RESEARCH IN MATHEMATICS EDUCATION IN AUSTRALIA: WHAT IT WAS - WHAT IT IS - WHAT IT MIGHT BE

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I am greatly honoured to have been invited to speak at this MERGA Conference in Adelaide, and I regret that this is the first of the 22 conferences that I have attended. I have chosen as the title of my talk today one that is derived from the title of books by F.W. Westaway. When I started teaching mathematics and science in Adelaide schools a little over 50 years ago, I was guided by the Mathematical Association booklets and books by Westaway on '*Craftmanship in the Teaching of Elementary Mathematics*' and '*Science Teaching - What it was - What it is - What it Might Be*'. 'These publications were built on the collective wisdom of countless mathematics and science teachers at universities and schools in England. Today, guidance is drawn from the findings of Australian research in the field of mathematics education that emphasizes not only the teaching of mathematics but also the learning and application of mathematics in schools and a world of science and technology.

The contribution of research to mathematics education is relatively recent. Only 30 years ago, 500 copies of book reporting the findings of research including the relationship between curricular time and achievement that I had written were pulped, with only a few copies being sent overseas, and the remainder destroyed. This was done because a Director General of Education who had reduced the time given to mathematics in the curriculum of the schools in his state could not approve a publication (Keeves, 1968) that reported on the relationships between mathematics achievement and curricular time. Research could not be reported for open debate if the findings were contrary to declared policy.

Eight years later in April 1976, a senior bureaucrat in Canberra directed that a chapter that I had written should be removed from a report of a research study before publication (Keeves and Bourke, 1976). A colleague challenged this decision with a letter to a newspaper and was led to resign from his position in a research institute. The chapter was concerned with the very low performance in numeracy and literacy of 10 and 14-year-old Aboriginal students in Australian schools. I pay tribute today to this colleague - John Foyster. In the discussion that followed his resignation, John wondered what he could do in the months ahead while he was seeking employment. The suggestion emerged that he should run a conference that would provide opportunities for free and open discussion of research in mathematics education leading to the dissemination and publication of research papers, and perhaps to the establishment of an association concerned with research in mathematics education. John Foyster's initiatives led within a few months to the first of the MERGA conferences, to the establishment of MERGA as an association, and subsequently to its publication program. This was the climate at that time for research in Australian education and mathematics education in particular.

Several changes have taken place that have supported the growth of research in mathematics education in Australia. However, the role of the Mathematics Education Research Group of Australia with its annual conferences and the publication of the papers presented, together with the reviews of research into mathematics education in Australia that are published in a four-year-cycle (Briggs, 1984; Blane and Leder, 1988; Atweh and Watson, 1992; Atweh, Owens and Sullivan, 1996) and the widely acclaimed international journal, the *Mathematics Educational Research Journal*, have led the way in the development of research in mathematics education in this country. The Australian Association of Mathematics Teachers (AAMT) which was formed from the Mathematics Associations in each of the Australian states, has also published in their journal *The Australian Mathematics Teacher*, the findings of research in a form relevant to teachers and has held biennial conferences to maintain communication between the states. In addition, the Mathematics Education Lecturers Association (MELA) has conducted annual conferences for its members with an interest in research, which are now run in collaboration with MERGA.

Research in the area of mathematics education in Australia is both active and well directed to the problems of learning mathematics at all levels of education. It has been greatly strengthened during the past decade by the inclusion of the former teachers' colleges and colleges of advanced education into the university system, with the expectation that members of the staffs of all universities should engage in research. A significant development in recent years has been the appointment of professors of mathematics education at several universities who provide leadership for the sizeable numbers of university staff, and graduate students who are engaged in research into the problems of the teaching and learning of mathematics. The higher degree students who are working in the field of mathematics education have had, in the main, extensive teaching experience, and as a consequence the studies they undertake are concerned with the practical problems of learning and teaching in Australian schools.

