Describing and supporting effective science teaching and learning in Australian schools - validation issues

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Abstract

The Science in Schools Research Project is a major Victorian government initiative aimed at developing a model whereby schools can improve their science teaching and learning. A consortium led by Deakin University has been working with an expanding number of primary and secondary schools across the state, supporting them in developing new initiatives in science, and monitoring the impact on school and classroom practice, and student outcomes. The research effort underpinning the project has included the development and validation of a set of components (the SiS Components) describing effective science teaching and learning, and of a school and teacher change strategy by which these can be implemented. The paper describes the research process by which the SiS Components have been developed and refined, and the different means by which they have been validated.

Introduction

The Victorian Government has identified science and technology as a major focus within its development strategy, and this has led to a major set of initiatives on science in schools, drawing on a considerable resource base. The policy of the government is to embed these initiatives within a comprehensive research framework. Indicators of the need for a focus on science teaching and learning include concern with student results in statewide testing including the TIMSS test, concern with declining interest in science over the years 7-10 and falling numbers taking senior science subjects, and concerns about teacher beliefs and knowledge, and classroom practice, arising from a large scale baseline survey of science teaching across the compulsory years (Gough et al., 1998). The Science in Schools (SiS) Research Project is a central constituent of the Science in Schools initiatives developed by the Victorian Department of Education, Employment and Training (DEET). The purpose of the SiS Research Project is to develop and trial a model for improving science teaching and learning in Victorian schools. The SiS Research Project is funded by DEET and run by a consortium managed by Deakin University.

During 2000 and 2001, the Deakin-based research team has been working with primary and secondary schools in each region of the State, and has developed an approach to the improvement of science teaching and learning which has two major features:

- The SiS Components, which provide a framework for describing effective science teaching and learning, and
- The SiS Strategy, which is the process by which schools can improve their science teaching and learning.

These features sit within a theoretical framework characterised by the SiS School Improvement Model. This model focuses on whole school improvement, and is closely related to other initiatives within Victorian schools. It draws particularly on the literatures dealing with science professional development, and whole school change (eg. Baird & Mitchell, 1986; Bell & Gilbert, 1996; Fullan, 1996; Hoban, 1997; Franke et al., 1998; Hall & Hord, 2001). In particular it utilises the design elements of the Hill-Crevola General Design for Improving Learning Outcomes (Hill & Crevola, 1999; Hill et al., 2000). The major features of the strategy relate also to the Concerns Based Adoption Model of Hall and Hord (2001).

The SiS Strategy provides flexibility for schools and teachers to plan and implement initiatives based on the particular needs of the school, within an overall framework provided by the SiS Components. The Strategy supports school science teams to identify and capitalise on their strengths and experience, and to channel the enthusiasm many students and their families have for science. In 2000 the project team worked with 27 schools to develop, refine and validate the strategy and the SiS Components. In 2001 we have worked with 126 Victorian primary and secondary schools, and the number will rise to 225 schools in 2002. In each school involved in the project, a 'SiS Coordinator' (larger schools support more than one coordinator) is provided with time release to plan, to work with teachers in developing ideas and materials or in classrooms, to manage the change process, and to work with the Project Team to implement a testing and monitoring program. Each school has access to funds to provide teachers of science with time release to plan, monitor and refine strategies, and to participate in professional development. The SiS Coordinator in each school is supported by a Consultant who visits regularly, provides input on a negotiated basis, and is in regular email contact. A website (www.scienceinschools.org) delivers support material. Currently, a professional development program is being devised to explicitly support the project, and also a training program for coordinators.

This paper will focus on the research methods by which the SiS Components were developed and the different senses in which they are being validated.

Describing effective science classroom practice: the SiS Components

It was important, at the outset of the project, to identify what we understood as effective teaching and learning in science, and describe it in a form that would guide teachers and schools in improving their practice. The SiS Components were developed at the beginning of the project to represent a core vision that drives teaching and learning practice. They continue to be refined and interpreted through use.

