DEVELOPING MATHEMATICS TEACHING AND TEACHERS

A Research Monograph

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CHAPTER 5:

Developing Mathematics Teaching Through Communities of Inquiry and Critical Intelligence

This chapter takes up notions of exploration, investigation and inquiry which have played an important part in developing teaching in mathematics in the UK over several decades. It recognises theory and research relating to the use of investigational work and inquiry in mathematical learning in classrooms, and critiques its institutionalisation as a result of government reports and assessment practices. Several sections of the chapter trace theoretical perspectives relating to inquiry approaches in mathematical learning and teaching development, including constructivism, sociocultural theories, communities of practice and communities of inquiry. The notion of critical intelligence is introduced to characterise the critical stance taken by teachers in communities of inquiry, and to highlight a dialectic between individual and social forms of learning in mathematics and mathematics teaching. A penultimate section on teachers researching teaching suggests the importance of links between teachers and educators in sustaining inquiry into teaching. The chapter concludes with a critical perspective on the implementation of inquiry approaches in school classrooms

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The Inquiry Movement and its Origins

Many of the initiatives and programmes discussed in Chapter 4 have been related to or informed by a movement in the UK that has taken place over a number of decades, becoming obvious in the 1960s and 70s, which might be called loosely the 'inquiry' movement. It includes approaches to teaching mathematics involving exploratory or investigational work in mathematics lessons, and has developed from inquiry in exploring mathematics itself to inquiry into the associated teaching processes (Love, 1988; Jaworski, 1994). The latter can also be seen to stem from the teacher research movement in the UK, dating back to Stenhouse, as we shall discuss shortly.

Inquiry in mathematics itself has been a key component of courses such as the Mathematical Association Diploma and the 20 day courses. Teachers participating in these courses were introduced to mathematics through problem solving approaches in which they explored mathematical ideas in a range of topics and became familiar with the use of mathematical processes. Inquiry into mathematics teaching can be seen in the LAMP and RAMP projects, in PrIME, and currently in teacher research programmes such as those supported by TTA grants (See the TTA website on www.canteach.gov.uk/home.htm), and the more recent Best Practice Research Scholarships (www.teachernet.gov.uk/bprs). The LAMP and RAMP projects, as Selinger (1987) acknowledged, resulted in teachers' new ways of thinking about teaching, as a result of their collaborative explorations of curriculum ideas and approaches to teaching, albeit without corresponding change in the perspectives of their students and other teachers. *Collaborative* inquiry approaches are seen as particularly fruitful for teaching development in a number of parts of the world (for

example, in the Japanese model described above), as is being demonstrated through their debate in international conferences in Europe and more widely (e.g., Krainer, Goffree and Berger, 1999; Lin and Cooney, 2001, Wood, Scott-Nelson and Warfield, 2001).

The idea of *inquiry* as a root for practices in learning and teaching has long been important to educators in the UK It can be seen, for example, in Rowland's (1984), *The Enquiring Classroom.* It was fundamental to the Children's Philosophy movement involving a model for a classroom community of philosophical inquiry, with children engaged in the pursuit of truth/knowledge through inquiry, especially through dialogue. (e.g., Lipman, Sharp and Oscanyan, 1980; Splitter and Sharp, 1995). Inquiry (seeking to know through creative exploration) as opposed to discovery (trying to find out what *is*) in the UK developed from the work of Stenhouse in the Humanities Research Project and subsequent Ford Teaching Project (e.g., Elliott and Adelman, 1975). From such projects, over three decades, teachers across the curriculum, started to inquire into classroom processes and practices leading to the establishing of the action research movement in the UK (Stenhouse, 1984; McNiff, 1988; Whitehead, 1989; Elliot 1991; Pring, 2000). This included the formation of a teacher-research network, the *Collaborative Action Research Network* (CARN) and the establishment (in 1993) of the journal, *Educational Action Research.* For example, Atkinson (1994) writes about her action research into her role as mathematics coordinator in a large city first school, and highlights the tensions for a teacher in engaging in such research. Day (1999) analyses a position of 'teachers as inquirers' suggesting a commitment to inquiry is a significant factor in behaving as a professional.

