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ABSTRACT

This book contains selected refereed papers from the 21st Annual Conference of the Australasian Science Education Research Association. The papers are as follows: "A Learning Model for Science Education: Developing Teaching Strategies" (Appleton); "Researching Balance between Cognition and Affect in Science Teaching" (Baird et al.); "Toward a Gender-sensitive Model of Science Teacher Education for Women Primary and Early Childhood Teachers" (Bearlin); "Learning in Science Project (Teacher Development): The Framework" (Bell, Kirkwood, & Pearson); "The Pupil as Philosopher" (Carr & Kirkwood); "New Data and Prior Belief: The Two Faces of Scientific Reasoning" (Dawson & Rowell); "The Influence of Gender, Ethnicity and Rurality Upon Perceptions of Science" (Dunne & Rennie); "Rediscovering Ignorance" (Edwards); "Practicalizing Piaget at the ASEP Guidelines Conference 1970" (Fawns); "The Quality of Teacher Education Programs" (Fensham & West); "Learning Environment, Learning Styles and Conceptual Understanding" (Ferrer); "Misconceptions and Light" (Fetherstonhaugh); "Scaffolding Conceptual Change in Early Childhood" (Fleer); "The Technology-Science Relationship: Some Curriculum Implications" (Gardner); "Year 12 students' Attainment of Scientific Investigation Skills" (Hackling & Garnett); "Outcomes of the Primary and Early Childhood Science and Technology Education Project at the University of Canberra" (Hardy, Bearlin, & Kirkwood); "Australian Studies: A Vehicle for Scientific and Technological Literacy?"

(Jane); "Developing a Taxonomy of Science Concepts Based on a Scale of Empirical Distance" (Jones); "'Expert' and 'Novice' Subjects' Approaches to Genetic Problem Solving in a Computer-Based Setting" (Kinnear & Simmons); "The Constructivist Paradox: Teachers' Knowledge and Constructivist Science Teaching" (Louden & Wallace); "Diagram Information and Its Organisation in Memory: Exploring the Role of Skill and Experience" (Lowe); "Research into the Environment of Science Laboratory Classes in Australian Schools" (McRobbie, Giddings, & Fraser); "Development of Student Inquiry Skills in a Computerised Classroom Environment" (Maor); "History, Philosophy and Science Teaching; Current British, American and Australian Developments" (Mathews); "Focus Folklore: Reflections of Focus Teachers on the Sci-Tec In-service Project" (Napper & Crawford); "Science Education Research in Papua New Guinea 1978-1990" (Palmer); "Aboriginal Studies and the Science Curriculum: Affective Outcomes from a Curriculum Intervention (Ritchie & Butler); "Effects of Background and Classroom Characteristics on the Science Achievement of 10-year-old Students" (Rosier); "A Research Method Using Microcomputers To Assess Conceptual Understanding and Problem Solving" (Simmons & Kinnear); "Integration of Technology in the School Curriculum" (Treagust); "'What's Your Science Teacher Like?': Using Students To Appraise Teaching and Teachers" (Walsh); "Chemistry Concepts and Group Cognitive Structure: A Study of Undergraduate Nursing Students" (Wilson); "How Confident Are Primary School Teachers in Teaching Science?" (Yates & Goodrum); "The Investigation of School Effects on Student Achievement in Science: A Multilevel Analysis of Educational Data" (Young); and "Evaluation of a Course Designed To Teach Physics to Students in Physiotherapy" (Zadnik et al.). (PR)

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EDITORIAL COMMENTS

"During the past two years informal meetings have been held by a group of persons engaged in research in science education. The 'foundation' meeting occurred at Monash University, Melbourne, in 1970, and the second conference was organised at Macquarie University, Sydney, in May 1971. At these last mentioned meetings, it was suggested that details of science education research should be disseminated more widely than had occurred in the past..."

(Editor's preface to Research 1971, the first ASERA publication.)

I was one of the people present at that foundation meeting at Monash twenty years ago, and so it is especially pleasing to be associated with this twentieth anniversary issue of Research in Science Education, as the publication became known in 1974. It appears at a time of renewed government interest in science (and mathematics and technology) education. When ASERA was founded, the federal government had been involved for some years in attempts to upgrade school science laboratories. It then began to support national curriculum projects, especially the Australian Science Education Project; Gregor Ramsey's paper in that first ASERA publication presented an outline of ASEP's formative evaluation procedures.

Later in that decade, national interest in science education began to wane. Recently, there has been a revival, reflected in the Prime Minister's phrase that we must become a "clever country". There is recognition that all is not well with science teacher education: that argument is elaborated in DEET's three-volume Discipline Review of Teacher Education in Mathematics and Science (1989). The Prime Minister has established a Science Council, consisting of scientists, politicians and industrialists; for its second meeting, in May 1990, it commissioned a set of papers on science education, Science and Mathematics in the Formative Years. The Australian Education Council (i.e. the state and federal ministers of education) has initiated National Mapping Exercises in various school subjects in an attempt to encourage national curriculum co-ordination. One must hope that these promising developments will be properly supported by the resources needed to bring about substantial improvements in the quality of science education at classroom level.

This issue of RISE contains a record number of papers (35) and is of record size (352 pages). It maintains the tradition of earlier issues of demonstrating the wide range of issues of concern to science education researchers. There are also a number of changes, some large, some small. Most importantly, as a result of discussion at the 1990 conference in Perth, we have adopted a policy of submitting all papers to independent referees. I am very grateful to the many members of my Review Panel (p. ii) for their work; I know, from the many comments made by authors when submitting revised versions of their conference papers, that the panel's efforts are appreciated. I am convinced that the policy has raised the quality of this publication. Less evident, but also important, is a technological breakthrough: this is the first issue wholly produced from floppy discs supplied by authors. I can now take an AppleMac

MSWord file on diskette, scan it for viruses, convert it to a text file, send it down a cable to an IBM PC, read it on to a floppy disc, take it to my PC and convert it to WPerfect, in about 15 minutes on a good day. (The editorial work takes a little longer!)

Sharp observers will note the addition of two letters to our masthead: we are now the Australasian Science Education Research Association, a move which formalises the close links between Australian and New Zealand researchers which began when the late Roger Osborne started coming to ASERA in 1977.

This issue contains an embryonic Research Notes section, with only one contribution this time; for future issues, authors should feel free to submit brief descriptions of new projects under way and summaries of papers whose length exceeds our 10-page limit. There is also (thanks to Jeff Northfield) a cumulative index of all papers published by ASERA since its inception. (Keen observers may note that only one member of ASERA, founding member and Business Manager Dick White, appears as an author in both the first issue and the present one. I hasten to add that he has also written a few papers in between.)

