988). "Feminist skepticism and the 'maleness' of philosophy." in *Journal of Philosophy*, 619-629.
- Braidotti, Rosi, Ewa Charkiewicz, Sabine Hausler and Saskia Wieringa. (1994). *Women, the environment and sustainable development*. London: Zed Books.
- Burton, Leone. (1987). in Roberta Mura. (1987). "Feminist views on mathematics." in *International Organisation of Women in Mathematics Education Newsletter*, 3(2):6-11.
- Burton, Leone. (1988). "Images of mathematics." in *The social context of mathematics teaching*, Paul Ernest (ed). Exeter: University of Exeter.
- Burton, Leone. (1995). "Moving towards a feminist epistemology of mathematics." in *Educational Studies in Mathematics*, 28(3):275-291.
- Busato, Vittorio V., Geert T. M Ten Dam, Pieter Van Den Eeden and Jan Terwel. (1995). "Gender-related effects of co-operative learning in a mathematics curriculum for 12-16 year-olds." in *Journal of Curriculum Studies*, 27(6): 667-686.
- Butler, Judith. (1990). *Gender trouble: feminism and the subversion of identity*. New York: Routledge.

- Cain, Maureen. (1993). "Foucault, feminism and feeling: what Foucault can and cannot contribute to feminist epistemology." in *Up against Foucault: explorations of some tensions between Foucault and feminism*, Caroline Ramazanoglu (ed). 73-96. London: Routledge.
- Campbell, Patricia. (1995). "Redefining the 'girl problem in mathematics'." in *New directions for equity in mathematics education*, Walter Secada, Elizabeth Fennema and Lisa Byrd Adajian (eds). 225-241. New York: Cambridge University Press.
- Carter, Michael. (1993). "Towards a new philosophy of mathematics." Paper presented at Mathematics Seminar Series, Department of Mathematics, Massey University, Palmerston North, New Zealand.
- Carter, Michael. (1994). Personal communication with Dr Michael Carter, Associate Dean of the Faculty of Information and Mathematical Sciences, Massey University, Palmerston North, New Zealand.
- Chew, Tuan Seng. (1994). Personal communication with Dr Tuan Seng Chew, Department of Mathematics, National University of Singapore, Singapore.
- Code, Lorraine. (1991). *What can she know: feminist theory and the construction of knowledge*. Ithaca: Cornell University Press.
- Code, Lorraine. (1995). *Rhetorical spaces: essays on gendered locations*. New York: Routledge.
- Cole, Eve Browning. (1993). *Philosophy and feminist criticism*. New York: Paragon House.
- Cole, Jonathan R. and Harriet Zuckerman. (1991). "Marriage, motherhood and research performance." in *The outer circle: women in the scientific community*, Harriet Zuckerman, Jonathan R Cole and John T. Bruer (eds). 157-170. New York: W. W. Norton and Company.
- Dain, Julia. (1991). "Women and computing: some responses to falling numbers in higher education." in *Women's Studies International Forum*, 14(3):217-225.
- Damarin, Suzanne K. (1995a). "Gender and mathematics from a feminist standpoint." in *New directions for equity in mathematics education*, Walter Secada; Elizabeth Fennema and Lisa Byrd Adajian (eds). 242-257. New York: Cambridge University Press.
- Damarin, Suzanne K. (1995b). "Gender and mathematics education: some implications from feminist science." in *Gender and mathematics education: an ICMI study*, Barbro Grevholm and Gila Hanna (eds). 129-136. Lund: Lund University Press.

- Davis, Philip J. and Reuben Hersh. (1980). *The mathematical experience*. London: Penguin.
- Day, Mary and Gillian Thornley. (1993). "Women mathematicians in New Zealand." in *Celebrating women in science: proceedings of the women's suffrage centennial science conference*, Mary Cresswell (ed). 98-102. Wellington: New Zealand Association for Women in the Sciences.