The Cockcroft Report, the outcome of a government inquiry into the teaching of mathematics in schools, emphasised the importance of problem solving and investigational work in a range of teaching approaches that included also discussion between teacher and pupils, and pupils themselves, and appropriate practical work (DES, 1982, para. 243 ff). Publication of the Cockcroft Report, followed by a significant consultation paper from Her Majesty's Inspectorate (HMI) on mathematics teaching (DES, 1985), put the official seal of approval on inquiry approaches as a valued part of mathematics teaching in schools and led to more teachers using investigational work in classrooms. Some practical implications of using investigational work in classrooms will be discussed towards the end of this chapter.

The use of inquiry (or investigation, or exploration) in mathematics teaching was reflected particularly in the seminal book by Banwell, Saunders and Tahta (1972) which set the scene for inquiry in classrooms by offering a range of activities as starting points. Its interest for teachers may be seen in issues of the journal *Mathematics Teaching* where teachers wrote about their experiences of engaging students in investigational activities (see for example issues 71, 73, 75 in 1975 and 1976). Such writings may be seen as early manifestations of teachers' engagement in

classroom research into ways in which mathematical exploration can lead to students' conceptual learning of mathematics. Ruthven (2001) speaks of them as "a form of "popular research" involving careful observation of exemplary cases and systematic reflection on them" (p. 173). Inquiry approaches were institutionalized in 1988 with the inception of the GCSE examination (General Certificate of Secondary Education) at 16+ which included an element of *coursework*, often interpreted as *investigational* work, that was assessed separately from the formal part of the examination. One version of the GCSE examination, offered by the ATM (Association of Teacher of Mathematics), was examined entirely by coursework.

The origins of investigational work in mathematics classrooms in the UK can be seen as part of an international movement in mathematics learning and teaching in the 1970s and 1980s that promoted conjecturing classrooms and problem-solving environments in the learning of mathematics. Based on the work of George Polya (e.g. 1945) in the USA, leading proponents were, in the USA, Alan Schoenfeld (e.g. 1985) and, in the UK, John Mason (e.g. Mason *et al*, 1982). Emphasis was largely on processes and heuristics of mathematical problem solving (see also, Burton, 1984). Much of the early developmental work in the UK was only loosely research-based as we have seen above; however, it has been a forerunner of research in the USA where researchers have devised teaching experiments to create and investigate 'inquiry classrooms' (e.g., Davis, Maher and Noddings, 1990) and in the UK where investigative approaches have been studied and characterised (Jaworski, 1994). In both of these cases research was based in a *constructivist* philosophy of knowledge and learning, acknowledging overtly that such theoretical positions are significant in studies of learning and teaching in classrooms. This takes us into some of the literature on theories associated with investigative or inquiry approaches to learning and teaching.

Knowledge Growth Through Inquiry

Collins (1988) speaks of 'Inquiry Teaching' as engaging the student in "using knowledge, so that it does not become 'inert' knowledge like much of the wisdom received from books and lectures". Such ideas date back to Emanuel Kant and further to Greek philosophers such as Aristotle; a little more recently John Dewey wrote

> … no such thing as imposition of truth from without, is possible. All depends upon the activity which the mind itself undergoes in responding to what is presented from without (Dewey, 1902/1990 p. 209)

The notion of inquiry relates particularly to perspectives in mathematics teacher education dealing with cognition and 'construction' of knowledge. Constructivism, rooted in the work of Piaget (e.g., Piaget, 1950) might be seen as describing cognitive activity in which individuals through processes of accommodation and reflective abstraction develop and modify mental schemata as their representations of knowledge. See for example, Steffe, (1977); Glasersfeld (1982, 1990); Cobb, (1988); Confrey, (1995); Goldin, (1998). Inquiry, or investigative methods in mathematics

teaching are seen to fit with a constructivist view of knowledge and learning as they offer challenges to stimulate mathematical thinking and create opportunities for critical reflection on mathematical understanding (Cobb, Wood and Yackel, 1990; Jaworski, 1994). Through interactions, physical and social, in the world around them, causing challenge to and reorganisation of existing mental formulations, learners are seen to develop *conceptual*, *relational* and *principled* understandings of mathematics (Skemp, 1976, Brown, 1979; Edwards and Mercer, 1987). In other words, learners go beyond the use and application of algorithms and rules to develop an understanding of *general* relationships in mathematics and to deal with problematic aspects of *abstraction* and *formalism* which are central to mathematics (Nardi, 1996).

