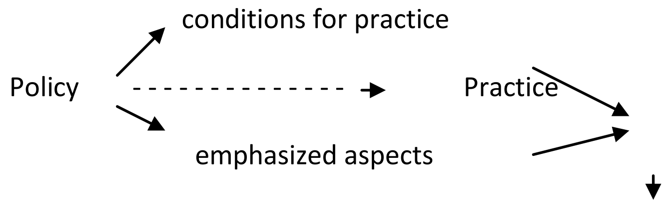
The link between policy and practice in science education: the role of research

ABSTRACT: Policy has been a much neglected area for research in science education. In their neglect of policy studies, researchers have maintained an ongoing naivety about the politics of science education. In doing so, they often over estimate the implications of their research findings about practice, and ignore the interplay between the stakeholders beyond and in-school who determine the nature of the curriculum for science education and its enacted character. Policies for education (and science education in particular) always involve authority and values, both of which raise sets of fascinating questions for research. The location of authority for science education differs across educational systems in ways that affect the role teachers are expected to play. Policies very often value some groups in society over others, as the long history of attempts to provide science for all students testifies. As research on teaching/learning science identifies pedagogies that have widespread effectiveness, the policy issue of mandating these becomes important. Illustrations of successful policy to practice suggest that establishing conditions that will facilitate the intended implementation is critically important. The responsibility of researchers for critiquing and establishing policy for improving the practice of science education is discussed, together with the role research associations could play if they are to claim their place as key stakeholders in science education.

INTRODUCTION

Researchers in science education very commonly study current practices in science classrooms. They also explore new practices that might become part of the wider repertoire of classroom practice. If these research studies reveal shortcomings in present practice or significant improvements in practice, how can such findings be heeded by the policy makers, who set the boundaries of how and what is practised in the name of science education? In what ways should professional researchers be involved? These are issues to be canvassed in this paper.

Policies for education, and for science education more specifically, influence the practice of science education by authorizing some conditions for practice of practice over others, and emphasizing some aspects of the ***What*** and ***How*** of science teaching and learning.



For example,

A policy that classroom learning in science is assessed by an authority beyond the school, using paper and pencil methods, has clearly different effects on practice from *a requirement that requires schools and their teachers to provide and justify this summative assessment internally.*

Under the former policy, those few aspects of science learning that can be assessed externally will inevitably be given greater emphasis. The latter makes possible a wider range of science learnings.

Again, funding policy, as in Scotland and Japan, that gives a school several laboratory technicians, leads to a greater likelihood for hands-on inquiry learning than is possible *under funding that provides no such supporting conditions*

Policy studies have not been high on the agenda of science education researchers for more fifty years. In much earlier times Francis Curtis (1926) published the first of what became six digests of research in science teaching, the **Curtis Digests** (up to 1957), that were intended to influence not only the research community but also practice, although policy was not explicitly mentioned. Certainly, since the 1960s the triad *policy/research/'practice* has attracted only limited attention. Richard White (2001) in the Science chapter of the most recent **Handbook of Research on Teaching** analyzed research studies in science education over several decades. Despite the breadth of his 45 categories of study, policy research was not featured. The same **Handbook** had 51 chapters to cover the whole field of teaching and only two chapters were listed under *Policy Studies* (Darling-Hammond, 2001; Calderhead, 2001) . Neither of these referred to any examples from science education. Darling-Hammond reviewed the efforts to establish standards for teaching, and argued that authorities are in two minds about implementing policies for standards that are effective, because they 'highlight shortcomings in current practices and meeting them requires change' (p.772). Science teaching standards has for a number of years been an issue in which ASTA, the professional association for science teachers in Australia has been much involved (Ingvarson, 1999). ASERA, the research association for science education in Australia has, in contrast, been quite uninvolved.

Two research handbooks, specifically for science education, also yielded blanks about policy research. One edited by Dorothy Gabel (1994) for NSTA and the other by Barry Frazer and Ken Tobin (1998) reflect very well the foci of what our interests as researchers have been, but again neither had a section on policy. In the Frase and Tobin **Handbook** the authors of the three papers on Curriculum Change and Reform remarkably managed to avoid making any reference to the word, *policy*. Finally, in the last two years of JRST, only one paper out of more than 100 addresses policy issues although one guest editorial drew attention to its importance.

It is, no doubt, because of this low profile given to policy issues, that the paper by Miller (2008) on the impact of the state testing and the NO CHILD LEFT BEHIND ACT on elementary science education was an isolated one, and not part of a major symposium at the NARST 2008 Conference despite its theme, *Impact of Science Education Research and Public Policy.*

Glen Aikenhead (2004), one science educator whose research has effected changes to policy and practice in Canada, commented: 'In research we are able to treat policy, practice and assessment as discrete subject fields for study. If research is to contribute to changes in practice, all three have to come together in some orchestrated fashion.' (page 170).

This paper has as its central theme this coming together.

POLITICAL NAIVETY IN SCIENCE EDUCATION.