There have been many approaches to the definition of effective science teaching and learning that are described in the literature. However, we felt that none of this work is sufficiently broad to deal with the complex concerns we were addressing, nor sufficiently explicit to drive a focused change process and to allow us to track this change. The starting point for our development of the components was, nevertheless, our knowledge of previous work, including:

Studies of school programs and questionnaires regarding classroom practice have been used in the US (eg. Yager & Penick 1984, Penick & Yager 1986, Brunkhorst 1992). These tend to have focused on the very top, 'exemplary' programs and teachers and produce only broad descriptions of their characteristics.

Direct studies of actual 'exemplary' classrooms provide valuable data (Tobin & Fraser 1998, 1990). These can tend to focus on classroom management principles, although in some cases quite sharp insights are generated, as with Treagust's (1991) comparison of two exemplary biology teachers with very different styles.

Another approach, seen particularly in the development of science teaching standards (eg. NSES 2000; National Science Standards Committee, ASTA, 2000; Goodrum, Hackling & Rennie, 2001) is to develop descriptors of effective teaching by workshopping ideas with leading science education professionals. This approach became one part of our own development of the SiS Components.

In recent years there has been considerable research into the nature of student learning in science, and students' conceptions. This has led to the development of constructivist / conceptual change teaching approaches which have gained broad acceptance in the literature as being effective (Wandersee, Mintzes & Novak, 1994; Duit & Treagust, 1998). The PEEL project (Baird & Mitchell, 1986; Baird & Northfield, 1992; Mitchell, 2000), highlighting the importance of metacognition in learning, arose out of this literature. This substantial literature has a lot to say about effective teaching and learning in science, although its focus tends to be on the conceptual, rather than attitudinal or broader cultural aspects of teaching and learning.

In Victoria as elsewhere there has been considerable concern about the declining interest in science across the middle years of schooling. The strategies developed to counteract this, for instance in the Victorian Middle Years Research And Development (MYRAD) project, focus on student engagement and autonomy, higher order thinking and learning, and relevance. These principles have influenced the way the SiS Components have been developed.

Starting with this background work, we set about developing a framework to describe effective teaching and learning in science, that would represent the core project innovation. The stages in development of these components were:

- *Preliminary categories describing quality school science practice were* *developed in a series of informal workshops within the project team, drawing on our previous research, and our knowledge of the broader literature described above;*

- *These were used as the basis for a telephone (in some cases face to face) interview schedule to explore the practice of teachers and schools with a reputation for effective science teaching. These were selected using a combination of school science performance on statewide tests, and peer reputation using informal networks;*

- *Initially 12 (and ultimately 19, including interstate) teachers were interviewed, and the data analysed to identify key components which seemed to stand out in all or most cases. This process involved a range of team meetings, as well as a reference group of science educators.*

The SiS Components have been successively refined during the project, based on teacher response and also on analysis of data from a Component Mapping process, described below, which tracks changes in teacher classroom practice. Some components have been split into sub-components in this process, to provide a more explicit account.

The SiS Components are shown in Figure 1. A fuller description, including examples, can be found on the project website. We believe the value of the SiS Components lies in the breadth of the vision of effective teaching and learning they offer, and the specificity of the descriptions.

Figure 1: The SiS Components of effective teaching and learning in science

In classrooms that effectively support student learning and engagement in science:

1. *Students are encouraged to actively engage with ideas and evidence*
   Students are encouraged to express their ideas and to question evidence in investigations and in public science issues. Their input influences the course of lessons. They are encouraged and supported

to take some responsibility for science investigations, and for their own learning.

2. *Students are challenged to develop meaningful understandings*
   Students are challenged and supported to develop deeper level understanding of major science ideas and to connect and extend ideas across lessons and contexts. They are challenged to develop higher order thinking, and to think laterally in solving science based problems.