- de Millo, Richard A., Richard J Lipton and Alan J Perlis. (1986). "Social processes and proofs of theorems and programs." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 267-286. Boston: Birkhauser.
- Dean, P. R. (1909). "A few algebra methods." in *The Mathematics Teacher*, 2, 41-47. in Gilah C. Leder, (1992). "Mathematics and gender: changing perspectives." in *Handbook of research on mathematics teaching and learning*, Douglas A. Grouws (ed). 597-622. New York: MacMillan.
- Dick, Thomas and Sharon Rallis. (1991). "Factors and influences on high school students career choices." in *Journal for Research in Mathematics Education*, 22(4): 282-292.
- Duran, Jane. (1991). *Toward a feminist epistemology*. Maryland: Rowman and Little.
- Eagly, Alice H. (1994). "On comparing men and women." in *Feminism and Psychology*, 4(4): 513-522.
- Eccles, Jacquelynne. (1985). "Model of students' mathematics enrollment decisions." in *Educational Studies in Mathematics*, 21: 311-314.
- Epstein, Cynthia Fuchs. (1991). "Constraints on excellence: structural and cultural barriers to recognition and demonstration of achievement." in *The outer circle: women in the scientific community*, Harriet Zuckerman, Jonathan R. Cole and John T. Bruer (eds). 239-258. New York: W. W. Norton and Company.
- Ernest, Paul. (1991). *The philosophy of mathematics education*. London: Falmer Press.
- Ernest, Paul. (1994a). "The dialogic nature of mathematics." in *Mathematics, education and philosophy: an international perspective*, Paul Ernest (ed). 33-48. London: Falmer Press.
- Ernest, Paul. (1994b). *Mathematics, education and philosophy: an international perspective*. London: Falmer Press.
- Ernest, Paul. (1995). "Values, gender and images of mathematics: a philosophical perspective." in *International Journal of Mathematical Education in Science and Technology*, 26(3):449-462.

- Fee, Elizabeth. (1983). "Women's nature and scientific objectivity." in *Women's nature: rationalizations of inequality*, Marian Lowe and Ruth Hubbard (eds). 9-27. New York: Pergamon.
- Fennema, Elizabeth. (1974). "Mathematics learning and the sexes: a review." in *Journal for Research in Mathematics Education*, 5(3): 126-139.
- Fennema, Elizabeth. (1990). "Teachers' beliefs and gender differences in mathematics." in *Mathematics and gender*, Elizabeth Fennema and Gilah Leder (eds). 169-187. New York: Columbia.
- Fennema, Elizabeth. (1995). "Mathematics, gender and research." in *Gender and mathematics education: an ICMI study*, Barbro Grevholm and Gila Hanna (eds). 21-35. Lund: Lund University Press.
- Fennema, Elizabeth and J. Sherman. (1977). "Sex-related differences in mathematics achievement, spatial visualization and affective factors." in *American Educational Research Journal*, 14: 51-71.
- Fennema, Elizabeth and J. Sherman. (1978). "Sex-related differences in mathematics achievement and related factors: a further study." in *Journal for Research in Mathematics Education*, 9: 189-203.
- Fennema, Elizabeth and Laurie E. Hart. (1994). "Gender and the JRME." in *Journal for Research in Mathematics Education*, 25(6): 648-659.
- Fennema, Elizabeth and Penelope Peterson. (1985). "Autonomous learning behaviour: a possible explanation of sex-related differences in mathematics in explaining sex-related differences in mathematics: theoretical models." in *Educational Studies in Mathematics*, 16: 309-311.
- Fennema, Elizabeth, Penelope Peterson, Thomas Carpenter and Cheryl Lubinski. (1990). "Teachers attributions and beliefs about girls, boys and mathematics." in *Educational Studies in Mathematics*, 21(55-69).