Science education has a rather spectacular record of naivety about educational policy and politics, and more specifically of the politics of science education itself. Three aspects of our naivety are:

1. development of new Curriculum materials
2. not recognizing the contested nature of Science in the curriculum
3. exaggerating the generalizability of research findings

1. In the 1960s the National Science Foundation in USA and the Nuffield Foundation in England poured hitherto undreamed of financial resources into developing long overdue, new approaches to the teaching of school science. Neither of these countries, at that time, had a national curriculum. Curriculum policy and its implementation were decentralized to more local authorities. The exciting and very expensive development of these new materials for school science thus took place in the absence of any commitment that they would be adopted and used in either country's schools. It was as if the scientists and science teachers working on these projects simply assumed that the sheer quality of their products would ensure their adoption. At the time dinted national pride re the authority and excellence of Science could ensure that substantial funds became available for these projects, but it was delusory to think that the same authority would hold sway in the much more complex worlds of elementary and secondary schooling.

Furthermore, a common educational policy in the USA that required schools, rather than parents, to provide text books was a condition that also weighed in favor of existing commercial texts, like Modern Biology, Modern Chemistry and Modern Physics (cleverly appropriating the perennial adjective "Modern" in the 1940s), rather than the expensive new ones. Indeed, the uptake of these NSF and Nuffield materials was more substantial in a number of other countries and states where centralized curriculum policy existed. In the Australian states of Victoria and Queensland every physics teacher and physics student used PSSC Physics for more than a decade.

Not so long after these materials became available, political sociologists on both sides of the Atlantic (Gintis (1972) and Apple (1996) in USA and Young (1971) and Jenkins (1979) in England) concluded from their analyses that ***these curriculum development projects took place as if school science occurred in a political vacuum***.

Stake & Easley (1978) edited a set of a dozen qualitative evaluations of the NSF's many projects. All too often it was reported in these case studies that these new science materials arrived or were announced in school districts and schools, when reform of their science teaching was not near the top of their agenda of issues to deal with. In that same year, an international meeting in Israel reviewed the wider impact of the new approaches to science education that the NSF and Nuffield initiatives had inspired in many other countries. So many reports of disappointing voluntary uptake and unauthentic adoption were forthcoming that Miriam Ben Peretz and Michael Connelly (1980), perhaps with tongue in cheek, proposed the idea of *Curriculum Potential*. Authentic adoption (or 'fidelity", a current term), they suggested, is not the measure to use about curriculum implementation, but rather the extent to which individual teachers, inspired by something in the new materials or the ideas behind them, may change their practice positively, albeit in ways not predicted by the developers.

2. Researchers and curriculum reformers too easily forget that science and its teaching is one of the most hotly contested components of the school curriculum. Layton (1973) in a genre establishing book described a fascinating tale of political contestation with respect to science in schooling. In this historical study, he takes us into the tensions that arose when a teacher and a science inspector in mid 19th C England tried to introduce some science teaching into an elementary school because of its relevance to the students' future as farm laborers. Engineers and earth scientists were unsupportive because they were busy exposing fossil bearing rocks in the cuttings for railway tracks to crisscross the land. The last thing they wanted was for earth science studies in schooling to involve them in the furor that Darwin's **Origin of Species** had recently created. Then there was shock and resistance to the thought that working class lads may be gaining knowledge that, at the time, was not part of the education of their upper class masters, etc., etc.

The case studies of curriculum issues in science education that have followed Layton's example have confirmed the depth of its contestation among the various stake holders for whom science education is important. The studies by Gaskell (1989) and Blades (1997) in Canada, Fawns(1989) and Hart (2001) in Australia, Jenkins (1979) and Donnelly (1994) in England, Őstman (1996) in Sweden, Lijnse et al (1992) in The Netherlands and Nelkin (1982) in USA, have each extended our understanding of the complex manner in which policy decisions about the science curriculum are made. The tragedy is that they remain far too few and far too sufficiently recognized in the communities of science education research.

In an earlier publlication I used Figure 1 with the six full boxes to schematically present the contested character of the school's science education (Fensham, 1988). Each box represented a demand from society on the education system's science curriculum that I, and others like Fawns (1989), had observed as active in the determination of new science curricula in Australia. Each is a potential influence on what happens in the classrooms within the large circle, and the final outcome of their contestation – usually a compromise - becomes policy with a more or less binding influence depending how tied to external assessment it is.

Insert Figure 1 about here

In the 1960s it was the POLITICAL demand from competition with Soviet Russia that fuelled the efforts of the National Science Foundation and the Nuffield Foundation. In the NSF (1983) explicitly acknowledged ECONOMIC demand in comparing USA with Japan. Currently, China and India fuel POLITICAL and ECONOMIC demands in USA and a number of other countries. the demand from SUBJECT MAINTENANCE is exercised very widely by many academic scientists and conservative science teachers (Fensham, 1993). The top three top demands usually carry much more weight in determining the detail of a curriculum's content and its assessment, than the lower three, CULTURAL, SOCIAL and INDIVIDUAL, which are often given prominence in the preambles to a curriculum as some sort of consolation prize. The science education research community interestingly puts a great deal of effort into studies that relate to the lower three demands. The urgency that is now associated with environmental issues like global warming and the shortage of potable water have such massive political and economic associations as well as social ones that ENVIRONMENTAL demand needs now to be added, poised between the upper and lower regions of the figure.