3. *Science is linked with students' lives and interests*
   Student interests and concerns are acknowledged in framing learning sequences. Links between students' interests, science knowledge and the real world are constantly emphasised.

4. *Students' individual learning needs and preferences are catered for*
   A range of strategies is used to monitor and respond to students' different learning needs and preferences, and their social and personal needs. There is a focused and sympathetic response to the range of ideas, interests, and abilities of students.

5. *Assessment is embedded within the science learning strategy*
   Monitoring of student learning is varied and continuous, focuses on significant science understandings, and contributes to planning at a number of levels. A range of styles of assessment tasks is used to reflect different aspects of science and types of understanding.

6. *The nature of science is represented in its different aspects*
   Science is presented as a significant human enterprise with varied investigative traditions and constantly evolving understandings, that also has important social, personal and technological dimensions. The successes and limitations of science are acknowledged and discussed.

7. *The classroom is linked with the broader community.*
   A variety of links are made between the classroom program and the local and broader community. These links emphasise the broad

relevance and social and cultural implications of science, and frame the learning of science within a wider setting.

8. *Learning technologies are exploited for their learning potentialities*
Learning technologies are used strategically for increasing the effectiveness of, and student control over learning in science. Students use information and communications technology (ICT) in a variety of ways that reflect their use by professional scientists.

Using the components to monitor teacher practice: the Component Map

In a school change project such as this, it is essential to monitor the extent and pace of implementation of the innovation, namely a change in classroom teaching and learning in line with the SiS Components. The casting of effective practice in the form of components allows this to happen through the vehicle of the Component Map, which measures the classroom practice of individual teachers against each of the eight components. These are in essence 'Innovation configuration maps' (Hall & Hord, 2001).

The sensitive integration of the development and research aspects of the project has been a central concern for the project team. Teacher change cannot be measured in a way that is seen as invasive or judgmental, and any monitoring must further the developmental aspects of the project. The component mapping process has proved to be extremely effective in balancing these dual needs.

For each component (or in some cases sub-component), descriptors have been developed of classrooms operating at four different levels. Each teacher is interviewed by the SiS coordinator and together they agree on the word description for each component that best applies to their current practice, thus giving them a score on a 4 point scale. The role of the SiS coordinator is to probe the teacher to move the measurement beyond a superficial response, to a thoughtful consideration of their teaching practice.

The mapping process has proved very successful in providing a measurement of classroom practice that would enable the tracking of change, and also in establishing classroom teaching and learning as the core business of the project, and encouraging teachers to begin a process of reflection on their practice, and change.

Validation of the SiS Components

There are a number of ways in which the project has gone about validating the SiS Components and in this paper I will describe these different forms of validation and how they relate to the different purposes of the components. Some of these forms of validation involve the Component Mapping process, for which a separate validation issue exists concerning whether it adequately measures science classroom practice. These different validation issues are discussed as responses to a series of questions. The first four questions relate to the extent to which the components comprise a defensible description of effective teaching and learning in science. The fifth question relates to whether they fulfil their purpose as vehicle for supporting improvement in science teaching and learning.

1. *Are the SiS Components plausible as a description of effective science teaching and learning?*
   This is an issue of 'face validity', and the evidence is necessarily anecdotal. The SiS Components have achieved wide acceptance within schools, and have been acclaimed by SiS consultants working with them. Some of the university-based consultants have used the Components in their teacher education programs. Some schools are using the Components in other learning areas. One of the dangers in describing effective teaching and learning is that the descriptions can be so general as to be unhelpful. We have continued to develop explicit interpretive descriptions for each of the components, to clarify and sharpen their meaning.

2. *Do the Components align with the literature on teaching and learning in science?*
   A comprehensive search of the literature dealing with effective science

teaching, student learning, major curriculum reform projects, and teaching standards, was undertaken (Tytler & Waldrip, 2001). The Components were found to align strongly with the literature. Where a component was not well represented in the mainstream science education literature, its inclusion could be justified by other research literatures, or by contemporary concerns such as those associated with the Middle Years of schooling.