Educators and researchers working with teachers have developed constructivist models to explain and guide developments in teachers' thinking (e.g., Carpenter, Fennema, Peterson and Carey, 1988; Cobb *et al.*, 1990; Schifter and Fosnot, 1993; Richardson, 1997; Jaworski, Wood and Dawson, 1999). Theories suggests that teachers will develop *conceptual*, *relational* and *principled* understandings of teaching that enable mathematical development in classrooms. Such models need careful scrutiny and critique as we shall address in Chapter 6.

Researchers and theorists, acknowledging the importance of communication and interaction and their resulting discourses to growth of knowledge in teaching have appended the word *social* to *constructivist*. So called 'social-constructivism', emphasises the importance of language and discourse in communicative environments through which learning occurs. Discussion of, and inquiry and investigation into classroom practices are seen to underpin knowledge growth in teaching and in teacher education (e.g., Simon, 1997; Lampert, 1998; Cobb and Bowers, 1999; Wood, 1999).

Although these theoretical positions recognise the importance of social interactions in promoting growth of individual knowledge, they focus largely on construction of knowledge by the individual learner. Challenges to these views have come from researchers and theorists working in Vygotskian traditions who locate learning centrally in the sociocultural environment in which the learner is situated. Individual learning is regarded as derivative of social learning (Vygotsky, 1962, 1978). Learning is seen as a process of social enculturation with the individual internalising knowledge from interactions in the social world (Bartolini-Bussi, 1994; Lerman, 1996). It is believed that such social location of learning, teaching and teacher education avoids our ignoring of pathological social circumstances that result in learners' alienation from schooling (Lerman, 2000). There is, however, vigorous defence of constructivist perspectives on knowledge and learning that challenges notions of internalisation and enculturation (e.g., Steffe and Thompson, 2000). *Intersubjectivity*, ways in which individuals and groups understand each other and construct reality, is seen as a key concept relating individual and social perspectives, although its roots are treated differently in the different camps.

A recent special issue of *Educational Studies in Mathematics* was devoted explicitly

to contrasting individual and social perspectives (Kieran, Forman and Sfard, 2001). Authors in this volume take *discourse* and *communication* as the basis of their analysis of classroom situations involving mathematical learning where "the focus is on the change generated by interpersonal interactions" which "results in a picture which is more complex and closer to life than in the traditional cognitivist studies" (p. 7). Such perspectives emphasis a concept of 'community' and it is through community that we propose some possible rationalisation with notions of inquiry.

Communities of Practice and Situated Cognition

There has been a growing interest in the importance of seeing learners less as individuals independently constructing knowledge, albeit within and supported by social interactions, and more as participants in and contributors to the social environment of the mathematics classroom, and beyond, in which learning takes place. In a classroom, learners can be seen to participate in a *community of practice*, the practice being that of mathematics learning and teaching. *Community of practice* is an extension of the socioculturalist position, mentioned above in which some regular integrated social purpose, and collection of norms and beliefs locate, or *situate*, knowledge and cognition *in* practice. The term 'communities of practice' has arisen with reference to the social communicative activity of groups based on social practices, such as those of tailoring, or alcoholics anonymous, (Lave, 1988; Lave and Wenger, 1991) and teaching (Lave, 1996; Adler, 1996, 1999; Wenger, 1998). Knowledge is seen to be in the practice and to grow through activity and interactions in the practice. For example, the novice tailor learns from absorption into the community of tailors, led by *master* tailors, and gradually reducing peripherality in the community through increasing participation in the community's practices. The process is seen as one of situativity, apprenticeship and enculturation (e.g., Brown, Collins and Duguid, 1989; Greeno, 1998a, b). Wenger (1998) emphasises the production of *identity* through participation in a community of practice. Learning is presented as a "process of becoming". Wenger states, "It is in that formation of identity that learning can become a source of meaningfulness and of personal and social energy" (p. 215). Linehan and McCarthy (2001) emphasise the need for community models to form a clearer conceptualisation of the 'often messy' relationships between individual and community especially where learning in classrooms is concerned (p. 129).