The interplay of these demands can lead to policies for science education that are very different depending on whether the dominant demand is for the next generation of scientific experts or for the scientific understanding of the public at large. The needs of these two groups in schooling and how they can be separately and together catered for in the curriculum are urgent questions for research.

3. The last naivety is quite rife among science education researchers. It is our tendency to claim more for our research findings than they are possibly worth. Claims of widespread usefulness and applicability are often made in the almost mandatory Implications section of publications. Jenkins (2004) has drawn attention to our failure to acknowledge that the narrow scientism behind much of our work has serious limitations in the face of the complex realities of transferring science education across schools, educational systems, and across countries. For example, a single study, often with cooperative volunteer teachers in a particular context in New Zealand, Israel, Germany or USA, is claimed to have implications for schools and science teachers in unspecified other places. This is a quite unjustified assumption. This is not to decry the worth of these studies as pieces of research, or

as a training in research, but rather that here needs to be some some realism about their generalizability. The critique about curriculum development's naivety above has now become ***much science education research takes place as if school science occurs in a political and cultural vacuum.***

POLICY AND VALUES

Policies in education, as in any other sphere of social life, are operational statements of values. Indeed, as Maurice Kogan (1975) argued, an educational policy authoritatively allocates values. Hence, *values* and *authority* lie at the heart of the link between policy, research, and practice. Two sets of research questions immediately arise when general and specific educational policies and their impact on the practices of science education are considered.

Set 1: Policy as Values

- *Whose values about science education are favored by this policy?*
- *Which stake holders in society have been successful in the shaping of this policy?*
- *Which groups in society will be advantaged and which disadvantaged by the science education practices that flow from this policy?*
- *Are disadvantaged groups favored in our studies of practice and would others be disadvantaged if policy was framed to support our practices?*
- .

Set 2: Policy as Authority

- *Where does authority lie in relation to this policy?*
- *Which stake holders have access to this authority?*
- *Where does the authority for practice lie?*
- *By whom and how is the link between policy and its intended practices monitored?*

These questions are all amenable to research, but this type of research is still very rare in science education. They will often require methodologies that are rather different from the range now commonly used. However, researchers in educational administration and in policy analysis will be familiar with them and, as the science education research community would gain if these other scholars could be persuaded to join us in research on these questions.

THE LOCUS OF AUTHORITY FOR SCIENCE EDUCATION

In 1978 I interviewed a number of persons who had worked on the large scale curriculum development projects in USA, Europe and Australia. From their accounts I was able to argue from their comments that the determining authority for the curriculum in practice in USA, Europe, and Australia was, respectively, the Textbook, the Teacher and the Education System's Curriculum Committee (made up of academic scientists and their acolytes, leading science teachers) (Fensham, 1980).

Much later, in the 1990s, this issue of the location of authority was more thoroughly canvassed in the discussions between researchers in North America and Germany about the role of subject content (see Hofmann and Riquarts, 1995). The spur for these discussions was Lee Shulman's (1986) reference to "content" as part of Pedagogical Content Knowledge (PCK) in his presidential address at AERA in 1985 and his elaboration of it in the years that followed. These discussions were very important in providing a bridge between two different educational traditions that for years had been kept apart. In one there was a tendency to ignore subject content as a research construct or issue, and there was confusion in both by one tradition's use of the German noun *Didaktik* (and its other language counterparts), carrying profound meaning for education, and the other tradition's use of the similarly sounding English adjective, *didactical,* carrying negative connotations about teaching.

With respect to the locus of authority for curriculum and its teaching, these two traditions have some significant differences. For convenience, they can be labeled, AngloAmerican and Germanic. In the Anglo American tradition, schooling is primarily about inducting the learner into authoritatively established bodies of knowledge and their ways of thinking and behaving, while in the Germanic tradition schooling draws on similar knowledge sources but is primarily concerned with the development (*bildung)*of the whole personality of the learner.

For example, Klafki (quoted by Uljens, 1995, p. 322) asks German teachers to address five sets of questions, only the last two of which, the methodological ones, are seriously addressed in science teacher education in the AngloAmerican tradition.

The first set: illustrates both the difference in goal and in expectation about the significance of pieces of science content in science education.

What wider or general sense or reality does this content exemplify and open up to the learner?

What basic phenomena or fundamental principal, what law, criterion, problem, method, technique, or attitude can be grasped by dealing with this content as 'an example'?(page)

In the case of science education, the authority in the AngloAmerican tradition for what is to be taught as science content and how its learning will be assessed is the Education System through a Curriculum and Assessment Authority. This authority in turn accepts the content of the disciplinary sciences as authoritative. Teachers, as agents of the System are responsible for the pedagogy of the teaching/learning. In the Germanic tradition, the Education System defines the purposes of education and the knowledge sources, but expects the teacher to be responsible first for transforming these knowledge sources (*didaktikal analysis*) into content that is meaningful to teach to students, and that will contribute to the prescribed goals and purposes. This teacher is then responsible for the pedagogy, and in a logically consequential way for the assessment of the students' learning.