There are also several stylistic changes: the inclusion of abstracts and authors' biographies, the single-spaced Times Roman 10-pt font, all designed to make this publication look like a proper journal, as well as be one. I hope you approve.

Paul Gardner
Editor.

Monash University, December, 1990.

GUIDELINES FOR AUTHORS FOR THE PREPARATION OF PAPERS AND DISKS FOR RESEARCH IN SCIENCE EDUCATION

SUBMISSION TO CONFERENCE ORGANISERS

Hard copies only are required for submission to the ASERA conference organisers. Setting out can be in the same format as required for publication, or in some other format if you prefer.

SUBMISSION TO EDITOR FOR PUBLICATION IN RISE

Papers submitted to the editor for publication in RISE should be on disk, with three hard copies. See Word Processing and Setting Out below. If it is impossible for you to provide a disk copy in the format requested, please advise the editor. Papers should be submitted within the month following the conference.

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Software The preferred software is WordPerfect, but WordStar, MSWord, Multimate, or ASCII files are also acceptable. Double-sided double-density 5.25" disks are preferred, but MSWord files on 3.5" disks are acceptable.

These software packages all have automatic wrap around. Please do not use hard returns except for new paragraphs, headings, etc. The use of hard returns at the end of normal lines creates problems. Please do not use bold type or italics.

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Length Each paper is to have a maximum length of 10 pages in RISE format. This length includes text, reference list and pages containing diagrams, figures and tables. All pages are to be numbered consecutively.

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Tables Tables should be given arabic numbers, with centred, capital headings:

TABLE 2

CORRELATIONS BETWEEN ANXIETY AND RUNNING SPEED

Simple tables should be incorporated directly into the word-processed text. Complex tables which cannot be treated in this way should be supplied separately as camera-ready copy, with appropriate space left in the body of the text.

Indented dot points Use asterisks, in preference to letters, numbers, or dots to mark indented dot points, e.g.

The project involved

* a conceptualization phase...
* an implementation phase...

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Fig. 3 A model of the learning process

Headings Main headings should appear in CAPITALS in the centre of the page. Sub-headings should be in lower case, underlined, and left-justified. They should be used at regular intervals to assist in the reader's comprehension of the text. Section and sub-section headings should not be numbered.

Reference notes - Footnotes are not to be used. For all notes (including references to unpublished material, personal communications, etc.) use the following system:

Arguments advanced by Smith (Note 1) ...

REFERENCE NOTES (prior to REFERENCES)

Note 1. J. J. Smith Oral presentation at ASERA annual dinner, Alice Springs, 1995.

References References to journals and books should follow the APA guidelines. In the body of the paper references should appear, for example, as Bernstein (1971), or Fisher and Fraser (1983). References in parentheses are presented as (White & Tisher, 1986). These references should be placed in the reference list as follows:

Bernstein, B. (1971). Class, codes and control. London, Routledge & Kegan Paul.

Fisher, D. L. & Fraser, B. J. (1983) A comparison of actual and preferred classroom environments as perceived by science teachers and students. Journal of Research in Science Teaching, 20, 55 - 61.

White, R. & Tisher, R. (1986) Natural sciences. In M. C. Wittrock (ed) Handbook on research on teaching (3rd edn) New York, McMillan.

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AUTHOR

DR. MARY SMITH, Senior Lecturer, Faculty of Education, University of Central Australia, Alice Springs, NT 0870. Specializations: biotechnology curriculum development, biology teacher education.

Research in Science Education, 1990, 20, 1 - 10

A LEARNING MODEL FOR SCIENCE EDUCATION: DERIVING TEACHING STRATEGIES

Ken Appleton
University College of Central Queensland

ABSTRACT

A learning model for science education was proposed by Appleton (1989), based on Osborne and Wittrock's generative learning theory (1983) and the Piagetian notions of disequilibrium, assimilation, and accommodation. The model incorporated many aspects of difficulties in learning science experienced by students, as revealed in the LISP projects and similar research. This paper examines how the model may be used to derive teaching strategies: components of the model are analysed in terms of specific types of teacher interventions which could facilitate students' progress to accommodation. Some established teaching strategies are analysed in terms of these interventions.

INTRODUCTION

Intuitively, teaching strategies which are based on learning theory hold the greatest potential for effective learning, depending on the appropriateness of the theory to the learning situation. An earlier publication (Appleton, 1989) presented a learning model for science education based on the Piagetian notions of equilibrium, assimilation, disequilibrium and accommodation, which also incorporated aspects of other research (Osborne & Freyberg, 1985) and theory (Osborne & Wittrock, 1983). I suggested then that the model could be used as a basis for teaching strategies. This study explores this possibility. Two approaches to teaching that emerged from the Learning in Science series of projects (Cosgrove & Osborne, 1985; Biddulph & Osborne, 1984) are then evaluated by comparison with the suggested strategies. A summary of the model is shown in Fig. 1.

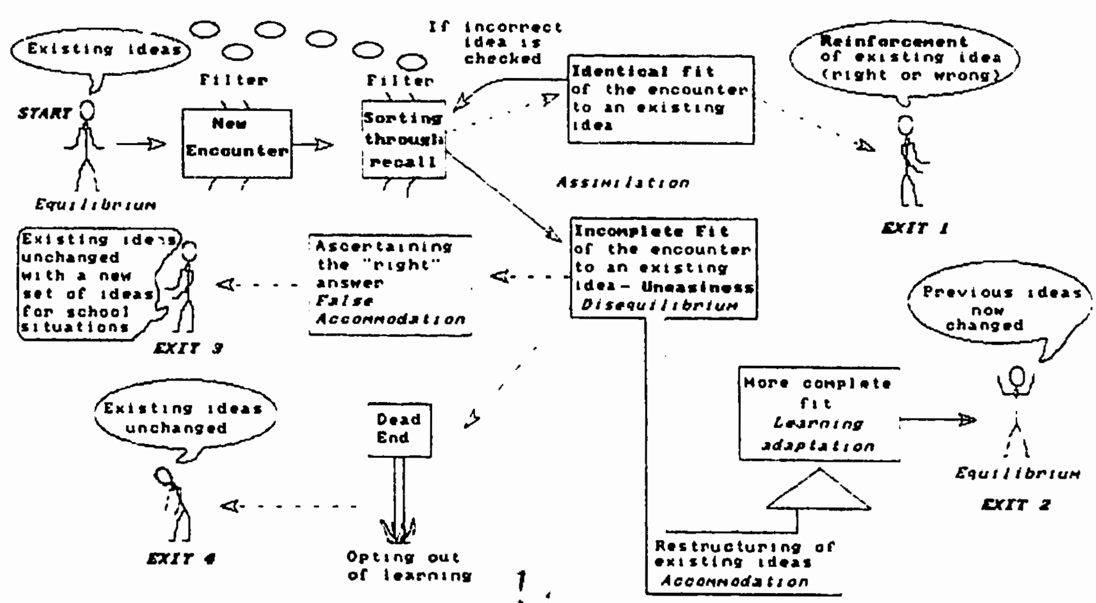
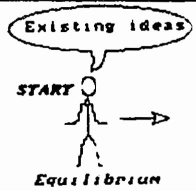