There are problems in extending ideas of community of practice to students' learning in classrooms, as it is not clear what exactly the practice is into which learners are being enculturated and of which teachers are 'masters'. Teaching and teacher education, on the other hand, *can* be conceptualised as involving communities of practice, with new teachers being drawn into the community through increasing participation modelled on existing well-developed practices (Adler, 1996). For any teacher, their employing school represents a well-established community of practice, distinct from, though overlapping with, the communities of practice which exist in other schools. In addition to the mediating effect of the individuals involved, the

organisational culture of the school will also affect teacher progress (Carré, 1993; Lave 1996). Nias, Southworth and Yeomans (1989) note the uniqueness of culture in each of their research schools and argue for induction processes which help new staff to become included and socialised into the culture of the school. Maynard (2000) confirms that student teachers, through engagement in staff room rituals and routines as well as through discussion with their mentors, are both able to learn from talk and to talk as legitimate members of the community. However, socialisation into existing cultures and practices can be seen also to perpetuate *ineffective* practices in teaching, with "some schools merely recycling their inadequacies" (Alexander, Ross and Woodhead, 1992, p. 53) and result in deficit views of teaching practice (Brown and McIntyre, 1993, Jaworski, 2000a).

So far we have not considered in what ways *inquiry* might form a part of such communities. A possibility is that including inquiry as a normative practice in a community might avoid the perpetuation of ineffective practices.

Communities of Inquiry

Alan Schoenfeld (1996) has described, vividly, a community of inquiry that developed through his mathematics education research group in a university environment. As researchers, members of the group were fundamentally engaged in inquiry. The power of the community could be seen in ways in which interactions within the group led to the growth of practices of questioning and critiquing perspectives in a mutually supportive fashion, so that relationships within the group were strengthened, a clearer understanding of inquiry, reflection and critique emerged, and knowledge of mathematics learning and teaching developed.

The term 'Communities of Inquiry' is used by Gordon Wells (1999) in a discussion of 'dialogic inquiry' rooted in the work of Vygotsky. Wells draws on notions of inquiry as "a willingness to wonder, to ask questions, and to seek to understand by collaborating with others in the attempt to make answers to them", and as a means to emphasise "the essential continuity of education (Dewey, 1938, 1956)". This continuity is shown through the use of inquiry by students in classrooms, teachers responsible for their education, and those who are responsible for teachers' initial preparation and continuing professional development (Wells, 1999, p. 122). Wells draws on interpretations of *community* by a number of authors including Brown and Campione (1994), Rogoff (1994) and Lave and Wenger (1991). However, he distinguishes communities of inquiry from communities of practice by highlighting the importance of "metaknowing through reflecting on what is being or has been contributed and on the tools and practices involved in the process" (p. 124). Wells' research focuses on teachers who are "attempting to develop such communities of inquiry and simultaneously making their attempts the objects of their own inquiries" (p. 124).

In the final chapter of a collection of papers called, *Understanding practice: Perspectives on activity and context*, one of the editors, Seth Chaiklin, writes as follows:

> Social science research has the potential to illuminate and clarify the practices we are studying as well as the possibility to be incorporated into the very practices being investigated. (Chaiklin, 1993, p. 394)

These words emphasise the nature of research, not only as a means to illuminate practice, but as a source of study in investigations of practice; the research itself being part of the practice under investigation. Both Wells and Chaiklin thus point to a community of inquiry as involving a dialectical relationship between a community of practice and its activities in inquiring into and developing practice.

Cochran Smith and Lytle (1999), referring to a conceptual framework for teachers' learning emanating from a three year study of the relationships of inquiry, knowledge and professional practice in urban communities in the U.S., introduce as a new construct 'inquiry as stance'. They use this construct to describe "the positions teachers and others who work together in inquiry communities take towards knowledge and its relationships to practice" (p. 288). Their usage and elaboration of this concept fits with our discussion above and below. These authors write:

> Teachers and student teachers who take an inquiry stance work within inquiry communities to generate local knowledge, envision and theorise their practice, and interpret and interrogate the theory and research of others. (p. 289)

Teachers taking an inquiry stance "[raise] questions about what counts as teaching and learning in classrooms" and "critique and seek to alter" systemic norms and relationships.