In cases involving science education within the AngloAmerican tradition an obvious focus for policy research is the *Curriculum and Assessment Authorities* and how it is established by, and operates for the Education System. Conversely the *Teacher* and his/her sense of authority re the content to be taught and learned and the processes of assessment is a place to start in the Germanic tradition.

Calderhead (2001), writing from within the AngloAmerican tradition, exemplified the place it quite often gives to teachers when he quoted from Novick (1996) '*policy makers view teachers as implementers of other people's ideas, without recognizing that they have developed considerable knowledge and expertise of teaching and learning and of the ways that classrooms and schools can and do operate' (p.792).*

An interesting comparison of the role of authority in these two traditions can be found in the reforms of science curricula that occurred in the 1990s following the calls for Science for All in the 1980s. In Australia, as in many English speaking countries, new policy in 1994 defined the school curriculum in terms of Key Learning Areas – English, Mathematics, Science, Languages other than English, Physical Education, Studies of Society and Environment, Technology, The Arts - a number of familiar subjects and subject combinations - into which was fitted what was to be taught and learnt. The subjects became the purpose of schooling and their disciplinary associations provided the authority for the intended content.

In the same year, the Norwegian Parliament endorsed the **Core Curriculum** as a document for education at all its levels. The sections of the **Core Curriculum** do not refer to subjects, but to *The Spiritual Human, The Cultural Human, The Working Hunan, The Socially Conscious Human, The*

Creative Human, The Environmentally Aware Human, and *The Integrated Human*. These are explicit purposes and intentions for schooling as a whole. In some way, they were also intended for science education and all other components of teaching and learning.

The **Core Curriculum** must be the one of the most beautiful educational policy document ever. It is illustrated on every page with color art works, and its language in Norwegian and in English has a resonant cadence, similar to the Bible or Shakespeare. Just two extracts will suffice to illustrate the character and tone of its purposes for education.

- *The aim of education is to expand the individual's capacity to perceive, to participate, to experience, to empathise and to excel.* (p.5)
- *Education must also implant generosity in the face of failure, so that the individual who flounders or falls short is also taken seriously, can be exonerated and begin anew.* (p. 9)

It was personally written and the illustrations chosen by the Minister of Church, Education and Research, a man (earlier a Professor of Sociology at Harvard) among the majority of women in the Bruntland Cabinet. It no doubt embodied values consistent with the social democratic character of this government and, not surprisingly, was replaced a decade later with another core curriculum when a conservative government was elected.

The **Core Curriculum** is curriculum policy at the grand level. As policy for science education it may also take the prize for the least influential policy document as far as science education is concerned. Indeed, the details of what was to be taught in science that ensued, also approved by the Parliament was quite traditional. The gap between the lofty phrases of the Core Curriculum and the classroom teaching of science is so great that it is hard to see how practice could have realistically affected. I became aware of the size of this gap when I was employed in Oslo to search my experience of science teaching in various countries in order to annotate the **Core Curriculum's** pages with examples of science education that could conceivably be connected. Grand level policy about schooling and mission statements for education (now increasingly common in the AngloAmerican orbit) are difficult or impossible to link directly to what happens in the science classroom and their authority can easily become the new justification for the traditional approach to the teaching and learning of science, as largely seems to have happened in Norway.

POLICY AND THE STRUCTURE OF THE CURRICULUM OF SCHOOLING

The AngloAmerican tradition of teaching discrete subjects, the content of which is specified beyond the school fits neatly into policy that presents the structure of schooling in a vertical fashion. The whole of schooling and the science curriculum, in particular, are seen in terms of a vertical structure stretching from Grade 1 to Grade 12 as shown in Figure 2.

Insert Figure 2 about here

This vertical structure readily accommodates long sequences for learning of content knowledge from the major science disciplines (Biological Sciences, Chemical Sciences, Earth Sciences and Physical Sciences) plus some sequenced attention to one or more scientific processes. The type of content for learning is set from top to bottom in a logical, developmental fashion for each science discipline. It is natural, within such a vertically structure, that their will be a recurring research interest in *Scope and Sequence* or in *Progression in Learning.*

This vertically structured view of schooling was evident in the reforms of the science curriculum in England and Wales (DES/WO, 1991), the USA, where influenced by Project 2061 (AAAS) (1993), and in many other countries, like Australia and New Zealand, in the AngloAmerican orbit. This structure also, of course, builds in a high probability of failure at some point up these long ladders for learning , which only an élite group of students will have the stamina and inclination to keep climbing. It quite naturally promotes what Roberts (2007) has recently called Scientific Literacy Vision I – for which meaning is derived by looking inward at the canon of orthodox natural science.

The values ascribed to the conceptual content of the science disciplines in this vertically structured view devalues other intentions for science education, such as that it should meet the differential needs of students as they move through schooling, and the divergence of these needs in the later years of schooling. Its maintenance, throughout all the years of schooling, of conceptual science as the core content also militates against recovery after failure or loss of interest –

Policy-wise the same years of schooling can be conceived as an horizontal structure as in Figure 3. Now each stage can have its own specific curriculum emphases or purpose(s) for science education. The emphases listed in Figure 3 are suggestions only, to make the possibilities clear. The content for learning, the pedagogies to use and the form of assessment, for each stage will all follow from these curriculum emphases. It is immediately evident that this is more conducive to a science education that is primarily about the needs and interests of the learners and how these change as the learners get older. It also is more able to accommodate second chance learning with students re-engaging in subsequent stages when the curriculum's emphasis is different.