- Flax, Jane. (1987). "Postmodernism and gender relations in feminist theory." in *Signs: Journal of Women in Culture and Society*, 12(4):621-643.
- Flax, Jane. (1992). "Beyond equality: gender, justice and difference." in *Beyond equality and difference: citizenship, feminist politics and female subjectivity*, Gisela Bock and Susan James (eds). 193-210. London: Routledge.
- Fonow, Mary Margaret and Judith A Cook. (1991). "Back to the future: a look at the second wave of feminist epistemology and methodology." in *Beyond methodology: feminist scholarship as lived research*, Mary Margaret Fonow and Judith A. Cook (eds). 1-15. Bloomington: Indiana University Press.

- Foucault, Michel. (1980). "Power/knowledge: selected interviews and other writings. 1972-1977." Colin Gordon (ed). New York: Harvester Press.
- Fox, Mary Frank. (1991). "Gender, environmental milieu, and productivity in science." in *The outer circle: women in the scientific community*, Harriet Zuckerman, Jonathan R. Cole and John T. Bruer (eds). 188-204. New York: W. W. Norton and Company.
- Friedan, Betty. (1963). *The feminine mystique*. New York: Norton
- Friedman, Lynn. (1994). "Meta-analytic contributions to the study of gender differences in mathematics - the relationship of mathematical and spatial skills." in *International Journal of Educational Research*, 21: 361-371.
- Geller, Sue. (1996a). Email 15 May.
- Geller, Sue. (1996b). Email 21 May.
- Gilligan, Carol. (1982). *In a different voice: psychological theory and women's development*. Cambridge, MA: Harvard university press.
- Goodman, Nicholas D. (1986). "Mathematics as an objective science." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 79-94. Boston: Birkhauser.
- Goodman, Nicholas D. (1991). "Modernizing the philosophy of mathematics." in *Synthese*, 88:119-126.
- Grant, Judith. (1993). *Fundamental feminism: contesting the core concepts of feminist theory*. New York: Routledge.
- Gray, Mary W. (1995). "Recruiting and retaining graduate students in the mathematical sciences and improving their chances for subsequent success." in *Gender and mathematics education: an ICMI study*, Barbro Grevholm and Gila Hanna (eds). 39-41. Lund: Lund University Press.
- Griffiths, Morwenna. (1988). "Strong feelings about computers." in *Women's Studies International Forum*, 11(2):145-154.
- Griffiths, Phillip A. (1993). "Mathematics - from servant to partner." in *Notices of the American Mathematical Society*, 40(6):594-600.
- Hacker, Sally. (1990). *Doing it the hard way: investigations of gender and technology*. Dorothy E. Turner and Susan M Smith (eds). Boston: Unwin and Hyman.
- Halpern, Diane F. (1994). "Stereotypes, science, censorship, and the study of sex differences." in *Feminism and Psychology*, 4(4): 523-530.

- Hanna, Gila; Erika Kundiga and Christine Larouche. (1990). "Mathematical achievement of grade 12 girls in fifteen countries." in *Gender and mathematics*, Leone Burton (ed). 87-97. London: Cassell Education.
- Haraway, Donna. (1988). "Situated knowledges: the science question in feminism and the privilege of partial perspective." in *Feminist Studies*, 14(3):575-599.
- Harding, Sandra. (1986). *The science question in feminism*. New York: Cornell University.
- Harding, Sandra. (1987). *Feminism and methodology: social science issues*. Bloomington: Indiana University Press.
- Harding, Sandra. (1991). *Whose science? whose knowledge?: thinking from women's lives*. New York: Cornell University.
- Harding, Sandra. (1993a). *The 'racial' economy of science: toward a democratic future*. Bloomington: Indiana University Press.
- Harding, Sandra. (1993b). "Rethinking standpoint epistemology: 'what is strong objectivity?'" in *Feminist Epistemologies*, Linda Alcoff and Elizabeth Potter (eds). 49-82. New York: Routledge.