Inquiry and Critical Reflection or Intelligence

In a community of inquiry, the novice practitioner is drawn into the community through processes of observation, practice, questioning of practices, and inquiry into practice, as indicated in Schoenfeld's (1996) example. Wells (1999) emphasises the importance of *collaboration* between teachers and researchers in investigating ways of improving practice. At the root of such a model is the belief in a critical mode of reflective practice in which the roots of social engagement are challenged so that practices are continuously reconceptualised and developed for the benefit of participants. Cochran Smith and Lytle (1999, p. 289) suggest that "the work of inquiry communities is both social and political", aiming to bring about change in traditional ideas of knowledge and develop richer conceptions of practice. (See also the work of Carr and Kemmis, 1986, rooted in critical theory following the Habermas school). In the case of developing mathematics learning and teaching, reconceptualisation of knowledge and practice would be for the benefit of the learner of mathematics, enabling a better quality of mathematical learning to result.

Such a model contains an inherent dialectic (related to the one mentioned with

reference to Chaiklin above) in terms of its conceptualisation as an individual or social process. It is a social process in the sense that a participant is a member of a community (e.g. of teachers) with its own practices and dynamics of practice which go through social metamorphoses as inquiry takes place. It is an individual process in that individuals are encouraged to look critically at their own practices and to modify these through their own learning-in-practice. Developments within the community result from rationalisations, implicit and overt, between ongoing practices. Wenger (1998) speaks of "modes of belonging", including *engagement*, *imagination* and *alignment*. We engage with ideas through communicative practice, develop those ideas through exercising imagination and align ourselves, critically, "with respect to a broad and rich picture of the world" (p. 218). It seems possible to conceptualise inquiry in these terms.

The notion of Community of Inquiry might therefore be seen to draw together elements of (social) constructivism and elements of social practice theory: participants grow into and contribute to continual reconstitution of the community through critical reflection; inquiry is developed as one of the norms of practice within the community and individual identity develops through reflective inquiry. This combination can be seen as particularly relevant to the development of teaching through teachers inquiring into their own practices of teaching mathematics. To be sustained, inquiry must be overt to a considerable degree, and it is through individuals and groups making inquiry explicit that critical intelligence develops. In a context of 'mentoring' in ITE in mathematics, Jaworski and Watson (1994) contrast the "inner-mentor" of the critically inquiring individual, with processes of "co-mentoring" through which the community or group develops. Inner-mentor and co-mentoring are seen to be reflexive modes of a process of critical inquiry.

Research by Jaworski (1987, 1990) explored the development of teaching through teachers' use of classroom videotape as a reflective device to enhance teaching through both individual and group activity (Open University, 1990). At the same time a group working for the Mathematical Association abstracted a model from their own activity in developing teaching, known as *the anecdoting process* (Mathematical Association, 1991; Jaworski, 1991). This was based on teachers' stories or anecdotes in a variety of forms (including video recordings) used as a reflective device to promote the raising of issues and addressing of critical questions relating to teaching.

These initiatives, researched through teacher interviews and two conferences in Suffolk and Cumbria, showed evidence of teachers' critically reflective practice leading to teaching development of individuals and to thinking about teaching development within constituted groups. Critical intelligence resulted from an increasing awareness of issues and questions that practitioners had to face in the processes of developing teaching. The application of these processes to initial teacher education can be seen in the use of 'Episodes and Issues' sessions in which student-teachers bring 'episodes' from their classroom activity to share with colleagues in their university group as a stimulus for raising issues and critical questioning of

practices (Jaworski and Watson, 2001).