Insert Figure 3 here

In the example the early years of science education would be devoted to extending the curiosity young learners bring to school by exposing them to a rich set of natural phenomena. The main aims of this exposure would be to heighten interest in scientific phenomena, to encourage the asking of questions, and through discussion of them to begin to recognize the different ways, including scientifically, they may be explored. This would be a welcome alternative for elementary teachers who now feel obliged to teach answers to science questions their children have not asked and concerning which they themselves are not very confident.

The idea of a curriculum with different curriculum emphases for science education was first suggested by Roberts (1982) and then developed by him in more detail in 1988. It makes very good sense when policy allows such a horizontal view of schooling, and he was able to achieve an implementation of it in Alberta in the junior high school (Roberts, 1995). This horizontally structured curriculum is also more conducive to what Roberts (2007) now calls Scientific Literacy Vision II – for which meaning is derived from the character of situations with a scientific component that students are likely to encounter as citizens. .

The recent 21st Century Science curriculum project in England provides an example of how horizontal curriculum policy can promote students' needs of both Vision I and Vision II, by offering three different science courses to students at the same level of Grades 10/11. The policy of this curriculum requires all students to take one subject, *Science* (of a Science for Citizenship type). In addition, if they wish they can study *Additional Science* (involving more traditional modules of Biology, Chemistry and Physics) or *Additional Applied Science* (emphasizing real world applications of science) (Millar, 2007). The policy for this subject, by involving all students in the mandatory *Science,* neatly avoided the association with low status that has dogged so many other attempts to offer alternative science subjects to the traditional science subjects in the senior years of schooling.

POSITIVE EXAMPLES OF POLICY TO PRACTICE

General educational policy

A number of science education researchers from the University of Maryland and from Monash University were privileged to work with the Institute for the Promotion of Science Teaching in Thailand when that country began in the 1970s its curriculum overhaul, a decade after this had been undertaken in many other countries. As a developing country that had not been a colony, Thailand was interesting and different in its capacity to link policy and practice via the requisite conditions that encouraged faithful implementation (Fensham 1986).

One policy decision in Thailand had a remarkably direct effect on student learning of the sciences. It required that students in the 'science stream' of studies in senior high school to study each of Physics, Chemistry and Biology for three years. As a result, at least in the very large Bangkok metropolitan area in the 1980s, Thai girls and boys were the first in the world to participate and perform equally in Physics (Klainin and Fensham, 1989) while in Chemistry the girls significantly outperformed the boys (Klainin and Fensham, 1987). Again, implementation was further encouraged by the requirement that students taking the other 'humanities stream' also had to take two years of Physical and Biological Science.

When questioned about why these policy decisions had been made, the Thai answer was given: "We heard countries like yours were having difficulty persuading girls to choose Physics and Chemistry, so we made them compulsory along with Biology.

After all, the girls can't perform well if they are not in these classrooms!!

Such a policy of "no choice" in senior high school, although common in a number of other countries, would be impossible in the senior high years in Australia, (and probably in USA) because of the strong cultural belief in "choice". But a policy for wide spread choice in the higher levels of schooling has the inevitable consequence of less choice of courses to study at university and fewer career possibilities. These consequences became very evident through the studies of the girls in science education that were conducted under the encouragement of the GASAT (Girls and Science and Technology) movement in the 19890s and 1990s. Kreinberg and Lewis (1996) discussed the comparative successes and failures that ensued, at the levels of both policy and practice, from the substantial efforts these studies inspired to reduce gender inequity in science and mathematics education in Australia and USA.

Policy for specific pedagogies in science education

One of the paradoxical aspects of relating research in science education to practice is the tradition in many countries, that the pedagogy for teaching/learning is the authoritative domain of the teacher. The "how" of teaching is seen as the teacher's province. Against this important recognition of teacher professionalism stands the fact that much research in science education is about teaching practices that will lead to more effective learning. These innovative studies usually begin between a researcher and one or more cooperating teachers. When positive effects are repeatedly found for this innovation for large numbers of students and in the classrooms of a wider cross-section of teachers, what should be the consequences for other teachers in the education system? Their students are not having the learning opportunities that the innovative classes have. In what senses should policy at the level of pedagogy determine common teaching/learning behaviour? Much inservice or professional development for science teachers is indeed pitched at this level. The advantages of these successful pedagogies can also be stressed in initial teacher education where researchers themselves are teaching. Can or should policy be concerned with making such proven pedagogy in some way mandatory in the classroom and in teacher education?