Australian research in mathematics education is not subordinate to research conducted in Britain or the United States as it once was. It is conducted with considerable vigour and commitment, but greatly benefits from regular contact with fellow research workers in other parts of the world. Moreover, Australian research workers in the field of mathematics education are well represented at international conferences, are contributors to international reviews of research, publish widely in international research journals and are strongly listed in overseas research citations.

MATHEMATICS EDUCATION - TODAY

The present-day setting which contains the strong program of research activity that has been built up over the past two decades has provided both the foundations and the support for mathematics education in schools that in Australia is undergoing a marked transformation. The regeneration is seen in both the *National Statement and Profile on Mathematics for Australian Schools* (Australian Education Council, 1990; Curriculum Corporation, 1994a, 1994b). The autonomy given to the schools in the mid-1970s and early 1980s in Australia for school-based curriculum development was both inefficient, ineffective, and substantial and widespread changes were required. The need for change came also from the impact of technology, through computers and calculating devices, on how mathematics was being used in industry, commerce and daily life, and the opening up of new fields of applied mathematics. Moreover, the opportunities available through computers for the storage and analysis of large amounts of data required that the ideas of probability and statistics should be taught to all students across all levels of schooling. The move towards a national curriculum in mathematics, as in other areas of the curriculum was perhaps the only way to introduce change effectively. In the late 1980s the Commonwealth Minister of Education took the necessary initiatives to rectify the situation before it was too late.

The work on the development of the *Statement* and *Profile* on mathematics was undertaken with very substantial collaboration and consensus by curriculum specialists, administrators, teachers and teacher educators form across the country. The manner in which the *Statement* and *Profile* were produced is a remarkable collaborative achievement underpinned by scholarly work and research. Nevertheless, the development has been plagued by controversy and beset by fierce contestation in many of the curriculum areas including Mathematics. Unfortunately, there are sometimes obvious shortcomings in the publications produced. However, there seems general agreement that these could and should be rectified, with the profiles made more specific and more useful. While some Australian states would seem not to endorse the *Statement* and *Profile* and examination agencies, supported by university academics whose scholarly domains are under threat, have blocked acceptance of the *Statement* and *Profile* at the highest level of schooling, there is little doubt that the movement towards a national curriculum in mathematics along with parallel development in other areas of the curriculum is established and is a marked advance in Australian education.

The changes that have occurred in this area of mathematics for Australian schools have been inspired and supported by the findings of research and the advancement of knowledge, although research in the fields of the mathematics curriculum and mathematics education was barely recognized as a domain of inquiry in the mid-1960s. The developments that have occurred in Australia are innovative and are a marked advance in a world context with the following key characteristics.

1. The *Statement* and *Profile* on mathematics introduce new content and new skills that arise from advances in knowledge, technology and the changes in the uses of mathematics in industry, commerce and daily life.

2. The developmental sequence of the *Statement* and *Profile* on mathematics order hierarchically both the curriculum content and the learning outcomes in terms of bands and levels in order to attempt to breakdown the former lock-step age and grade structure that existed in Australian education in the mid-1960s.

3. The *Profile* on mathematics that accompanies the curricular statement specifies in detail the performance outcomes for each aspect of the mathematics curriculum in terms that emphasize and guide the assessment of student learning.

4. The *Statement* and *Profile* on mathematics were developed to provide a framework rather than a detailed syllabus and were designed to permit individual students and class groups to progress systematically through an ordered curriculum at an appropriate pace.

5. The *Statement* and *Profile* on mathematics emphasize consistent and regulated learning sequences with (a) an underlying scale of development in mathematics learning and (b) bench marks or standards of performance that should be attained by students as their learning advances.

Some similar developments have occurred in Britain and the United States with respect to the specification of performance outcomes and the identification of attainment levels and bench marks. However, the *Statement* and *Profile* on mathematics forms a coherent and carefully planned curriculum structure for mathematics teaching and learning across all levels of schooling, with a latent scale of achievement to facilitate the assessment of learning and to guide instruction. The tasks and items on the profile can, as a consequence, be validated against a scale of achievement, and content and topics in the statement can be reordered in an appropriate way for instruction and assessment.