- Hare-Mustin, Rachel T. and Jeanne Marecek. (1994). "Asking the right questions: feminist psychology and sex differences." in *Feminism and Psychology*, 4(4): 531-537.
- Harrison, Jenny. (1991). "The Escher staircase." in *Notices of the American Mathematical Society*, 38(7):731-734.
- Hawkesworth, Mary E. (1989). "Knowers, knowing, known: feminist theory and claims of truth." in *Signs: Journal of Women in Culture and Society*, 14(3):533-559.
- Hekman, Susan. (1990). *Gender and knowledge: elements of a postmodern feminism*. Boston: Northeastern University Press
- Hekman, Susan. (1994). "The feminist critique of rationality" in *The polity reader in gender studies*, 50-61. Cambridge: Polity Press.
- Henrion, Claudia. (1991). "Merging and emerging lives: women in mathematics." in *Notices of the American Mathematical Society*, 38(7):724-729.
- Hersh, Reuben. (1986). "Some proposals for reviving the philosophy of mathematics." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 9-28. Boston: Birkhauser.
- Hersh, Reuben. (1991). "Mathematics has a front and a back." in *Synthese*, 88:127-133.

- Hesse, Mary. (1994). "How to be postmodern without being a feminist." in *The monist*, 77(4):445-461.
- Hilbert, David. (1900). Address to the Second International Congress of Mathematics. in *Mathematics: the loss of certainty* Morris Kline (author). 1980: 344-345. New York: Oxford University.
- Hollway, Wendy. (1994). "Beyond sex differences: a project for feminist psychology." in *Feminism and Psychology*, 4(4): 538-546.
- Humm, Maggie. (1995). *The dictionary of feminist theory*. (2nd ed). Columbus: Ohio State University Press.
- Hyde, Janet, Elizabeth Fennema and Susan J. Lamon. (1990). "Gender differences in mathematics performance: a meta-analysis." in *Psychological Bulletin*, 107(2): 139-155.
- Hyde, Janet. (1994). "Should feminists study sex differences? Yes, with some guidelines." in *Feminism and Psychology*, 4(4): 507-512.
- Isaacson, Zelda. (1988). "Of course you could be an engineer, dear, but wouldn't you rather be a nurse or teacher or secretary?" in *The social context of mathematics teaching*, Paul Ernest (ed). 17-25. Exeter: University of Exeter.
- Jackson, Allyn. (1991). "Top producers of women mathematics doctorates." in *Notices of the American Mathematical Society*, 38(7):715-720.
- Jaco, William. (1994). "Defining mathematical scholarship." in *Notices of the American Mathematical Society*, 41: 426.
- Jaggar, Alison. (1983). *Feminist politics and human nature*. Sussex: Harvester Press.
- Jardine, David W. (1994). "On the ecologies of mathematical language and the rhythms of the earth." in *Mathematics, education and philosophy: an international perspective*, Paul Ernest (ed). 109-123. London: Falmer Press.
- Jayratne, Toby Epstein and Abigail J Stewart. (1991). "Quantitative and qualitative methods in the social sciences: current feminist issues and practical strategies." in *Beyond methodology: feminist scholarship as lived research*, Mary Margaret Fonow and Judith A. Cook (eds). 85-106. Bloomington: Indiana University Press.
- Johnston, Sue. (1994). "Choosing mathematics: 'you need it even if you don't want to do it'." in *Australian Journal of Education*, 38(3): 233-249.
- Keller, Evelyn Fox. (1983). *A feeling for the organism*. San Francisco: W. H. Freeman.

- Keller, Evelyn Fox. (1985). *Reflections on gender and science*. New Haven: Yale University.
- Keller, Evelyn Fox. (1992). *Secrets of life, secrets of death: essays on language, gender and science*. New York: Routledge.
- Kimball, Meredith M. (1989). "A new perspective on women's math achievement." in *Psychological Bulletin*, 105(2): 198-214.