3. *Do the SiS Components adequately capture the practice of the teachers from whom they were developed?*
   In a 'reverse validation' process, nine of the primary teachers who had been originally interviewed as effective practitioners agreed to undertake the Component Mapping process and also to comment on how well it, and the case descriptions generated from the original interviews, matched their practice. The result vindicated our analysis, with the mean score on each component exceeding 3.2 out of a possible 4 (and exceeding 3.5 on 'meaningful understandings'). These teachers all claimed to be comfortable with the Component Map as allowing them to represent the core of their practice.

4. *Do the components support the generation of a reliable profile of the practice of individual teachers?*
   Examination of patterns in teacher highlighting of phrases within the component map, and discussions with SiS Coordinators involved in the interview process, exposed some ambiguities in descriptions, and the existence of separate dimensions in some components. This led first to the separation of the original Component 1 describing the classroom learning environment, into the first two components listed above. These have recently been further separated into three sub-components each. The language has also been tightened. A selected sample of Coordinators, following trials of the modified map, provided confirmation that this clarified the mapping process and led to more reliable descriptions of teacher practice.

5. *Are the Components effective in supporting the change process?*

Part of the evidence for effectiveness is anecdotal, based on numerous presentations by SiS Coordinators in workshops in which they represent significant initiatives their schools have undertaken in terms of the SiS Components. An examination of responses from a review questionnaire showing the pattern of initiatives undertaken by schools confirmed that each of the Components is well represented. Component 1 (engagement) stood out as a core focus overall. The patterns of use were different for primary compared to secondary schools.

Other evidence of the effectiveness of the Components and Component mapping came from the same questionnaire sent to all schools following the development of draft Action Plans. Table 1 shows mean scores for the Component Mapping aspect of the auditing process, and for the SiS Components. For each process coordinators were asked to "rate each of the following aspects of the strategy in terms of its usefulness in framing the direction of the innovation in the school". The results show a strong acceptance of the Components and the Component mapping.

The scoring system was:

Score	4: Of critical importance;	3: Very useful;
	2: Somewhat useful;	1: Not very useful

Table 1: Perceived importance of aspects of the SiS Strategy

Aspect of strategy	Mean (Primary Schools)	Mean (Secondary Schools)
SiS components as part of the support structures	3.3	3.3
Component mapping as part of the auditing process	3.4	3.1

Comments on the mapping process in formal and informal reports from schools, and field notes taken at workshops, support the finding that this is an extremely valuable part of the auditing process, with the following effects:

- Evaluation of teachers' current practice - "identifying teacher strengths and areas that they would like to improve on";
- Providing ideas and a clear direction and a focus for discussions leading to the school action plans - "the SiS components and mapping tools provided clear direction and wonderful ideas";
- Encouraging a more thoughtful approach to teaching and learning, and raising teacher awareness of the basis of the project. The mapping "allowed teachers to identify and be open about their limitations and expertise"; and
- Encouraging the development of a shared vision of science.

Coordinators used the mapping process to gain insight into teacher practice which helped them extract common concerns and issues that could feed into the school action plan, but also to shape their response to individual teachers as the project developed. There were a number of stories of the development of new classroom strategies immediately following the mapping process, as recognition by teachers of gaps in practice acted as a catalyst for change.

Validation of the Component Map as a monitoring instrument

Even if the SiS Components are accepted as a valid description of science teaching and learning, effective in supporting improvement in practice, there is a further question as to whether the Component Mapping process provides a valid measure of the practice of individual teachers. The questions below focus on this validation issue.

1. *Do Coordinators believe the interview process provides a valid description of teachers' practice?*
Given that the Component Map measure is based on an interview between colleagues, there is a possibility that teachers may judge their practice superficially, and either under or overrate themselves on particular components. There is also an issue with learning to use the

language of the Component Map. We suspect, for instance, that the November component mapping result is more reliable than the April result since in the first year of the project it took some time for coordinators and teachers to come to terms with the meaning of the components and arrive at an agreed language.