Fig. 1: Appleton's (1989) learning model

TEACHER INTERVENTIONS

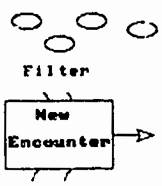
The strategies derived from the model are best considered as teacher interventions appropriate to different phases of the model. Many interventions could be implemented in various ways, so strictly speaking each intervention may give rise to various strategies.

Intervention 1: identify preconceptions.



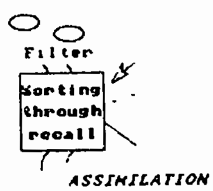
The teacher should identify the preconceptions, related to the chosen topic, which students hold. Information about these could be obtained generally, from the literature, or specifically from the students themselves.

Intervention 2: new encounter.



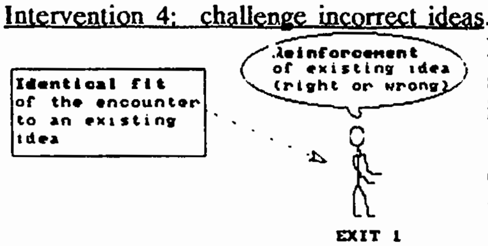
The teacher must choose and present to the students an appropriate encounter which will be motivating, interesting, provide a link to past experiences, allow first-hand exploration, and at the same time lead to an incomplete fit for most, if not all, students.

Intervention 3: ideas links are being made to.



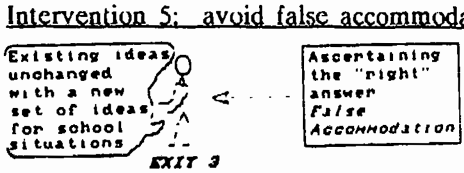
The teacher should ascertain what existing ideas the students are linking to, and what aspects of the encounter they are focussing on. If Intervention 1 was conducted with a specific group of students, the information obtained then may make this intervention unnecessary for some topics. However, it would still be important to determine which aspects of the encounter were being focussed on. These can be elicited from students by encouraging them to talk freely about the encounter.

Intervention 4: challenge incorrect ideas.



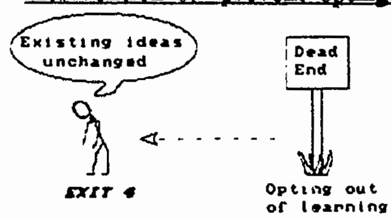
If, in Intervention 3, the teacher discovers students who are likely to exit with an incorrect idea reinforced, then the teacher needs to take specific action to prevent them exiting. Students may have linked to an inappropriate idea because of a prior misconception, because they have focussed on an inappropriate aspect of the encounter, or because they failed to observe a key aspect of it. Specific action by the teacher could be to challenge the idea directly; encourage the students to test the idea; seek other ideas, and evaluate them; or draw students' attention to key aspects of the encounter. If various incorrect ideas emerge, this intervention would need to be repeated for each.

Intervention 5: avoid false accommodation.



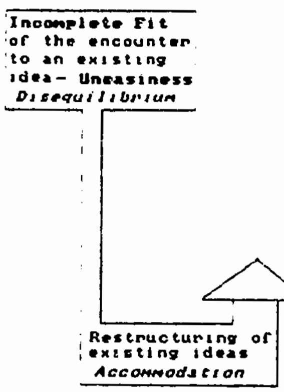
Many students who take the false accommodation route wait for somebody else to provide "the answer" for them to "learn" (Appleton, 1989). The teacher must recognise when students are merely trying to find "the answer" to the cause of disequilibrium. Teachers should ensure that they do not engage in the type of games which help students guess the intended answer, such as those described by Biddulph (1982). Nor should the teacher allow students to sit back and wait for "the answer" to be given to them. To reduce the likelihood of these events, students should be expected to provide their own tentative answers.

<u>Intervention 6: prevent opting out</u>.



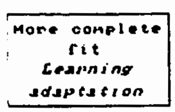
The teacher needs to know the students well enough to recognise when individuals are losing interest or reaching a sufficiently high frustration point to opt out of the learning situation. The teacher should be ready to step in with encouragement, and perhaps provide a little more structure or some other form of help to draw the student back into a meaningful and fruitful task.

<u>Intervention 7: help towards accommodation</u>.



Some students reach accommodation without assistance, but many need help. The type of help needed can be quite diverse, depending on: the topic; the students' personalities, learning styles, and existing knowledge frameworks; the teacher; and resources available. Specific teacher actions may include helping students plan activities, providing an explanation of a theory or phenomenon, helping find suitable books, audiovisual material or a resource person, providing a forum for discussion and comparison of ideas, and interpreting the ideas of others into a more understandable form. Driver (1988) suggested some strategies she has found useful which would fit in this category. It is part of the professional activity of a teacher to select and use the most appropriate of these for a given situation and group of students.

<u>Intervention 8: applying new ideas</u>.



Accommodation by itself may be short-lived and tentative. To improve the status of the newly accommodated ideas, the teacher should provide opportunities for students to use them in practical, real-life situations. The practice should preferably be in a problem solving form, and the problems should address issues which are real to the students and their world.

<u>Intervention 9: diagnosis and remediation</u>.

The teacher cannot assume that because all this learning activity has occurred, students will have developed the desired learnings. Understanding may be incomplete, or even completely inappropriate. The teacher must again diagnose the ideas students have formed, and decide whether to introduce a remedial experience, and the type of experience most appropriate. Suitable experiences to provide closure of the unit of work should also be included. Diagnosis can readily occur as the teacher monitors ideas expressed during accommodation and problem solving. Students can be involved in self-diagnosis by contrasting before and after ideas using techniques such as concept mapping or factual account writing.