- Kitcher, Philip. (1986). "Mathematical change and scientific change." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 215-242. Boston: Birkhauser.
- Kline, Morris. (1980). *Mathematics: the loss of certainty*. New York: Oxford University.
- Knorr, Karin. (1979). "Tinkering toward success." *Theory and Society*, 8: 347-376.
- Koehler, Mary Schatz. (1990). "Classrooms, teachers and gender differences in mathematics." in *Mathematics and gender*, Elizabeth Fennema and Gilah Leder (eds). 128-148. New York: Columbia.
- Kramer, Pamela and Sheila Lehman. (1990). "Mismeasuring women: a critique of research on computer ability and avoidance." in *Signs: Journal of Women in Culture and Society*, 16(1):158.
- Lather, Patricia Ann. (1991). *Getting smart: feminist research and pedagogy with/in the postmodern*. New York: Routledge.
- Leder, Gilah C. (1982). "Mathematics achievement and fear of success." in *Journal for Research in Mathematics Education*, 13(2): 124-155.
- Leder, Gilah C. (1986). "Mathematics: stereotyped as a male domain?" in *Psychological Reports*, 59(955-958).
- Leder, Gilah C. (1990a). "Gender and classroom practice." in *Gender and mathematics*, Leone Burton (ed). 9-19. London: Cassell Education.
- Leder, Gilah C. (1990b). "Gender differences in mathematics: an overview." in *Mathematics and gender*, Elizabeth Fennema and Gilah Leder (eds). 10-26. New York: Columbia.
- Leder, Gilah C. (1990c). "Teacher/student interactions in the mathematics classroom: a different perspective." in *Mathematics and gender*, Elizabeth Fennema and Gilah Leder (eds). 149-168. New York: Columbia.
- Leder, Gilah C. (1992). "Mathematics and gender: changing perspectives." in *Handbook of research on mathematics teaching and learning*, Douglas A. Grouws (ed). 597-622. New York: MacMillan.

- Leder, Gilah C. (1995). "Guest editorial." in *Educational Studies in Mathematics*, 28(3): 195-198.
- Lewis, D. J. (1991). "Mathematics and women: the undergraduate school and pipeline." in *Notices of the American Mathematical Society*, 38(7):721-723.
- Linn, Marcia C. (1994). "The tyranny of the mean: gender and expectations." in *Notices of the American Mathematical Society*, 41(7): 766-769.
- Longino, Helen E. (1989a). "Can there be a feminist science?" in *Feminism and science*, Nancy Tuana (ed). 45-57. Indiana: Indiana University.
- Longino, Helen E. (1989b). "Feminist critiques of rationality: critiques of science or philosophy of science?" in *Women's Studies International Forum*, 12(3):261-269.
- Longino, Helen E. (1990). *Science as social knowledge: values and objectivity in scientific inquiry*. Princeton: Princeton University.
- Longino, Helen E. (1993). "Subjects, power and knowledge: description and prescription in feminist philosophies of science." in *Feminist epistemologies*, Linda Alcoff and Elizabeth Potter (eds). 101-120. New York: Routledge.
- Longino, Helen E. and Evelyn Hammonds. (1990). "Conflicts and tensions in the feminist study of gender and science." in *Conflicts in feminism*, Marianne Hirsch and Evelyn Fox Keller (eds). 164-183. New York: Routledge.
- Maines, David. (1985). "Preliminary notes on a theory of informal barriers for women in mathematics." in *Educational Studies in Mathematics*, 16: 305-311.
- McNabb, Alex. (1994). Personal communication with Dr Alex McNabb, Research Fellow, Department of Mathematics, Massey University, Palmerston North, New Zealand.
- Mehrtens, Herbert. (1993). "The social system of mathematics and national socialism: a survey." in *Math worlds: philosophical and social studies of mathematics and mathematics education*, Sal Restivo, Jean Paul van Bendegem and Roland Fischer. (eds). 219-246. Albany: State University of New York Press.