In February of the second year each coordinator was interviewed as part of a verification exercise, to elicit their opinion on the validity of the scores they had negotiated with each teacher. Table 2 gives the percentage of scores judged by SiS Coordinators to be high, appropriate, or low. It can be seen that there is a high degree of confidence in the results. The component mapping process, like many monitoring instruments, needs to be learnt and understood, and this takes time. We believe it will become more reliable over time as coordinators and teachers become more familiar with it and develop a shared language and experience surrounding it. For the third year of the project we are designing a training program for coordinators, that will focus on component mapping amongst other things, and a PD program for teachers to clarify the meaning of the components.

Judgment of validity. Were the scores:	Primary teachers (N=230)	Secondary Teachers (N=203)
High?	6.5	9.9
Appropriate?	80	76.8
Low?	13.5	13.3

Table 2: Validity of the March 2001 Component Map

2. *Do the Component Map results align with student views of the classroom?*

   A student attitude survey administered in April and November has items that relate to each component so that teacher and student judgments about how well each component is represented can be aligned. This analysis is currently under way.

3. *Do differences in the Component Map results reflect reported differences in the practice of primary and secondary teachers?*

An interesting outcome of the component mapping process is the comparison it allows between the classroom practice of primary and secondary teachers. Figure 2 shows this comparison based on the November 2000 mapping exercise. A score of 3 or more on any component is an indication of good practice on that component.

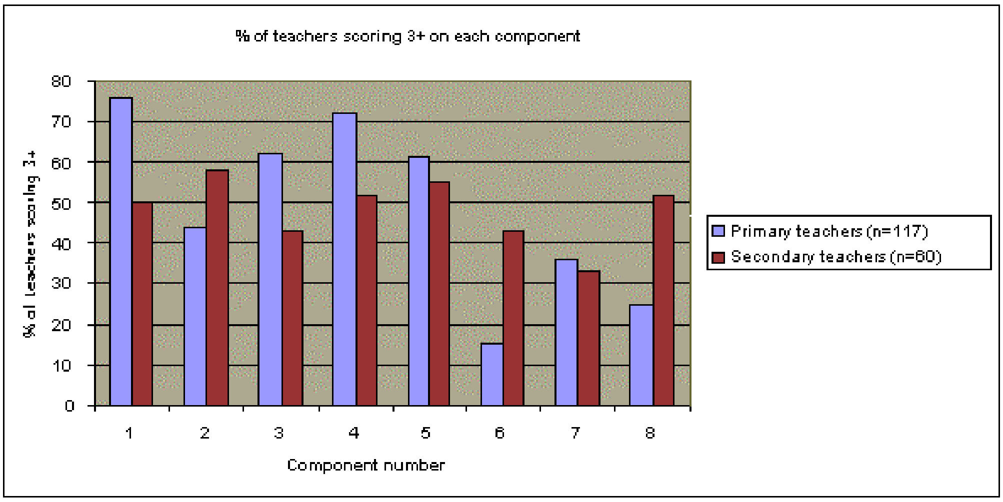

Figure 2: Comparison of primary and secondary teachers component map profiles

Primary teachers, who were found on a state wide survey (Gough et al. 1998) to exhibit a wider range of pedagogical practices, and who for reasons of organisation tend to develop closer personal relations with their students, scored higher on student engagement, catering to student lives and interests, catering for individual differences, and community links. Secondary teachers scored higher on meaningful understandings, denoting a greater emphasis on science concepts, use of ICT, and aspects of the nature of science. The latter is possibly due to a perceived inappropriateness of this component for primary school children, and also limited experience of the different ways science can be represented in primary school classrooms.