In the cases described above, communities of inquiry can be seen to have developed critical intelligence. The process of developing critical intelligence from which teaching develops can be seen as related to Schön's (1983, 1987) notion of *reflection-in-action* in which teachers recall issues discussed in critical reflection outside the classroom and act consciously in response to events in the classroom. Similarly, in a theory called the *discipline of noticing*, Mason (e.g., 2001) has suggested that critical reflection on past events, in collaboration with colleagues, can lead to *noticing in the moment* in practice, allowing the possibility for alternative decisions and actions. Examples of such noticing in classroom teaching and learning of mathematics may be found in Jaworski (1994).

Thus, theory suggests that teachers' reflective questioning outside the classroom, of practices *in* the classroom (reflecting on action), leads to a more overt in-classroom awareness of issues (reflecting in action) resulting in corresponding classroom action and, possibly, changes to practice. The research described here is small scale and localised, involving a few teachers in a few schools, which raises questions about the applicability of such processes or models for teaching development more widely (Eraut, 1994). Although anecdotal evidence exists to suggest that such situations occur, systematic research is needed to test these ideas and gain further insights to these processes.

Teachers Researching Teaching

Teachers' engagement in inquiry in teaching, involving both the use of inquiry approaches to classroom mathematical activities and inquiry into teaching itself, led to mathematics teachers engaging in small scale action research in classrooms. The *Association of Teacher of Mathematics* initiated a group of teacher researchers in the 1980s, leading to a publication entitled *Teacher is/as Researcher* (ATM, 1987). The play on words here reflected the question of what exactly was the role of the teacher engaging in research.

In mathematics education around the world, projects focusing on teaching development in mathematics encouraged models of critically reflective practice resulting in the development of communities of inquiry, of critical intelligence within these communities, and examples of teacher action research. A working group at the conferences of the *International Group for the Psychology of Mathematics Education* (PME) studied processes and practices in this work over a decade (Zack, Mousely and Breen, 1997). In most cases, those leading such projects found their own thinking and practices developing alongside the teachers and students with whom they worked. For example, Jaworski, studying investigative practices in secondary mathematics classrooms found that *naive* questions, from the researcher's perspective, were seen as *hard* questions by teachers and led to teachers critically reviewing their own theories of teaching. A reflexive relationship between researcher and teacher led to each critically examining their bases of conceptualising teaching

and its development (Jaworski, 1994). In Austria, Krainer and colleagues (e.g. Krainer, 1993) developed a university course in which teachers, alongside educators explored aspects of teaching practice. The resulting inquiry led to developments in practices at all levels. In New Zealand, Britt, Irwin and colleagues (e.g. Britt, *et al.*, 1993) worked with teachers from intermediate and secondary schools to enhance teaching through inquiry approaches. Learning at all levels resulted from mutual inquiry. Again in the UK, a project in Oxford was funded to explore developments in teaching resulting from teachers undertaking overt inquiry into their own practice (Jaworski, 1998). Findings showed teachers accommodating to notions of teacher-research. As confidence in research approaches developed, teachers gained insights into classroom approaches and ways of developing them that had previously been no more than implicit in their work. More recent research in the UK by a school teacher and a teacher educator jointly, involving inquiry into learning and teaching practices, was conducted by Brown and Coles in a project which saw teacher and students as a *community of inquirers*, together inquiring into aspects of mathematics (e.g., Brown and Coles, 2000).

A consequence that became clear from many of the projects above, was that teacher-research was hard to sustain without support or stimulus from externally based colleagues, such as university researchers, or from experienced researchers within a school environment. Recent initiatives on the part of the TTA, and DfES (described in the chapter on CPD above) into teacher research premised on notions of developing evidence-based practice, have acknowledged the importance of the relationship between teachers and their university colleagues. Modes of funding are now based on formally agreed relationships between schools and HE Departments to support research in schools and the hoped-for evidence-based practice. This coincidence of the inquiry movement and the official rhetoric offers perhaps an opportunity to take further the somewhat idiosyncratic developments in the inquiry movement through national projects with official backing and associated funding. A breadth of vision here could lead to establishment of wider communities of inquiry in which all learners (students, teachers, educators and researchers) engage in collaborative inquiry at a variety of levels for the enhancement of school learning.

Implications for the Use of Inquiry Approaches in Practice

Chapter 5 has followed, largely, a theoretical pathway that has situated ideas about inquiry approaches to doing and teaching mathematics in theories of learning and development. This concluding section will look at some of the practical implications of implementing inquiry approaches.