APPLICATION OF THE INTERVENTIONS TO TEACHING SCIENCE

The above interventions may be used by teachers who wish to increase their effectiveness; they provide specific actions that increase the likelihood of students taking exit four (accommodation) on the learning model, rather than another exit. For example, teachers wishing to reduce the number of students engaging in false accommodation could change their teaching behaviour to include opportunities for students to provide their own answers to the problem at hand, and to avoid providing a one correct, authoritative answer which the students are expected to learn (Intervention 5).

The interventions can be combined to form various strategies, depending on the relative emphasis given to different interventions. Although they logically fit into a linear sequence, it should not be assumed that they occur linearly in any or all teaching situations. Other educational and pedagogic issues would also affect how the various interventions were implemented. For example, concern over classroom management could result in most interventions being conducted in a whole-class context under the teacher's direct control. Alternatively, less concern over management could result in most interventions occurring at the small group level.

The interventions may also be used to diagnose limitations and problems associated with existing teaching approaches and strategies, with a view to finding ways of making them more effective in terms of student learning outcomes.

COMPARISON OF INTERVENTIONS WITH OTHER TEACHING APPROACHES

A variety of approaches for teaching science has been suggested over the years, with varying degrees of success attributed to each. The interventions outlined above provide a means of evaluating their potential for success in helping students through the accommodation route in the learning model. Such an evaluation would also provide specific indications where teaching approaches could be modified to improve their likelihood of success. In the following discussion, selected teaching approaches are evaluated. The teaching approaches selected were the Interactive Approach (Biddulph & Osborne, 1984), and the Generative Learning Teaching Model, a form of Cognitive Conflict (Cosgrove & Osborne, 1985). These approaches were chosen because they have arisen specifically from considerations of misconceptions research, and could therefore be expected to incorporate many of the interventions described.

Interactive Approach

The Interactive Approach was proposed as a result of the Learning in Science Project (Primary) at Waikato University, New Zealand. A full description of the Approach may be found in Biddulph and Osborne (1984). Table 1 summarises its main steps.

TABLE 1
THE INTERACTIVE TEACHING APPROACH

Step 1: Preparation.

Familiarity with the teaching approach.
Background to the topic - choosing an appropriate topic, gaining a personal understanding of the topic, preliminary explorations of children's likely understanding of the topic.
Assembling resources.

Step 2: Exploration.

Clarifying the topic - identifying children's meanings and ideas, working with children to clearly define the topic, outlining to children the components of the study.
Exploratory activities.

Step 3: Children's questions.

Questions derived from the children.
Other children's questions.
Selecting questions for investigations - factors influencing questions to be selected, children's proposed answers to questions selected.

Step 4: Specific investigations.

Planning and conducting investigations - helping children plan an investigation, helping children develop needed skills, maintaining continuity in the classroom.
Seeking the views of experts.

Step 5: Reflection.

Reporting - helping children to consider and communicate their findings.
Evaluating.

The following discussion compares each intervention with the respective aspects of the approach.
Intervention 1: identify preconceptions
In the teacher's preparation (step 1), students' ideas about the topic to be commenced should be explored either from the literature, or from students by means of small-scale interviews with a few children. Preconceptions could also emerge during the clarification of ideas as part of the exploratory phase (step 2). Further, when students propose answers to their own questions (step 3), their ideas are revealed.

Intervention 2: new encounter.
Part of the exploratory phase (step 2) includes investigations which are chosen on the basis of students' ideas, and which would preferably challenge those which may be misconceptions in the way that, for example, a discrepant event would.

Intervention 3: ideas links are being made to.
Students' questions (step 3) arising from the exploratory phase and their proposed answers to their own questions, show which ideas they are linking to, and how firmly they hold those ideas.

Intervention 4: challenge incorrect ideas.
This could occur in the exploratory phase (step 2) if a suitable discrepant event were used. It would also occur in the students' investigation of answers to their questions (step 4), though the challenges may not be necessarily explicit.

Intervention 5: avoid false accommodation.
False accommodation could be reduced by the focus on students' questions and answers (step 3), and by students planning their own investigations (step 4).

Intervention 6: prevent opting out.
Students are less likely to opt out if they are involved in setting the parameters of their investigations, particularly as the climate of the classroom would be less likely to make them feel failures. Investigative skills taught on a needs basis would make the acquisition of skills meaningful. Challenging ideas would also create a desire to find an answer that would hold up under scrutiny (step 4).

Intervention 7: help towards accommodation.
This is not explicit in the approach, but would occur in the regular student-student and teacher-student conferences (steps 2, 3 and 4). The use of books, media, and visiting experts would also provide help for some students.

Intervention 8: applying new ideas.
This is not an explicit feature of the approach. Some form of application may occur as students share ideas and report their findings (step 5).

Intervention 9: diagnosis and remediation.
The reflection phase (step 5) where students compare new ideas with other ideas, including those of any visiting experts, provides the teacher with the means of diagnosing final misconceptions, and the opportunity to engage in some remediation.

In summary, the Interactive Approach addresses all interventions quite well, except for intervention 8, applying new ideas. This is not specifically included, and may only occur on an ad hoc basis. It would be fairly simple to modify the teaching approach to include an application phase.

Generative Learning Teaching Model

This teaching approach was proposed by Cosgrove and Osborne (1985) as a result of the work on misconceptions revealed in the Learning in Science Project, the precursor to LISP (Primary). Like many other similar teaching approaches (for example, Eaton et al, 1983; Driver, 1988), its main focus is on cognitive conflict as a means of generating cognitive change. Table 2 summarises the main steps in the approach.

TABLE 2
GENERATIVE LEARNING TEACHING MODEL

Step 1: Preliminary.
Ascertain students' views - from the literature, or from students directly.
Seek scientific views.
Identify historical views, and how they changed.

Step 2: Focus.
Provide motivating experiences which serve as a context for later work - clarification of meanings for words, focussing attention on particular phenomena.
Questioning students about what they think, and helping them interpret their responses.

Step 3: Challenge.
Students present their own views to each other.
The teacher ensures the scientists' view is also presented. Students test the various views, and seek evidence for the scientists' views.
Students raise many questions as they try to accommodate new ideas.

Step 4: Application.
Problem solving where solutions require the scientific view.
Discussion about proposed methods of solving the problems.
Continuation of the challenge step where appropriate.

The following discussion compares each intervention with the relevant aspects of the approach.

Intervention 1: identify preconceptions.

During the preliminary phase (step 1), the students' ideas are obtained either from the literature or from the students themselves. The teacher's own misconceptions can also be revealed as the teacher investigates the scientific viewpoint.

Intervention 2: new encounter.