4. *Do the results align with other evidence of changes in classroom practice?*

An analysis of the change scores for each school, on each component, was scrutinised by members of the research team who had close knowledge of the schools. The scores were judged to reflect the different commitments of each school. The picture presented by the component mapping, and from the school reports and anecdotal evidence, seemed reasonably consistent.

5. *Do the Component Map scores align with differences in student achievement and attitude outcomes?*
   At the beginning and end of the year for schools entering the project, and at the end of subsequent years, all students in selected year levels undertake multiple choice achievement tests and an attitude survey. The component mapping exercise took place in the 27 Phase 1 schools in April and November 2000, and in Phase 2 schools in March 2001. Each teacher was identified by a code which was matched against their classes, so that links with student attitudes and outcomes could be made. If we can demonstrate statistically significant links between component mapping scores and student attitude and achievement outcomes, then this will demonstrate the validity of both the Components, and the Mapping process.

Teacher component map scores were linked to the November student achievement testing results. Based on the mean scores from the November component mapping exercise, students were separated into two groups. The first group comprised students who were in a class with a teacher who was measured to be high on the SiS components ('high-SiS' classes). The second group comprises students who were in a class with a teacher who was measured to be low on the SiS components ('low-SiS' classes). Three broad patterns emerged from the analysis.

- Early years (Prep-2) students in high-SiS classes grow at a faster rate than students in low-SiS classes.
- In the middle and later years of primary schooling (Yr 3 - Yr 6) and the first year of secondary schooling (Year 7), students in high-SiS classes were already outperforming students in low-SiS classes as early as April. Both groups of students then demonstrated growth with students in the high-SiS classes either showing slightly faster growth than students in low-SiS classes, or at least maintaining the

differential.

- In years 8-10 the picture became very complex, with no discernible pattern of advantage of high-SiS over low-SiS classes, and with results in general showing no consistent growth between April and November. This was due, we believe, to difficulties in secondary schools with the web based test regime we put in place in November. We expect to generate more reliable analyses from the November 2001 testing.

The testing of new schools in March-April 2001, which was intended to produce a baseline for comparison of results, again showed considerable influence of the teacher on achievement scores. Students in high-SiS classes achieved at a level 8-12 months in advance of students in Low-SiS classes, across the primary school years and to a lesser extent in Year 7. There was no discernible evidence by March-April of the effect of high SiS teachers in Years 8-10.

Discussion: Issues of methodology

In a large and complex project such as this, the methodological approach is inevitably eclectic. In a sense, the project has moved beyond the 'methodology wars', utilising qualitative methodologies for developmental and for evaluative purposes, and quantitative measures based on interpretive criteria or on test scores. The project as a whole is situated within an action research design. Hence, the approach and research methods are a state of continual refinement, and the research findings could be seen as perpetually provisional.

The use of the component map as both a developmental and a monitoring instrument is one example of the tension created by the dual intervention/research nature of the project. As the paper has described, this led to complexities in validation that may have been circumvented in a more controlled, small scale research environment. There are other tensions inherent in conducting research in an environment where there is continual pressure on time, and where procedures are varied as greater insight is gained, greater resources made available, and the model extended to an increasing number of schools. Scale is a major determinant of both the change model, and the evaluation methods. Further complexities relate to the political nature of the project, and the need to balance the requirements of the funding agency against our own requirement to take a critical and complex stance in relation to purposes and outcomes. What do these issues mean for description of effective science teaching and learning?

The provisional, political nature of the components

It is not possible, in any account of science classrooms, to capture reality. The classroom must be conceived of as a site that affords multiple interpretations (see, for example, Clarke, 2001). Any attempt to describe effective teaching and learning must involve decisions about the level of description, what aspect of practice are to be focused on, and where the emphasis is to be put. The validity of the SiS Components, described thus far, must therefore be regarded as partial and provisional. That is why the question of purpose is central.