THE CONTRIBUTIONS OF RESEARCH

This national curriculum in mathematics introduces into Australian schools many of the findings of research in mathematics education that has been undertaken in Australia and overseas during the past three decades. Key developments that are derived from research involve:

(a) an awareness that all students can learn mathematics, with an increased concern for gender and social equity;

(b) an acknowledgement that attitudes and values associated with the learning of mathematics are of importance, since they not only influence achievement directly, but also influence future participation in mathematics courses as well as the application of mathematics in industry, commerce, and daily life;

(c) an appreciation of the processes of mathematical inquiry, with a recognition that computers and calculators can be used for computation, thereby reducing the emphasis on the learning of algorithms for calculation;

(d) a recognition of the importance of using mathematics during learning, both for purposes of motivation as well for subsequent application to new situations;

(e) an understanding of the importance of the interrelations between educational objectives, methods of teaching, and scaled achievement outcomes in the construction of the *Statement* and *Profile* on mathematics.

It is of considerable interest to examine each of these five domains in which the findings of research have greatly influenced the *Statement* and *Profile* on mathematics and as a consequence the teaching and learning of mathematics in Australian schools. It is, however, important to emphasize that this is only a selection of the relevant research that has been carried out in Australia over the past 30 years in the field of mathematics education.

1. All Students can Learn Mathematics

The studies conducted under the auspices of the International Association for the Evaluation of Educational Achievement (IEA) on mathematics (Keeves, 1968; Rosier, 1980; Lokan et al. 1996, 1997) have identified the effects of gender and social context on learning outcomes in mathematics.

(a) *Gender and mathematics learning*

Leder (1992) undertook a major review of gender differences in mathematics learning from an international perspective. The research evidence shows (Keeves, 1973; Baker and Jones, 1993) marked differences across countries and over time indicating that such differences are likely to be related to the roles of women in society rather than to biologically based factors. Moss (1982) examined the data collected in the First and Second IEA Mathematics studies in Australia and showed that at the lower and middle secondary grade levels gender differences were very small, and that some reductions had occurred with respect to the size of gender differences in mathematics achievement between 1964 and 1978 at the upper secondary school level, where the differences were noticeably larger. Jones (1988) in a follow-up study of the 13-year-old students from the IEA Study in 1978, reported that sex of student as well as attitudes and achievement in earlier grades were found to have noticeable direct effects on participation in both general mathematics and advanced mathematics courses at Year 12 and in subsequent choice of scientific and technological careers.

The debate informed by these research findings together with the findings contained in other reviews of research in the field (Leder, 1984; Barnes, 1988; Leder and Forgasz, 1992; Barnes and Horne, 1996) have maintained interest in the area and supported action research based on the proposition that all students can do mathematics. From the time of publication in 1975 by the Schools Commission of the report *Girls, Schools and Society* (McKinnon, 1975) and a subsequent report a decade later *Girls and Tomorrow: The Challenge for Schools* (Miland, 1985) there have been programs for change to remove all aspects of discrimination associated with gender in schools particularly in the area of mathematics learning.

(b) *Social background and mathematics learning*

Medium size correlations of 0.2 and 0.4 between achievement in mathematics and various measures of home background have been reported from all three IEA Mathematics Studies (Keeves, 1968; Rosier, 1980; Lokan *et al.* 1996). Relationships were also found between social background and retention at school at the post-compulsory grades (Keeves, 1968). Deckers *et al.* (1986, 1991) have also documented the steadily increasing rates of students staying on at senior secondary school levels and undertaking some mathematics courses. Although, there has been a growing expectation that all students should be learning some mathematics at all levels of schooling, Malone (1993) has reported a decline in the popularity of the more demanding mathematics subjects in most parts of Australia. Moreover, Ainley *et al.* (1994) have shown a strong relationship between rates of participation in mathematics-type courses and social background of students at Years 11 and 12 across Australia. More recently Brinkworth and Truran (1998) have investigated the reasons given by students for continuing study or not to study mathematics at the Year 12 level.