A case in point was reached in the late 1980s with the many studies in a variety of countries and classroom settings reporting that concept mapping was a very good tool for students to use to consolidate the learning of the relations between science concepts and the links between concepts, experiments and everyday phenomena. In the Australian state of Victoria these findings were pressed so strongly that it became part of the policy for a new chemistry course that all students should be given the opportunity to practice concept mapping. *Concept mapping* became what was called in the state's curriculum a Work Requirement for students, which meant it had to be practiced by all chemistry teachers with their students. The success of practice from this policy was again due to it being supported by peer/peer teacher monitoring of the Work Requirements, that meant there was rapid learning of this new pedagogy by most teachers (Fensham & Corrigan, 1994). Another less contentious Work Requirement in senior Physics and Chemistry was *An Extended Open Investigation,* which also, by this time, had strong research support as contributing to the student's appreciation of the investigative nature of science.

It is probable that some other pedagogies for science education could now be added to *concept mapping* and *open investigations* as having such positive research outcomes in so many contexts that they should be recommended or required for general use by teachers. Could the more international research associations like NARST, ESERA, and ASERA make decisions about what to add to the list, check them with national associations and encourage them to strive to have them recognized in policy? Would a small, but important list of pedagogies emerge?

INTERNATIONAL ASSESSMENTS OF SCIENCE AND POLICY

Currently, there are two very large projects for international assessment of science learning, *Trends in Mathematics and Science Study (TIMSS)* and *Programme for International Student Achievement (PISA)*. Both set out to measure students' learning of science, albeit very differently - conceptually and methodologically. TIMSS is an assessment of intended curriculum learning in science at ages 8 and 14. It is severely constrained by the fact that it needs to include curriculum topics and processes that are reasonably common in the science curriculum of its many participating countries. PISA, on the other hand has a very different charter that requires it to provide information (representative, reliable and valid) to the governments of participating countries about how well 15 year old students are prepared for life in 21st C society in Reading, Mathematics and Science. Thus PISA is not primarily concerned with the students' passive stores of school scientific knowledge and its applications to the familiar or contrived situations so common in text books and school science examinations. It is concerned with what students at age 15 can <u>do</u> with their knowledge of science, from whatever sources, when faced with the situations involving science and technology that commonly confront today's citizens.

To meet this challenging goal the Science Expert Group for PISA has focused on students' ability to actively use their Knowledge <u>of</u> Science and Knowledge <u>about</u> Science in novel situations that are real life examples of science and technology in 21st C society.

The design of the PISA Science test begins with a description of a real world S&T situation or context. The Framework for the design is represented in Figure 4 (OECD, 2006).

Insert Figure 4 here

Three scientific competencies are measured – *identifying scientific issues, explaining scientific phenomena*, and *using scientific evidence.* Each of these competencies is an aspect of the scientific literacy the project has defined as important for its task of measuring the preparedness of students for life in 21st C. These three competencies will in turn be influenced by the students' scientific knowledge and attitudes towards S&T issues. The OECD is primarily concerned with the economy of its member countries. Nevertheless, it Education Division has shown an interest and a willingness, over the last decade, to support aspects of science and mathematics education that are more related to the public's capability in these fields, rather than simply to the supply of the economy's Science, Technology, Engineering and Mathematics (STEM) specialist workforce. This interest began with its project on innovative teaching developments in mathematics, science and technology (Atkin, 1998) and was followed by the PISA project with its clear focus on the science education of all students as future citizens. Contrary to the more traditional view of science learning in TIMSS, the PISA Science project has been able to be pioneering in science education

- in its use of real world S&T contexts as the starting point for its assessment units,
- in defining science ability in terms of scientific competencies,
- in emphasising application of knowledge to novel real situations, and
- in its use of some novel types of assessment items.

Both the PISA and TIMSS projects also collect a large amount of data that is used to derive measures of social constructs relating to the educational context that have been judged likely to influence the students' performances. The management groups of the projects, the I.E.A and the OECD, both claim that their projects, and especially the interactions of these two sets of measures, will lead to policy implications for the participating countries (for example, see OECD, 2007, which has an "implications for policy" in each section reporting findings). Despite the considerable contextual data that each project collects these policy implications of their relations with the findings on science performance remain, in my opinion, of little use to science educators or to national policy makers.

Elsewhere I have discussed the inadequacy of the positivistic paradigm used in both PISA and TIMSS to measuring social constructs as indicators of educational contexts that are assumed to influence science learning, and concluded it has led to little of value (Fensham, 2007). Educational contexts – the target of this aspect of the TIMSS and PISA projects – are not, I argue , the same as educational cultures, and it is the latter that are more important sources for policy implications of these projects' performance findings. In every country the teaching of science (and indeed the whole of schooling) takes place in ways that have a long and firmly established cultural history. It is quite inappropriate to pluck some feature of a higher performing country and imagine it can be simply transplanted into another educo-cultural setting. For example, after the first TIMSS results, there was a flurry of such simplistic comparisons in the USA about that country's relative performance. Almost every issue of

Phi Delta Kappa for several years, for example, carried articles by G.W.Bracey (1997, 1998), which on the one hand derided the worth of the TIMSS study and then took its findings seriously identifying variable in other countries as salvation possibilities for America. A more balanced position was taken by Baker (1997) who argued that the comparisons these international studies reveal are better used as stimuli to reflect on how policies in one's own educo-cultural setting might be responsible for the performance in these international tests and whether different policies could lead to improved performance.