This is not clearly defined in the approach. While the focus (step 2) should include motivating experiences, the nature of these is not explicit. Apparently it could mainly be a discussion of meanings for words. Considerable reliance seems to be put on the subsequent discussions to provide the key role of the encounter in revealing areas of cognitive uncertainty.

Intervention 3: ideas links are being made to.

The teacher should find out which ideas students are linking to in the discussion phase of the focus step (step 2), where the teacher questions students for their ideas, which are then discussed. This continues into the challenge step (step 3), with students explaining their views to each other.

Intervention 4: challenge incorrect ideas.
As students debate the pros and cons of the different ideas presented during the challenge step (step 3), and test them, all ideas including the scientists' view are challenged.

Intervention 5: avoid false accommodation.
Students are encouraged to accept all ideas equally, and to evaluate them against the evidence (step 3). Such a climate where students feel comfortable about presenting ideas, and the teacher accepts the tentative nature of them, is likely to reduce students' engaging in false accommodation as a deliberate strategy.

Intervention 6: prevent opting out.
It is difficult to see how this is addressed within the approach. The potentially competitive nature of evaluating ideas could lead to students opting out. Participation by all students in the discussion components would also be important to prevent opting out. The teacher's skill would be critical in preventing these areas from becoming problems.

Intervention 7: help towards accommodation.
During the challenge step (step 3), the teacher should make the scientists' view intelligible and plausible by experimentation, demonstration, analogy, explanations, or discussions. Students are also asked to describe verbally their solution to problems in the application phase (step 4), and the teacher may also engage in further explanations and so on at this time if students are still struggling to accommodate new ideas.

Intervention 8: applying new ideas.
The teacher endeavours to present students with problems which draw upon the scientists' views (step 4). Discussions about how to solve the problems, and the relative merit of proposed methods and solutions are also part of the application step.

Intervention 9: diagnosis and remediation.
These aspects are included in the application step (step 4), but are not explicit. As students discuss the problems and solutions, misconceptions are revealed and can be dealt with by the teacher as appropriate. Test and examination procedures often used in science are seen as inappropriate (Cosgrove & Osborne, 1985), as they do not seem to provide reliable diagnosis of misconceptions for remediation, and can often reward students who engage in false accommodation but have no meaningful understanding.

In summary, the Generative Learning Teaching approach includes most interventions explicitly, but is not explicit regarding a few, such as the nature and role of the new encounter, means for ensuring students do not opt out, and diagnosis and remediation processes towards the conclusion of the topic. While these are largely implied in the approach, they are highly dependent on the skill of the teacher. Making the points more explicit would improve the applicability of the approach.

The evaluations of both teaching approaches are summarised in Table 3.

TABLE 3
EVALUATION OF TEACHING APPROACHES

INTERVENTION	TEACHING APPROACH	
	INTERACTIVE STRATEGY	COGNITIVE CONFLICT
1 Identify preconceptions	Literature. Pre-topic from students. During the topic.	Literature. Pre-topic, from students.
2 New encounter	Chosen from students' interests in order to challenge ideas.	Not clearly defined. Discuss meanings of words & events.
3 Ideas linked to	Students' own questions, and their answers to their own questions.	Teacher questions for students' ideas, which are discussed.
4 Challenge incorrect ideas	Exploratory phase. Students' investigations of their answers.	Students debate all ideas and test them.
5 Avoid false accommodation	Students propose their own questions, answers and investigations.	Climate where all ideas are accepted.
6 Prevent opting out	Students plan investigations. Testing ideas creates des[illegible] to know.	The open classroom climate. The teacher's skill.
7 Help towards accommodation	Not clearly defined. Regular conferences; use of books, experts.	Teacher makes ideas intelligible and plausible. Students explain their solutions to the problems
8 Applying new ideas	Not explicitly included.	Teacher presents problems; students discuss their solutions.
9 Diagnosis and remediation.	Student reflection.	Not clearly defined. Could be included in Intervention 8.

CONCLUSION

The above discussion illustrates how the interventions arising from the learning model can serve as a useful evaluation tool in determining the potential effectiveness of particular teaching approaches and strategies, and can provide clues as to how to increase the effectiveness of approaches which have a weakness revealed. Not only can the interventions be used as an evaluative tool, but they could also be used to derive new teaching approaches. Other dimensions of teaching, such as management issues and degree of teacher structure, would necessarily overlay the nine interventions so that a series o: parallel approaches could be developed incorporating, for example, the nine interventions implemented with high teacher structure, or with low teacher structure. Space limitations prevent such an analysis in this paper.

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RESEARCHING BALANCE BETWEEN COGNITION AND AFFECT IN SCIENCE TEACHING AND LEARNING

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ABSTRACT

This paper is based on findings from a three year collaborative action research project on classroom teaching and learning. The research, which involved 33 teachers, over two thousand students from six schools, and the authors, centred on exploring how various features of the classroom context influence teaching and learning processes. We interpret project findings as indicating the importance of balance between cognition and affect for effective teaching and learning. We advance the notion of challenge as a way of conceptualising this balance. Challenge comprises a cognitive/metacognitive demand component and an affective interest component. Nine major features of a teaching/learning event were found to interact to influence these cognitive and affective components of challenge.

INTRODUCTION

Teaching and Learning Science In Schools (TLSS) was a three-year project (1987-1989) to research secondary school science teaching and learning. It was a naturalistic study (e.g. Aksamit, Hall, and Ryan, Note 1) of the thoughts, feelings, and actions of teachers and students as they engaged in everyday science lessons. We have already reported the general aims of the project, and some initial findings (e.g. Ross et al., 1988). As the project has now concluded, we can provide a more comprehensive review of its outcomes. We consider one such outcome in this paper. It concerns the importance of balance between cognition and affect for effective science teaching and learning. In discussing this outcome, we shall also consider its genesis - the manner in which research findings were transmuted into educational theory. First, however, we present some information regarding the project, some procedures, and some findings.

RESEARCH PERSPECTIVE; STRUCTURE OF THE PROJECT

The style of our research was interpretive (Erickson, 1986), and directed to the meanings and intentions that underlie classroom teaching and learning behaviours. Three fundamental beliefs guided our choice of methods and procedures: that teachers and students should assume a central role in researching their teaching and learning; that careful, focussed reflection is necessary for enhanced understandings, confidence, and competence; and that reflection is fostered by collaborating with others.