There is considerable evidence, reported from both academic research and popular research, of UK teachers' use of inquiry approaches in mathematics teaching that involve and inspire students and promote mathematical thinking of a non-ritualistic kind (Jaworski, 1994; Ruthven, 2001). In the 1970s and early 80s, such approaches to teaching were promoted mainly by enthusiasts such as teacher educators or members of the *Association of Teachers of Mathematics* in the UK (Love, 1988). With support

from the Cockcroft Report (DES, 1982) and the later inclusion of coursework for examination at GCSE (in 1988) inquiry approaches and classroom investigational work became more widespread and institutionalised. Such activity was engendered to fit with examination requirements: evidence of exploration, conjecture, formulation and testing. However, teachers' approaches to teaching were often geared more to exposition and exploration than to investigative work. Lerman (1989) describes a teacher who "went round the classroom offering advice such as 'no, not that way, it won't lead anywhere, try this'". According to Lerman, "there had been no opportunity for the teacher to discuss or examine … how [an investigation] might differ from 'normal' mathematics" (p. 73). Jaworski (1994) reports a number of dilemmas for teachers in developing investigative approaches to mathematics teaching; for example, "the teachers' dilemma", to "inculcate knowledge, while apparently eliciting it" (p. 123; see also Edwards and Mercer, 1987, p. 126). Another problem with institutionalisation was that in some classrooms investigative work took on a ritualised form (Love, 1988; Morgan, 1998): activity seemed to be reduced to a formalistic procedure such as trying out a small number of cases, and spotting and representing a pattern. Hewitt (1992, p. 7) asked, "Is the diversity and richness of the mathematics curriculum being reduced to a series of spotting number patterns from tables?" Ruthven reports on the activity of student teachers required to engage in a professional exercise involving investigation, and their subsequent critical examination of the outcomes. One student teacher, particularly, felt that certain investigations were "so tightly structured as to lose their key qualities". She pointed toward "teacher exposition dressed up as practical work", "right and wrong answers, with no creativity possible in the solution", and "the problem of time constraints" (Ruthven, 2001, p. 177). Such reported experiences reflect many of the difficulties teachers face in beginning to use inquiry approaches in classrooms where the focus is on students' achievement according to narrowly conceived goals within an increasingly prescribed curriculum (DfEE, 199b, 2001) that is not geared towards investigational work.

Evidence from programmes such as LAMP and RAMP showed that inquiry and investigative approaches to mathematics teaching in classrooms, the design of such teaching and subsequent reflection on outcomes resulted in changed thinking and (sometimes) changed practice for the teachers who engaged in them (Selinger, 1987). The observable effects of this changed thinking for pupils and other teachers, to whom the project was disseminated, were less positive. We mentioned, in Chapter 4, Ruthven's reflections on this research: the suggestion that such activity leads to "in groups" and "out groups", in which the former discount the views of the latter. Thus, although this project can be seen as effective in teachers' changed thinking and practice, its outcomes for pupils and dissemination to other teachers seem not to be effective. Selinger wrote, "[The teacher researchers] now believe effective in-service strategies should be provided through active participation of the recipients" (Selinger, 1987, pp. 57-9; quoted in Ruthven, 1999, p. 206).

The above discussion points to two main issues related to the successful implementation of inquiry approaches; the first might be seen to be a consequence of the second:

- the issue of institutionalisation leading to a ritualised implementation that ignores students' creativity of thinking and associated conceptual understanding;

- the issue of teachers generally needing more opportunity to think through the philosophy of investigative approaches and to work on the dilemmas they raise for teaching.

Research has shown certain teachers, enthusiasts, or the 'in group' giving the time and thought (or provided, in projects like RAMP, with opportunity to think and explore) to developing such approaches and dealing with the dilemmas that arise. Disseminating the positive experiences of the 'in group' to enable other teachers to use inquiry methods in a non ritualised way has been shown, largely, to be unsuccessful. We suggest that forms of dissemination are problematic in that they use all too rarely methods of collaborative participation, relying instead on cascading information through written materials or oral exposition and demonstration. The work of the Cockcroft 'missionaries' was more successful, shown where advisory teachers worked closely, in the classroom and in workshops, with other teachers, encouraging participation and collaborative engagement with issues (e.g. Nolder and Tytherleigh, 1990).