Another limitation of the studies is their failure to be sufficiently specific about national contexts. For example, the relation between the PISA results for scientific literacy in Australia and the index of economic, social and cultural status (ESCS) of the student's family background (one of the more robust of the contextual measures) (Thomson and De Bortoli, 2007). On average, Australian 15 year olds performed very well, but they also manifest a higher socio-economic gradient than some other countries, including those that have higher mean scores. Almost one quarter of the students from the lowest quartile of ESCS background performed below level 2 (out of 6 levels) compared with just 5% of the students from the highest ESCS quartile. At the other end of science performance 26% from the highest ESCS quartile performed at level 5 or 6 compared with just 6% from the lowest quartile. Such results are consistent with a decade of conservative government policy encouraged socio-economic segregation of students. This critical feature of the Australian educational culture was not part of the contextual data collected by the PISA survey instrument. The very recent change in national government has heralded an 'education revolution', and it will be interesting to see if its policies address in any serious way the marked inequity in Australian schooling.

The relative mean performance of the PISA scientific literacies of a country's students can attract more attention than it should, since what PISA is measuring as scientific literacy may not at all be a priority in a particular country's curriculum. Publishing about science, when many other aspects of education are not so publicized, can certainly have a distorting influence. Sjøberg, (2007) and Ogawa (2005) have both made this point and other points about PISA very forcefully for Norway and strongly for Japan respectively. Germany is another country where the impact has been high (Prenzel, 2003), but in many other countries response has been more muted, if any.

A very frustrating aspect of the TIMSS and PISA findings, from policy point of view for science education, is that the variance in students' scientific literacy in many countries is the way the variance in performance is split - 20% *between schools* and 80% *within schools* (OECD, 2007). Students' ESCS backgrounds and schools' resources and conditions account for most of the *between schools* variance, but the much larger *within schools* variance remains quite a mystery, and data that might demystify it has not been collected

RESEARCH TO SUPPORT A CHANGE IN POLICY AND PRACTICE

Calderhead, (2001) pointed out the tendency of policy makers to use products of research when they support their own ideas, and ignore other contributions that research might make Too often they get away with this because this usage is not challenged by the researcher or his/her research community In Australia, findings from the science conceptions research, so popular among science educators around1990, have been used recently to support policy that would include more conceptual science content in the elementary years. Other more recent research findings were ignored that point to this type of science content, so early in schooling, being a cause of the attitudinal malaise about science that now exists.

It is not sufficient to establish from research that an innovation is worthy of policy support. It is equally important that research studies also establish the weaknesses in the implemented practice of the current policy. That is:

CURRENT POLICY	*argument for change*	PROPOSED POLICY
research-based case of its inadequacies	→	***research-based case for its positive prospects***

Queensland, is an educationally interesting state in Australia because it is the only one without a common state wide examination for graduation from high school - a critical point for university entrance and employment.   Accordingly, it is the only state in which, when dissatisfaction with an existing subject curriculum has reached a certain level, a decision to trial an alternative curriculum in some schools can be made..

2007 was the end of a several year of for a *Context-based Chemistry* and a *Context-based Physics* course for Years 11 and 12 in a small, but significant fraction of Queensland schools. When these trials were evaluated, not surprisingly, it was noted that he trial teachers had experienced a number of difficulties in teaching the new approach. On the basis of this evaluation it was recommended that the trial courses be abandoned. In other words, the dissatisfactions with the mainstream courses, the original reason for these trials, were now forgotten. Only strong reminding of these dissatisfactions staved off a policy of abandonment and a slower approach to the context-based teaching of these sciences is now policy for all schools.

LINKING POLICY OPTIONS TO RESEARCH

Early in 2007 I was asked by UNESCO to prepare a Draft Policy Options Paper for the World Conference of the International Council of Associations for Science Education (ICASE), the umbrella organization for bodies of national science teachers like NSTA. I decided to take a number of contemporary issues in science education that were affirmed as important by curriculum policy advisers across a number of countries as either current points at issue or ones like ICT, assessment and elementary science education for which significant funds for development are being spent. Each issue was briefly outlined from the national contexts – both more developed and less developed - with which I was familiar, including the associated inadequacies that have been identified. The issues were each so multi-faceted that that no single research study could possibly be quoted as definitive, about either the status quo or change in it that could justify a policy shift. Nevertheless, by drawing widely on the research literature, it was possible to come up with a set of findings that, together, could be made into a case for the inadequacies in present policy and another case for positive prospects from policy changes. In the Draft Paper the likely advantages and the probable disadvantages that went with each policy option were set out. Policy makers are not researchers so they are not impressed by long lists of references. The case for change, and the case for any proposed policy options, need to be made forthrightly in plain prose that can, under questioning, be supported by relevant research studies.

In an excellent process at the World Conference the 1200 delegates were able to comment on this Draft Paper, and the 100 or so who were more involved in science education policy and curriculum spent a day critiquing it in small groups. There was strong advice that the advantages and disadvantages that could follow from each policy option be listed, together with the concomitant changes in conditions that would be needed to encourage implementation of the new policy as intended. Too many policies, it was universally agreed, have been announced and failed to have impact, because these concomitant changes in condition have not been recognised or supplied.