Having teachers and students take a central role in educational research, by reflecting critically on themselves and their practice, is being advocated increasingly as a means of fostering desirable educational and professional outcomes (e.g. Hopkins, 1987; Rudduck, 1988). For us, this idea was strengthened by the success of some earlier research (Baird & Mitchell, 1986). That research also demonstrated to us the efficacy of close, protracted collaboration between teachers, students, and researchers. Collaboration for educational research and development is similarly gaining increasing support (e.g. Campbell, 1988; Druger, 1989; Erickson, Note 2; Kyle & McCutcheon, 1984).

Consistent with our beliefs, large numbers of science teachers and students collaborated with us, and each other, over the period of the project. The nature and extent of this collaboration varied widely. For some participants, collaborative reflection simply involved them in describing for us their perceptions, attitudes, and beliefs; for others, this reflection was set within action research (Baird, Mitchell, & Northfield, 1987) to improve the quality of classroom practices. Similarly, the extent of collaboration varied, from irregular and short-term (days-weeks), to more regular and protracted (months-years). Overall, 33 teachers and over 2,000 students from six schools participated in the project. Of these, 19 teachers and approximately 500 students collaborated actively for periods of at least several weeks.

SOME METHODS, PROCEDURES, AND FINDINGS

The interpretive nature of the research meant that we commonly used such methods as individual and group interviews, class discussions, written evaluations, and participant observation. Usually, these methods were used as part of one of two main types of collaborative reflection. The first type was group-based collaborative action research. Depending on the procedures used, members of the group shared ideas and information, reflected jointly, and made decisions, either during lessons or in regularly scheduled out-of-class meetings. The second type of reflection stemmed from intensive, protracted 1:1 collaboration between a teacher or student and one of the authors.

Over the three years, we completed over 25 separate investigations into aspects of science teaching and learning. We have space here to give only a scant description of six of these investigations; these, and others, are described more fully elsewhere (e.g. Baird, Fensham, Gunstone, & White, Note 3, Note 4). Our main reason for outlining these six is to provide a background to the process of theory generation, to be discussed later. We have grouped these investigations according to whether they involved inquiry by means of questionnaires, or by the repeated responses in group collaboration and in 1:1 collaboration.

Investigations based on questionnaires.

We used large-scale questionnaires regularly throughout the project. This may seem surprising given our espoused research perspective, but there were two main reasons. First, we used questionnaires to set findings from our work with individuals or small groups within the broader class, year, or whole-school context. Second, and conversely, we used them to identify issues that were then explored using more intensive, collaborative methods. By using both questionnaires and intensive collaboration, we sought both "nuance and numbers" (Miller & Lieberman, 1988).

In one investigation, we used questionnaires to determine Year 6 and Year 7 students' perceptions of Year 7 Science. The results were striking, and quite concerning. Ninety-three per cent of the 208 Year 6 students wrote that they enjoyed their science work, and were looking forward to continuing it in Year 7. They believed that next year's Science would be active, interesting and fun. They were especially looking forward to doing experiments, dissections, investigations, and projects. For many students, the reality of Year 7 Science was a considerable disappointment, as is obvious in such comments as:

> We hardly do anything except copy notes that the teacher has written (not our own words) and do experiments that the teacher does for us. In other words we aren't given any real work.
>
> A lot of people are getting low marks because they are bored with the things we've been doing. All we do is sit there and watch demonstrations and listen to the teacher talk. Everyone just sits there and looks like they're listening. I hate science.

The 176 Year 7 students (88 males; 88 females) who completed this questionnaire were in eight classes. More of the negative comments were made by students who were taught by three of the five Year 7 science teachers. More girls than boys were disenchanted with Year 7 science. In response to the questionnaire item "How does Year 7 science compare with what you expected?", 50% of all the girls clearly believed that it was worse (compared with 33% for the boys). This difference was magnified in the three classes already mentioned: in these classes 29 girls, and only 9 boys, answered "Worse".

In a series of six more extensive surveys taken over the three years, over two thousand Years 7-10 students at three schools responded to questionnaires regarding their attitudes to, and perceptions of, science. One trend, observed across all schools, was that the levels of students' interest in, application to, and enjoyment of, science diminished sharply after Year 7. Depending on the school, these levels were at their lowest at either Year 8 or Year 9. Students forwarded many reasons for their disenchantment with science; these reasons are considered later.

<u>Investigations based on group collaboration</u>

Various investigations involved teachers, students, and one of the authors reflecting jointly on classroom practice, during lessons as part of the on-going action research. Two such investigations were a "Shared Perceptions" activity, and an "Agreement for Change" procedure. They are described in Baird et al. (in press), and will simply be outlined here. In the Shared Perceptions activity, teachers and students independently completed written evaluations of a series of science lessons. The students answered such questions as "How much did you understand what you were doing and why you were doing it?", and "Do you think [teacher's name] is teaching science well? Why?" Subsequently, one of the researchers reported to the class the collated student data, and the teacher's responses to similar questions. A general discussion of these results ensued. Features that were identified as diminishing students' interest, application, and enjoyment then became the basis for the second investigation, the Agreement for Change. Each class of students and their teacher spent one lesson considering the features highlighted earlier, and reaching agreement on three changes to improve classroom practice that the teacher would make to his or her classroom behaviours, and three changes that students would make to their behaviours. Examples of changes agreed to by the twelve teachers and 316 students in the fourteen Years 8-11 classes were: for the teacher -- more clarity of instruction and direction, more variety in the work; for the students -- more initiative, independence, and responsibility for completion of work.

Teachers and students then worked together, in some cases for up to fourteen weeks, to try to implement the changes, and monitor their effects on students' interest, application, and understanding. The results proved to be very positive (Baird et al., in press), seemingly because the participants considered the changes to be important, and because there was a clear path of joint responsibility for progress towards the shared goals.

Investigations based on 1:1 collaboration.
Detailed, protracted 1:1 collaboration proved to be an especially useful method of enhancing understanding of the relations between thoughts, feelings and behaviours. One investigation involved 64 Years 8-11 students at two schools in individual collaboration with one of the authors, for periods of up to four months. This collaboration centred on a process of phenomenological reflection. It required each student, once a month, to write responses to four questions. Two of these questions were: "What is it, to be a science student? (Base your answer on how you feel). For me, it is:", and "What is science learning? (Base your answer on what you do). For me, it is:". Together with these written tasks, we interviewed each student individually or in a small group at approximately two-weekly intervals. In these interviews, students clarified and elaborated upon their written responses. Through these tasks and the interviews, students were encouraged to reflect upon aspects of their lived experiences of learning, teaching, and of being a student.

As a result, many of the students came to understand more about their feelings, beliefs, and behaviours, and they increasingly valued careful reflection as a means of personal improvement (Baird et al., in press). Also the responses of these students taught us much about the diverse factors that determine students' approach to, and progress through, their classwork (Baird et al., Note 4).