Two exceptions to this somewhat uninspiring picture of implementation can be seen in initiatives which seem on the face of it to be assessment initiatives, but which had, or are currently having, significant influence on teachers and teaching with which they were or are involved, with, in one case, recognised gains in student achievement.

The first was the ATM GCSE (General Certificate of Secondary Education) by 100% coursework, mentioned above, which ran as a pilot project in six schools for five years from 1988 to 1992. The scheme for the assessment of pupils' work involved the domains of Communication, Implementation, Mathematical Knowledge, Interpretation, Mathematical Attitude and Autonomy. In reports from an evaluation, commissioned by the Association of Teachers of Mathematics (ATM), Love and Shiu (1991a, b) show that the assessment scheme resulted in teachers' development of evidence on which to base assessment, changed practice in the classroom related to finding evidence, and the development of curriculum related to conducting investigational mathematics. A study of the student performance by the examination board found a greatly increased proportion of girls gaining higher grades. Unfortunately, despite such positive indications from the pilot project, the government of the day decreed that coursework in GCSE would be reduced to 50% and later 20% of the overall assessment of GCSE, the rest being by examination, thereby ruling out the ATM 100% mode. Several accounts of the project by participants can be found in the literature (e.g. Ollerton and Hewitt, 1989; Watson,

1990; Ollerton, 1990; Sutcliffe, 1991; Askew and Haines, 1991).

The second project developed from an extensive survey of the research literature on classroom formative assessment (Black and Wiliam, 1998a) which resulted in a publication (Black and Wiliam, 1998b) setting out a strong case for effective teaching (in terms of pupil achievement) developing from teachers' engagement with formative assessment practices. The authors report on three areas in which teachers' practice was seen to develop, resulting in enhanced achievement for students, particularly those seen as low attainers: rich questioning, quality of feedback and the role of learners in their learning (Wiliam 1999a, b; 2000). These developments can be seen to embody significant aspects of communicative inquiry as discussed above. The project that developed from this earlier work was the *Kings-Medway-Oxfordshire Formative Assessment Project* based at King's College, University of London. The project involved an intervention with six schools in each of two Local Education Authorities. This consisted of a series of in-service sessions during which mathematics and science teachers (two of each, from each school) were introduced to principles of formative assessment, and visits to schools by members of the project staff. In the visits teaching was observed and teachers had the opportunity to discuss their ideas, and how they could be put into practice more effectively (Wiliam and Lee, 2001). The project was designed to build on the professionalism of teachers rather to impose a model of 'good formative assessment' on them. These reported aspects of the project suggest a communicative inquiry model in its implementation. The research design built into the project a (quantitative) measure of the effects of teachers' use of formative assessment practices, through a choice of suitable control groups for each teacher and the use of whatever assessment instruments the school used to measure pupils' attainment. Conservative estimates suggested an average gain equal to between one-quarter and one-half of a GCSE grade per student per subject, which would predict a significant rise in achievement across the whole school (*ibid*).

Finally, this chapter proposes that the collaborative engagement of students and teachers in inquiry approaches leads to situated and *principled* learning (Edwards and Mercer, 1987): learning that results from engagement with content, process and issues in a non-superficial (or non-ritualistic) way, dealing with the issues and dilemmas that arise. Those who teach, whether teachers teaching mathematics in classrooms, or teacher educators (including LEA advisors) teaching teachers, need opportunity to address the theory and philosophy that underpins inquiry approaches and struggle with the dilemmas that arise in practice. *Systemic* issues become obvious and give rise to questions such as: how can we rationalise an increasingly prescribed curriculum with encouragement of teacher groups to develop research-based, innovative approaches to classroom teaching? What forms of in-service activity encourage collaborative inquiry as part of the daily life of schools? How can government initiatives such as Best Practice Research Scholarships scheme be linked to wider school developments? The thrust of this chapter, and this final section in particular, suggests that such issues have to be addressed.