The revised document is thus based on:

argument

CURRENT POLICY *for* **PROPOSED POLICY** *conditions needed*

change *for implementation*

research-based case ***research-based case***

of its inadequacies ***for its positive prospects***

and has been published by UNESCO (Fensham, 2008) covering the eleven issues in Table1

Table 1. Science Education Policy-making
eleven emerging issues

A. Access and equity in science education
B. Interest in and about science
C. Science in school and its educational purposes
D. How Technology relates to Science in education
E. The nature of science and inquiry
F. Scientific literacy
G. Quality of learning in science
H. The use of ICT in science and technology education
I. Relevant and effective assessment in science education
J. Science education in the elementary years
K. Professional development of science teachers

While UNESCO cannot compare with the OECD or the European Union as an influence on policy in more developed countries, it is a major source of ideas and support for change in the more developing world. In many of these countries research studies, even those that are locally based, are not readily available and so summaries of this type are particularly useful.

RESPONSIBILITY FOR LINKING RESEARCH TO POLICY

Policy in education, and in science education more specifically as Jenkins (2001) has argued, involves more than positive research findings. On the other hand, policies in education are often made on grounds that ignore research or not uncommonly actually fly in the face of research findings. In considering where responsibility lies for drawing attention to these discrepancies, lessons can be learnt from other professional fields. In Law, Engineering, Medicine, and Agriculture there are ongoing means, through policy sub-committees, for the professional organizations to be alerted to proposed and actual new policy formulations and to critique them against agreed criteria that emphasise research.

Foremost among our criteria, as science education researchers should be our research knowledge, and what it points to as likely, albeit not certain, outcomes of existing and proposed new policies. Because of our symbiotic relationship with science teachers, another criterion should be the impact policies have on the status and quality of science teachers.

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An overarching question could be: *What will be the likely consequence of this policy on the quality of science teaching and learning?*

This question is not something an individual researcher can easily undertake. Nor is it really appropriate for one person to draw up the research-based cases needed to recommend a shift in policy. Each policy or proposed policy involves the findings from a number of studies, and are more likely to be substantial and convincing, when drawn up by a group of researchers than by any single researcher. An exemplary model for effective policy action is the compilation by a group of researchers in England of the publication, **Beyond 2000**, a short but powerful report on the problems that had been found in the implementation of that country's first national curriculum for Science and what could be suggested amore promising way forward (Millar and Osborne, 1998). As direct consequences of this action, very significant funding for developing alternative science curricula and materials and for professional development have been made available.

In the USA a guest editorial in **JRST** by Abder, Atwater and Lee (2006) drew attention to the need for a similarly research-based report that would guide policies for reducing the science achievement gaps in urban schools. This raises the question of how the production of such policy commentary can be more permanently constituted. Research associations, such as NARST in USA, ESERA in Europe, ASERA in Australia and New Zealand and KARSE in Korea and JARSE in Japan. are obvious possibilities for establishing a Standing Committee on Policy.

The terms of reference for these Standing Committees could include:

1. *set criteria, based on research findings that have a probability to predict likely outcomes from any suggested or established policy in education or in science education specifically*
2. *monitor existing policies with respect to their role in facilitating or inhibiting quality science education, and recommend review or amendment where inhibition is found*
3. *scrutinize any proposed new policies from the viewpoint of their likely impact on the quality of science education, and which groups of learners in society are most likely to benefit and which will be further disadvantaged*
4. *proactively choose each year one or two large issues in science education, bring to bear on them the relevant research studies and, on that basis, propose new policies that could move these issues on.*
5. *have the power to co-opt temporarily researchers with expertise in relation to a particular policy or issue.*

The Committee on Policy would then recommend any matters for action to the Association's Board, submit an annual report to the Association, and be responsible, in relation to its chosen special issue, for a Symposium at the annual conference that illustrates the ways in which research can be related to policy. Simply establishing a Policy Standing Committee will, however, not be enough. It must demonstrate itself to be become part of the policy making process itself. It must first demonstrate its worth and ability by preparing and distributing widely a short but powerfully supported report on the operation of an existing policy situation. Secondly, it must position itself by association with a body to which the policy makers are already attuned. For example, the Australian Science Teachers Association was skilful in locating its national executive officer in the Academy of Science building in Canberra and are now regular involved in policy discussions.

Penny Gilmer (2007), in her presidential statement, was eager to bring the issue of policy making before the NARST community at its annual conference in 2008 in Baltimore. The success of her and other key persons' efforts is already evident with the NARST Board deciding that its Policy and External Relations Committee to take on such a more proactive role and that its journal's editorial policy should encourage publication of policy research papers.

This example in USA is a promising start to the science education research communities around the world catching up with our close professional colleagues in the Sciences and Engineering, who expect to have their research heeded. They and their organizations have a record, even when unwelcome, of challenging public policy when it flies in the face of their established work. As research communities who value our own research, it is time to explore how it can be used to influence policy, and hence, the practice of science education.

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