- Meyer, Margaret and Mary Schatz Koehler. (1990). "Internal influences on gender differences in mathematics." in *Mathematics and gender*, Elizabeth Fennema and Gilah Leder (eds). 60-95. New York: Columbia.
- Mies, Maria. (1991). "Women's research or feminist research? The debate surrounding feminist science and methodology." in *Beyond methodology: feminist scholarship as lived research*, Mary Margaret

- Fonow and Judith A. Cook (eds). 60-84. Bloomington: Indiana University Press.
- Milne, Catherine. (1996). "Is it fair science? school science stories of discovery." in *Proceedings of the second Australasia and South Pacific region GASAT conference*, Elizabeth Godfrey (ed). 86-95. Auckland: University of Auckland.
- Ministry of Education. (1992). *Mathematics in the New Zealand curriculum*. Wellington: Learning Media.
- Morrison, H. C. (1915). "Reconstructed mathematics in high school." in *The Mathematics Teacher*, 7, 141-153. in Gilah C. Leder, (1992). "Mathematics and gender: changing perspectives." in *Handbook of research on mathematics teaching and learning*, Douglas A. Grouws (ed). 597-622. New York: MacMillan.
- Morton, Margaret, B. Reilly, I. Reilly, J. Pemberton and A. Lee. (1989). "Bursary mathematics with calculus revisited." in *The New Zealand Mathematics Magazine*, 26(3): 17-40.
- Morton, Margaret, B. Reilly, J. Pemberton and A. Lee. (1991). "1991." in *The New Zealand Mathematics Magazine*, 28(1): 1-22.
- Mura, Roberta. (1987). "Feminist views on mathematics." in *International Organisation of Women in Mathematics Education Newsletter*, 3(2):6-11.
- Nelson, Lynn Hankinson. (1993). "Epistemological communities." in *Feminist epistemologies*, Linda Alcoff and Elizabeth Potter (eds). 121-160. New York: Routledge.
- Oakley, Ann. (1981). "Interviewing women: a contradiction in terms." in *Doing feminist research*, Helen Roberts (ed). 30-61. London: Routledge and Kegan Paul.
- Petocz, Peter. April (1993). "Higher degrees in mathematics and statistics completed in Australia in 1991." in *Australian Mathematical Society Gazette*, 20(1):11-17.
- Pitman, Allan. (1989). "Mathematics education reform in its social, political and economic contexts." in *School mathematics: the challenge to change*, Nerida F. Ellerton and M. A. (Ken) Clements (eds). 101-119. Geelong: Deakin University Press.
- Polya, George. (1986). "From the preface of 'Induction and analogy in mathematics'." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 99-102. Boston: Birkhauser.

- Purser, Prudence and Helen Wily. (1990). "Where have all the mathematicians gone in New Zealand?" in *Gender and mathematics*, Leone Burton (ed). 131-142. London: Cassell Education.
- Putnam, Hilary. (1986). "What is mathematical truth?" in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 49-66. Boston: Birkhauser.
- Ramazanoglu, Caroline. (1993). "Introduction." in *Up against Foucault: explorations of some tensions between Foucault and feminism*, Caroline Ramazanoglu (ed). 1-25. London: Routledge.
- Rav, Yehuda. (1993). "Philosophical problems of mathematics in the light of evolutionary epistemology." in *Math worlds: philosophical and social studies of mathematics and mathematics education*, Sal Restivo, Jean Paul Van Bendegem and Roland Fischer (eds). 80-109. New York: State University of New York Press.
- Reinharz, Shulamit. (1992). *Feminist methods in social research*. New York: Oxford University Press.
- Restivo, Sal. (1983). *The social relations of physics, mysticism, and mathematics*. Dordrecht: D. Reidel.