The SiS Components, looked at coldly, contain nothing that a careful reading of the literature may not have uncovered. Their strength lies, however, in the way they have harnessed significant themes to a particular purpose:

- their explicitness that both clarifies practice and enables monitoring and hence empirical validation;
- their recognition of a broad range of science education literatures, beyond the purely conceptual;
- their embedding in recognisable and demonstrable effective practice;
- their explicit challenge to transmissive teaching approaches; and
- their framing in terms of classroom and learner, rather than teacher characteristics.

The strength of the SiS Components lies, therefore, in their political nature rather than in their representation of any fundamental new truths about teaching and learning. It could be argued that the SiS Components to some extent represent a status quo view of teaching and learning, being derived from current practice and consistent with the literature. However, the extent to which they have challenged teachers in the project to shift their practice attests to their power in supporting change. What is status quo for a reader of the literature is very different from the status quo in schools. For a project such as this, the challenge is not so much to uncover fundamental learning principles, but to find an expression of these which serves the particular purpose. The tension, however, between the need to provide a proven framework, and the need to encourage innovation, has been a constant planning issue.

The level of description

A choice we had to make within the project concerned the level at which effective teaching and learning is described. The SiS Components, with their interpretive documentation, are pitched at a variety of levels, to try to cater for the twin demands of explicitness and lattitude for individual variation. There are two concerns with this level of description. Firstly, there may be some deep seated beliefs that underlie the components that should be made more explicit, and we have been attempting to address this through a more careful alignment with the research literature, and by a reanalysis of the original interviews to uncover broader themes.

Secondly, there is a concern that even carefully structured teacher self reporting may either misrepresent actual practice, or may miss something more fundamental that underlies the Components. Our plans for 2002 include finer grained analysis of classroom teaching and learning, to align the Component Map results with observations of classrooms, interviews with students and teachers, and student achievement results from a wider range of assessment instruments.

Practicalities and politics

Both the time frame within which the project has worked, and the political background to the project, has created issues with the framing and validation of the SiS Components. For instance:

- The need to act often requires decisions to be made, advice given to schools, or documents and monitoring instruments produced before we can carry out the full analysis which would normally be expected of such research.
- The speed with which instrumentation is required, and the scale on which testing is carried out, has impacted considerably on the nature of the tests and the method of delivery. The type of testing we are carrying out is also influenced by the concerns about TIMSS results that led to the project, and prevailing public views of knowledge and learning that are not necessarily completely aligned with the project vision. Thus, there is an acknowledged tension between the breadth of vision represented by the SiS Components, and the rather narrower view of 'effectiveness' represented by the tests.

In a large scale public project such as this, it is difficult to achieve the coherence between aims and research design that would be expected of smaller scale, more deliberately planned research projects. The research aspects of the project are in a continual state of working towards coherence, and this includes the need to work with teachers, researchers, and government to develop an agreed, and a more refined understanding of the real issues.

Intersecting audiences and interests

There is inevitably some sensitivity in projects such as this, that project reports should not expose either Government or schools and teachers to negative publicity. Under these circumstances, what place do socially critical perspectives have? In fact, because this project has been concerned with school and teacher change, it has been possible to openly air findings without being seen to be criticising "from the outside". Some of the negative perceptions of teachers and schools which surface in the literature (eg. DEET, 1989; Goodrum, Cousins & Kinnear, 1992) have been also the experience of the SiS project. However, because we have been working with teachers within an essentially collegial and supportive framework, we are in a position to take a critical perspective but also acknowledge the factors that lead to these problems. Our political stance thus tends to be sympathetic to the nuances of the daily lives of teachers and schools.

Conclusion

In large funded projects such as this one, the tensions between development and research, between advocacy and critical appraisal, and between the practicable and the possible, are ever present. The SiS Research project has allowed an exciting exploration of science teaching and learning within real and challenging contexts. It is research that makes a difference. The layered nature of the validation processes described in this paper is a response to the way the research sits within a complex project environment, and the multiple purposes served by this description of effective science teaching and learning.

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