Southwell and Khamis (1992) compared responses to attitudinal statements held by primary school students, secondary school students and primary school teachers. They reported that the view that careless errors and a lack of effort contributed to poor performance, appeared to be stronger among secondary school students and teachers than among primary school students. This finding suggested that Australian students would appear to attribute their success more to their efforts, than to their level of ability, a view that is very different from the views expressed by teachers and students in Britain and the United States. Nevertheless, the lower levels of participation and performance of students from lower socio-economic status homes would seem to be an issue warranting attention together with action research programs.

2. Studies of Attitudes and Values

The introductory strand in the *National Statement on Mathematics for Australian Schools* (Australian Education Council, 1990) is concerned with 'Attitudes and Appreciations' and states:

> An important aim of mathematics education is to develop in students positive attitudes towards mathematics and their own involvement in it, and an appreciation of mathematical activity. (Australian Education Council, 1990, p. 31)

While difficulties were clearly encountered in specifying the corresponding facets of the profile in this strand across levels, it is evident that attitudes and values are seen to have a key role in mathematics learning.

The First IEA Mathematics Study provided in 1964 the impetus to undertake an examination in Australia of students' attitudes towards mathematics. This study examined several aspects of attitude towards mathematics with well constructed Guttman type scales (Keeves, 1966). Rosier (1980) and Afrassa (1998) have presented evidence to show, at the lower secondary and pre-university levels, a decline over a 14-year period from 1964 to 1978, in students' attitudes towards the importance of mathematics, but a general increase in attitudes towards the ease of learning mathematics. Subsequently, Keeves, (1972, 1986) developed a scale concerned with liking mathematics and in a longitudinal study of change in mathematics performance during the first year of secondary schooling showed the influence of initial attitudes on later achievement and examined the factors that influenced changes in attitudes towards mathematics and achievement over time. Fraser (1980) has documented a decline in attitudes towards mathematics across year levels in Victorian lower and middle secondary schools, as well as the more favourable attitudes held by students towards mathematics than towards some other school subjects, such as social studies and art.

Research studies in the United States have reported the influence of attitudes of 'avoidance of success' and 'fear of success' on mathematics learning and Leder (1979) in a study of Australian high school students reported the following findings concerned with the learning of mathematics: (a) girls were more likely than boys to attribute sex differences in participation in a career requiring the study of mathematics to external factors than could be modified than to innate ability factors; (b) girls had on average higher levels of fear of success than boys; and (c) girls who chose to continue with intensive courses in mathematics, tended to be relatively low on fear of success.

3. New Technology and the Use of Calculators and Computers

New technology has both directly and indirectly transformed the teaching of mathematics in Australian schools and further change must be expected. The initial impetus for reform at the primary school level came from the introduction of decimal currency in the mid-1960s and the subsequent introduction of metric measures in preparation for the widespread use of calculators and computers.

From the findings of local and international studies, the *National Statement on the Use of Calculators for Mathematics in Australian Schools* (Australian Association of Mathematics Teachers, 1987) recommended that calculators should be used at every grade level in Australian schools. Subsequently, longitudinal research was carried out in six schools in Victoria from 1989 to 1993 into the use of calculators in the early years of schooling involving approximately 1000 students. This work by Stacey and Groves (1996), reported very favourably on the effects of the frequent use of calculators in the teaching of mathematics in the first five years of schooling which supported very clearly the policies and practices advanced in the *National Statement on the Use of Calculators.*

Doig, Carss, and Galbraith (1992) reviewed research into the use of computers in the teaching and learning of mathematics and observed that computers were more readily accepted than were calculators. However, they cautioned that the long-term benefits to be derived from the use of computers were unclear. Subsequently Rowe (1993) prepared a monograph on *Learning with Personal Computers* which addressed the issues involved and examined the research associated with learning through computers especially in mathematics. While the costs of providing computers for schools in less affluent areas raises problems of equity for universal computer usage, as each year passes there is more and more acceptance of widespread computer usage at all levels of schooling.