- Restivo, Sal. (1988). "Modern science as a social problem." in *Social Problems*, 35(3):206-225.
- Restivo, Sal. (1990). "The social roots of pure mathematics." in *Theories of science in society*, Susan Cozzens and Thomas F. Gieryn (eds). 120-143. Indiana: Indiana University.
- Restivo, Sal. (1991). "The sociological worldview." in *The social construction of mathematics*, Sal Restivo (ed). 161-173. Cambridge, Massachusetts: Basil Blackwell.
- Restivo, Sal. (1992). *Mathematics in society and history: sociological inquiries*. Dordrecht: Kluwer Academic.
- Restivo, Sal. (1993). "The social life of mathematics." in *Math worlds: philosophical and social studies of mathematics and mathematics education*, Sal Restivo, Jean Paul van Bendegem and Roland Fischer (eds). 247-278. Albany, New York: State University of New York.
- Reyes, Laurie and George Stanic. (1988). "Race, sex socioeconomic status and mathematics." in *Journal for Research in Mathematics Education*, 19(1): 26-43.
- Riley, Denise. (1988). *'Am I that name?' Feminism and the category of women in history*. Minneapolis: University of Minnesota Press.

- Rose, Hilary. (1986). "Beyond masculinist realities: a feminist epistemology for the sciences." in *Feminist approaches to science*, Ruth Bleier (ed). 57-76. Oxford: Pergamon.
- Rose, Hilary. (1994). *Love, power and knowledge: towards a feminist transformation of the sciences*. Bloomington: Indiana University Press.
- Rota, Gian-carlo. (1991). "The pernicious influence of mathematics upon philosophy." in *Synthese*, 88:165-178.
- Rotman, Brian. (1994). "Mathematical writing, thinking and virtual reality." in *Mathematics, education and philosophy: an international perspective*, Paul Ernest (ed). 76-86. London: Falmer Press.
- Schafer, Alice T. (1991). "Mathematics and women: perspectives and progress." in *Notices of the American Mathematical Society*, 38(7):735-737.
- Scott, Joan. (1992). "Experience." in *Feminists theorise the political*, Judith Butler and Joan Scott (eds). 22-40. New York: Routledge.
- Secada, Walter G. (1995). "Social and critical dimensions for equity in mathematics education." in *New directions for equity in mathematics education*, Walter Secada, Elizabeth Fennema and Lisa Byrd Adajian (eds). 146-164. New York: Cambridge University Press.
- Shelly, Nancy. (1989). "A perspective on mathematics." in *International Organisation of Women in Mathematics Education Newsletter*, 5(2): 4-5.
- Sherman, J. and Elizabeth Fennema. (1977). "The study of mathematics among high school girls and boys: related factors." in *American Educational Research Journal*, 14: 159-168.
- Smith, Dorothy. (1979). "A sociology for women." in *The prism of sex: essays in the sociology of knowledge*, Julia A. Sherman and Evelyn Torton (eds). Madison: University of Wisconsin Press.
- Soper, Kate. (1990). "Constructa ergo sum?" in *Troubled pleasures: writings on politics, gender and hedonism*, Kate Soper (ed). 146-161. London: Verso.
- Spender, Dale. (1995). *Nattering on the net: women, power and cyberspace*. Melbourne: Spinifex.
- Stanley, Liz. (1990). "Feminist praxis and the academic mode of production: an editorial introduction." in *Feminist praxis*, Liz Stanley (ed). 3-19. London: Routledge.
- Stanley, Liz and Sue Wise. (1990). "Method, methodology and epistemology in feminist research processes." in *Feminist praxis*, Liz Stanley (ed). 20-62. London: Routledge.

- Taylor, Vera and Leila J Rupp. (1991). "Researching the women's movement: we make our own histories, but not just as we please." in *Beyond methodology: feminist scholarship as lived research*, Mary Margaret Fonow and Judith A. Cook (eds). 119-132. Bloomington: Indiana University Press.