A second 1:1 collaboration activity was entitled the Joint Lesson Evaluation. In this activity, four teachers from one school collaborated individually with one of the authors over a sequence of six typical science lessons. After each lesson, each partner completed an 8-page form that required detailed review of the nature of, and the interaction between, curriculum content, lesson activities, and teaching and learning behaviours and outcomes. Perceptions were then compared, and issues that arose discussed. One such issue related to the finding that the teachers, in their teaching, were paying much more attention to cognitive (content-related, competence) aspects than to affective (interpersonal, humanistic) ones. Both partners agreed that this disproportionate attention to cognitive aspects may be limiting their teaching effectiveness.

The involvement of both cognition and affect in effective science teaching and learning is the subject of this paper. As the project progressed, we (the authors) came to realize how this joint influence was pervading the findings from all of the investigations in the project. As we discuss in the next section, this nascent understanding formed part of the process by which we transmuted research findings into educational theory.

TRANSMUTING RESEARCH FINDINGS INTO EDUCATIONAL THEORY

In order that meaning and understanding can be drawn from one's observations and experiences, one must be able to discern some structure, order or regularity, upon which relationships may be based or predictions made. This process involves generalization. Erickson (1986) makes the point that, in educational research, one's research perspective determines the type of generalization considered important:

> Positivist research on teaching presumes that history repeats itself; that what can be learned from past events can generalize to future events--in the same setting and in different settings. Interpretive researchers are more cautious...[In interpretive research] the search is for concrete universals, arrived at by studying a specific case in great detail and then comparing it with other cases studied in equally great detail. (pp.129-130)

In this section, we consider our search for concrete universals. We base this consideration on the relationship between educational theory and professional knowledge; we then describe our beliefs regarding the manner in which educational theory and professional knowledge developed in this project.

In considering this relationship, Elliott (1989) cites Maxwell's two contrasting outlooks regarding the aims and purposes of the educational disciplines. The first outlook, the "philosophy of knowledge" is consistent with a rationalist view of the relationship, where "the process of theory generation is quite separate from the process of its acquisition and utilisation for practical purposes" (p.81). Here, decontextualized theory is available to be applied to inform the particulars of one's practice. The second outlook, the "philosophy of wisdom", requires practical inquiry, where "the most important and fundamental inquiry is the thinking that we personally engage in...in seeking to discover what is desirable in the circumstances of our lives, and how it is to be realized" (Maxwell, quoted in Elliott, 1989, p.83). From this perspective, educational inquiry, classroom practice, and theory generation are intertwined.

In this project, the action research we used was of the second outlook. Our method of educational inquiry aimed at linking practice with theory, teaching with research, in order to generate structure, order, regularity-our findings, our "practical wisdom" (Elliott, 1989, p.83). Central to this generation of practical wisdom was an inductive process of naturalistic generalization (Stake, 1978), carried out by the various participants (teachers, students, researchers) in the project. These naturalistic generalizations, derived from "tacit, personal, experiential learnings" (Stake, Note 5, p.2), were shared (albeit in various modified forms) by the participants as they responded to questions or entered into discussion. Subsequently, in transmuting these findings into educational theory-which is a different type of structure, order, or regularity-we (the authors and to a lesser extent, the teachers) applied formalistic generalization, which involves more formal (received) knowledge and reasoning (Stake, Note 5).

Our beliefs regarding this manner of theory generation support the contentions of Altrichter and Posch (1989) - that action research can involve processes that are more complex than the Glaser and Strauss (1967) notion of grounded theorizing. In reflecting and acting, participants draw on both personal, often tacit, professional knowledge and formal, often propositional, theory. The outcomes of this process of theory generation are our contentions, to be discussed next, regarding the importance of both cognition and affect for effective teaching and learning. A central aspect of these contentions, our theory, is the notion of challenge.

A MAJOR REGULARITY IN FINDINGS: BALANCE BETWEEN COGNITION AND AFFECT

As mentioned above, a major regularity in the project's findings became evident. This regularity was the involvement of both cognition and affect in influencing teaching and learning attitudes, beliefs, behaviours, and performances. The six investigations outlined above varied considerably in nature, intent, and manner of implementation. Yet certain features of the teaching/learning situation were highlighted repeatedly by the participants as influencing their approach, progress and outcomes. We found that we could assign each of these features to one of nine categories. These nine categories are the perceived:

* amount of work;
* difficulty of the work;
* importance of the work;
* relevance of the work to, and the opportunity it provides to extend, existing knowledge, abilities and interests;
* novelty or variety of the activities;
* extent of individual control over the process (which, for students, includes control over personal learning and assessment);
* opportunity for active involvement (both physical and mental) in the process;
* interpersonal (teacher-student; student-student) features of the teaching/learning context; and,
* physical features of the teaching/learning context.

Here, then, is an instance of how regularities embedded in personal experience have been transmuted, through interpretation and abstraction, into categories of influence. A further stage of interpretation and abstraction led to the notion of challenge, a notion that arose largely through a process of formalistic generalization by us, the researchers.

We contend that the nature and extent of a teacher's or learner's engagement in a task is mediated by the extent to which the person feels challenged by it. The notion of challenge, as given here, accommodates the joint influences of cognition and affect on action. We envisage challenge as comprising two main components - a cognitive/metacognitive Demand component and an affective Interest (and Enjoyment) component. The nine features listed above interact to influence the level of these two components of challenge.

Two points regarding this conceptualization need to be mentioned. First, the conceptualization is supported by the fact that at least some, and usually many, of the nine features were identified in each of the investigations in the project. Second, the notion of challenge (or, as was more often the case, lack of challenge) illuminated many of the results of these investigations. For instance, the drop-off in students' interest, application, and enjoyment after Year 7 is readily interpretable in terms of diminished level of challenge. Particularly, many project results indicate that improved quality of teaching and learning centres on striking a better balance between the cognitive and affective components of challenge (e.g. the results of the Agreement for Change and Joint Lesson Evaluation procedures mentioned above, and reported more fully in Baird et al., Note 4).

Another notion, related to challenge, is boredom. On numerous occasions at interview, in discussion, or in their written responses, students described their work as boring. The notion of challenge as described invites reflection on the possible meaning of this boredom. Boredom is usually taken to indicate simply a lack of interest or enjoyment. While it may mean this, the notion of challenge may provide for a more comprehensive perspective. Rather than a unitary lack of interest and enjoyment, boredom may arise from a more multi-faceted lack of challenge. For example, let us consider four different situations, all related to different levels of the cognitive and affective components of challenge. Let us propose that, for each situation, both (cognitive) Demand and (affective) Interest are at one of two levels -- High (but, for Demand, not too high), or Low.