4. Problem Solving, the Processes of Inquiry and Using Mathematics

The *Statement* and *Profile* on mathematics clearly reject the approach to teaching mathematics as a collection of algorithmic procedures, or a logical system in which logical deduction plays a central role. The approach adopted, while in some places lacking in coherence and consistency, draws on many fields of research concerned with the functions of the brain, the roles of concrete experience and hypothetical thinking, problem solving, transfer and student learning. The findings from many fields of research are drawn together to make the learning of mathematics today very different from the teaching of mathematics that most critics experienced as highly intelligent students in a competitive school climate in which the learning of mathematics was only for the very able. The modern world demands that a knowledge and understanding of mathematical ideas and relationships are required by all who complete 12 years of secondary schooling. Consequently, the development of mathematical competence by individual students must occur in a systematic way across the years of schooling.

It is not possible to name the many scholars and research workers who have contributed to the new vision of mathematics learning that is presented in the *Statement* and *Profile* on mathematics. However, reference must be made to some who have made distinguished contributions and the fields in which they have worked: Piagetian theory (Dienes, 1960, 1963, 1964; Collis, 1975a, 1975b); Information processing theory (Halford, 1978a, 1978b; Halford and English, 1996; Boulton-Lewis et al, 1986; Sweller and Chandler, 1994); Constructivist theory (Leder and Gunstone, 1990; Clarke and Kessel, 1995); and Problem solving (Stacey, 1989, 1992; Rowe, 1985; Lawson and Chinnappan, 1994).

The perspective of modern cognitive science, based on neural net accounts of brain functioning provides a comprehensive view of cognition as situated action and rejects the view that cognition is merely symbol processing (Lakomski, 1999). The internalization of knowledge and the development of understanding from this perspective is built upon situated cognition and interactions with other people and physical systems. The instructional approach and the specification of curriculum content in the *Statement* and *Profile* on mathematics would appear to be developed from such perspectives which are derived from cognitive science and cognitive psychology.

5. A Scale of Performance Outcomes

Underpinning both the *Statement* and the *Profile* on mathematics that have been advanced for the teaching and learning of mathematics in Australia is the view that the learning of mathematics lies along a scale of development. This idea derives in part from the work of Biggs and Collis on the assessment of student learning in terms of the Structure of Learning Outcomes (SOLO) Taxonomy (Biggs and Collis, 1982).

Australian researchers have pioneered several aspects of the use of new measurement techniques to develop a scale of performance that is independent of the items or tasks used in assessment and independent of the samples of individual students employed to calibrate an interval scale (Andrich, 1978; Masters, 1982; Wilson and Adams, 1995). These procedures are not restricted to situations where multiple choice test items with simple right or wrong responses are scored, but extend to the use of constructed response questions in which partial credit is given for incomplete responses and to problem solving tasks where levels of performance are assessed. A further use of these scaling procedures has been to validate and calibrate the mathematics profiles for the different strands in the *Statement* and *Profile* on mathematics (Bailey, Adams and Wu, 1992).

It is the introduction of the idea of scales of development and learning into the statements and profiles in the planning of the Australian curriculum that has made the Australian National Curriculum unique in a world where new curricula are being constructed. These perspectives permit the assessment methods to be substantially widened from formal testing to programs which employ a variety of other methods including observations with detailed records in the primary school, and project work in the secondary school in the learning of mathematics. Work is, however, required to develop further appropriate scaling procedures.

This account of the research in mathematics education as it is today in Australia is highly selective. It is simply focused on what is seen to be the major development in mathematics education in Australia during the past decade, namely the preparation and publication of the *Statement* and *Profile* on mathematics. A remarkably wide range of other research studies has been conducted into the teaching and learning of mathematics in Australia. Time does not permit the presentation of the more complete overview which has been prepared and recently published (Keeves and Stacey, 1999).