- Thom, Rene. (1986). " 'Modern mathematics': an educational and philosophic error?" in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 67-78. Boston: Birkhauser.
- Thomas, F. W. (1915). "What mathematics subjects should be included in the curriculum of the secondary schools?" in *The Mathematics Teacher*, 5, 206-213
- Thurston, William P. (1994). "On proof and progress in mathematics." in *Bulletin of the American Mathematical Society*, 30(2):161-177.
- Time. (1996). "Time's 25 most influential Americans." in *Time Magazine*, June 17
- Tomm, Winnie. (1989). "Introduction." in *The effects of feminist approaches on research methodologies*, Winnie Tomm (ed). 1-12. Ontario: Wilfred Laurie University Press.
- Traweek, Sharon. (1992). *Beamtimes and lifetimes: the world of high energy physicists*. Massachusetts: Harvard University.
- Trinh, Minh-ha. (1989). *Woman, native, other: Writing postcoloniality and feminism*. Bloomington: Indiana University.
- Tsatsaroni, Anna and Jeff Evans. (1994). "Mathematics: the problematical notion of closure." in *Mathematics, education and philosophy: an international perspective*, Paul Ernest (ed). 87-108. London: Falmer Press.
- Turkle, Sherry and Seymour Papert. (1990). "Epistemological pluralism: styles and voices within the computer culture." in *Signs: Journal of Women in Culture and Society*, 16(1):128-157.
- Tuttle, Lisa. (1986). *Encyclopaedia of feminism*. Essex: Longman.
- Tymoczko, Thomas. (1986). "The four-color problem and its philosophical significance." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 243-266. Boston: Birkhauser.
- Vogel, Wolfgang. (1994). Personal communication with the late Professor Wolfgang Vogel, previously Professor of Pure Mathematics, Department of Mathematics, Massey University.
- Walberg, H. and G. Haertel. (1992). "Educational psychology's first century." in *Journal of Educational Psychology*, 84: 6-19.

- Walkerdine, Valerie. (1989). *Counting girls out*. London: Virago.
- Walkerdine, Valerie. (1994). "Reasoning in a post-modern age." in *Mathematics, education and philosophy: an international perspective*, Paul Ernest (ed). 61-75. London: Falmer Press.
- Wang, Hao. (1986). "Theory and practice in mathematics." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 129-152. Boston: Birkhauser.
- Weyl, Hermann. (1949). A talk quoted in *Mathematics: the loss of certainty* Morris Kline (author). 1980: 344-345. New York: Oxford University.
- Wilder, Raymond L. (1986). "The cultural basis of mathematics." in *New directions in the philosophy of mathematics*, Thomas Tymoczko (ed). 185-200. Boston: Birkhauser.
- Willis, Sue. (1990). "The power of mathematics: for whom?" in *Hearts and minds: self-esteem and the schooling of girls*, Jane Kenway and Sue Willis (eds). 191-212. London: Falmer Press.
- Willis, Sue. (1995). "Gender reform through school mathematics." in *Equity in mathematics education*, Pat Rogers and Gabriele Kaiser (eds). 186-199. London: Falmer Press.
- Witt, Charlotte. (1996). "Working on the margins: feminist theory and philosophy." in *Metaphilosophy*, 27(1 & 2):226-229.
- Yentsch, Clarice and Carl Sindermann. (1992). *The woman scientist: meeting the challenges for a successful career*. New York: Plenum Press.
- Zevenbergen, Robyn. (1994). *The construction of educational inequality: a critique of dominant discourses in mathematics education*. Geelong: Deakin University Press.
- Zuckerman, Harriet. (1991). "The careers of men and women scientists: a review of current research." in *The outer circle: women in the scientific community*, Harriet Zuckerman, Jonathan R Cole and John T. Bruer. (eds). 27-56. New York: W. W. Norton and Company.