There is no doubt that the research in mathematics education in Australia today is rich, varied and useful with some contributions that are both unique and powerful in a world context.

RESEARCH IN MATHEMATICS EDUCATION AS IT MIGHT BE

Research into mathematics education in Australia cannot tackle all the questions to be answered and all the problems that are seen to exist. However, it should maintain a broad coverage of the range of problem situations in order to inform effectively both curriculum planning and development in this country as well as teaching and instructional practice and the assessment of student learning. Moreover, it should build on existing research strengths in Australia, and focus on clearly identified problems, such as youth unemployment and the decline in the relative performance of boys. Furthermore, it should seek to profit from the advances and opportunities provided by new technology. In addressing the question concerned with **What it Might Be**, I would merely wish to draw attention to five areas where I think progress can be made over the coming decades.

1. Catering for Individual Differences

Forty years ago W.C. Radford (1961) drew attention to the problems of the proper handling of individual differences to break down the crippling effects of lock-step grade-level instruction. For a decade the resources of the Australian Council for Educational Research were directed towards this problem until efforts were diverted by policies of curricular freedom and school based curriculum development. Unfortunately, the curriculum guidelines provided by the *Statement* and *Profile* on mathematics are not accepted today in all parts of Australia and individual differences in rates of learning can never be appropriately handled without a coherent curriculum framework, which is too complex a task for individual schools and individual teachers to develop. Moreover, with increased mobility between the states and territories of Australia, there is a need for the curriculum frameworks to be adopted across the country.

2. The Use of Technology in Schools

New technology, including the use of computers, calculators and the Web for information storage and retrieval are no longer future developments. They exist and will continue to exist in classrooms and homes. Moreover, new information technologies will emerge over the coming decades. The issue to be addressed is one of how to use them effectively to (a) promote learning; (b) allow students greater control over their own learning; (c) provide effectively for different learning rates among individuals; and (d) inform students and teachers of new knowledge, understandings and applications as they occur.

3. Investigate Changing Conceptions of Learning

Major advances have been and are being made in the fields of cognitive science and learning theory, with respect to (a) memory and the structure of knowledge, (b) problem solving and reasoning, (c) early learning prior to attendance at school, (d) meta cognitive processes and self-regulatory capabilities, (e) participation in cultural experiences (Bransford *et al* .1999). Not only do these advances suggest new designs for learning environments, but also new modes for effective teaching. Educational research needs to undertake the task of integrating these developments for the advancement of learning. Thus educational research should become an integrative science.

4. Scales of Learning

One of the great strengths of educational research in Australia is the widespread acceptance of the idea of scales of learning, and in particular the development of procedures by which measurements can be readily made using such scales. Further research work is required to advance the effective use of these scales in the statement of curriculum objectives, in the design of teaching and learning experiences and in the assessment of learning outcomes through the curriculum profile.

5. The Study of Factors Influencing Learning and Development

With scales to measure learning and procedures to equate measurements made with different assessment instruments, the monitoring and measurement of student learning and development can be undertaken. Furthermore, analytical procedures have been advanced for the investigation of change in performance over time that go beyond the simple test and retest comparison which has uncertain and unknown reliability. These procedures pave the way for the systematic investigation of the factors that influence change, and student learning and development.

CONCLUSION

In conclusion, the establishment of the Mathematics Education Research Group of Australia opened the door for free and unfettered release and discussion of research results, and for peer assessment of research findings removed from the political control of bureaucrats. MERGA over 20 and more years has supported and widely publicized the findings of research in mathematics education in Australia. As a consequence, the program of research in mathematics education is wide, relevant, vital and with significant impact on the teaching and learning of mathematics in schools. Nevertheless, considerable efforts are required to raise the standards of performance in mathematics of students in Australian schools and to ensure that students at all levels of schooling in Australia are learning mathematical ideas and relationships that will increase their employability, their quality of life and their more effective participation in Australian society.

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