In the first situation, both Demand and Interest are High. Here, the cognitive and affective components assume a desirable balance, and the student is challenged to become actively involved. A second situation is where Demand is High, but Interest is Low. In this case, the challenge is less desirable-at best, the student submits to externally-derived pressure to comply. Third, Demand is Low and Interest is High. This situation comprises a lack of challenge, possibly characterised by frustration and limited involvement. The fourth situation is where both Demand and Interest are Low. Here, challenge is absent, and the student fails to engage in the task.

Through discussion with students, it appears that they may label each of the last three situations as "boring", even though the word has a different underlying meaning in each case. In none of these three situations are cognition and affect balanced actively and productively, in a way that stimulates the student to invest a desirable level of effort. In each case, the outcomes would also be expected to be less than desired. Often, lack of (cognitive) achievement would be associated with (affective) feelings of lack of accomplishment, self-assurance, and fulfilment.

Before concluding this discussion on the need to balance cognition and affect in teaching and learning, we shall briefly mention some related research that also highlights the importance of affect. It is research into metacognition (the knowledge and regulation of one's own learning) and problem-solving behaviour. Experienced researchers in these fields are now acknowledging the interdependence of cognition and affect for these desirable educational outcomes (e.g. Brown, 1988; Flavell, 1987; Lester, Garofalo, & Kroll, 1989; Weinert, 1987).

CONCLUSION

The results of the TLSS project indicate that science teaching and learning are determined by a complex array of cognitive and affective influences. In this project we have tried to show how naturalistic research findings were transmuted into educational theory centring on the notion of challenge. According to this notion, in order that teaching and learning be effective, these cognitive and affective influences must be actively and productively balanced so as to provide for an adequate level of challenge. We consider the notion of challenge to be a worthy focus for further interpretive research, and an important goal for both teachers and students to jointly strive for in their science classwork.

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TOWARD A GENDER-SENSITIVE MODEL OF SCIENCE TEACHER EDUCATION FOR WOMEN PRIMARY AND EARLY CHILDHOOD TEACHERS.

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ABSTRACT

Female teachers predominate in primary schools, and tend both to have more negative perceptions of their teaching skills in the physical sciences than males, and to expect girls to perform less well in these areas than boys, with likely serious consequences for girls. In this context the WASTE (Women and Science Teacher Education) Project sought to identify characteristics for teacher education programs which, in the opinion of their conveners, were productive in changing the attitude toward the teaching of science, or in changing the actual mode of teaching science, of women preservice and practising teachers. This paper reports the findings of the WASTE Project which surveyed the conveners of pre- and inservice programs and outlined the three models of exemplary practice used to classify responses: subject-centred, learner-centred and knowledge and person-centred. These models were based largely on differing explanations given for attitude change and on implicit concepts of knowledge, persons, and teaching and learning, and on the importance attributed to gender as a variable. Secondly, it shows how the Primary and Early Childhood Science and Technology Education Project, a gender-sensitive action-research project, was built on these findings. Finally, using these models, it offers a critique of the gender perspective of the Discipline Review of Teacher Education (DEET, 1989).

INTRODUCTION

This paper provides an overview of WASTE, The Women and Science Teacher Education Project, which was directed at identifying science teacher education practices successful in changing the attitude of women primary and early childhood teachers to science. Based in the Faculty of Education at the University of Canberra, formerly the Canberra College of Advanced Education, the WASTE Project sought to identify characteristics of teacher education programs which, in the opinion of their conveners, were productive in changing the attitude toward the teaching of science, or in changing the actual mode of teaching science, of women preservice or practising teachers. Analysis of WASTE Project findings provided the basis for PECSTEP, the Primary and Early Childhood Science and Technology Education Project, a gender-sensitive action research project involving both preservice and inservice teachers, which is now in its second year of development.

This paper outlines the three models of exemplary practice, and their underpinning assumptions, which were used in the WASTE Project to classify conveners' responses: viz subject-centred, learner-centred, and knowledge and person-centred models. It then shows how the PECSTEP Project built on these findings. Finally it will offer a brief critique of the gender perspective of the Discipline Review of Teacher Education (DEET, 1989) using these models.

CONTEXT

The WASTE project was initiated in the context of increasing concern about general standards of scientific and technological literacy and expertise, a setting in which girls had been identified, on grounds of both equity and utility, as needing special attention. To overcome their under-representation in science beyond the compulsory level and their low self-confidence especially in the physical sciences, both curriculum reform and improvement in teacher education at all levels had been recommended (Commonwealth Schools Commission, 1987; Dawkins, 1987).

PURPOSE OF THE PROJECT

The WASTE project was directed at the primary and early childhood levels of teacher education because children's attitudes to science are formed at this time, if not earlier. It was directed at women because female teachers predominate in primary schools, and tend both to have more negative perceptions of their teaching skills in the physical sciences than males, and to expect girls to perform less well in these areas than boys, with likely serious consequences for the girls (Parker, 1987).

It is this seemingly self-perpetuating cycle of low self-confidence (often combined with low achievement in science) in women early childhood and primary teachers, linked with low expectation of girls in primary science classes, that was the central concern of this project. If we want girls in primary schools, both to be taught science and to develop positive attitudes to it, it is crucial that women teachers become more confident and competent in science, and aware of the way in which their attitudes and expectations are communicated to girls.

Objects of the Project

Our intention then was to identify and collect examples of teacher education curriculum practices, both inservice and preservice, that have been found to be productive in changing the attitudes or mode of teaching of primary and early childhood women preservice and practising teachers, in the area of science and technology. In this context, exemplary or successful curriculum practice, was seen to be that which transforms the response of women to science, and the response of women to themselves as teachers of science, or which breaks the cycle of low self-confidence and low competence in a lasting way (Note 1).

Related Research

The study builds on a major Commonwealth Tertiary Education Commission study of science in primary preservice education, reported in Primary Concerns (Owen et al., 1985). This study was comprehensive in the gathering of information and in proposals for reform, but paid little direct attention to the gender of primary preservice teachers, though the importance for girls of teachers addressing sexism and stereotyping was stressed in part of the report. While there is considerable evidence at the secondary level that certain curriculum practices are important in increasing the positive response of female students to science, (Kelly, 1987; Smail, 1984; Whyte, 1986; Yates, 1985), there is virtually no similar gender-differentiated research at the tertiary level related to the teaching of science or to the science education of preservice teachers. However, Rennie, Parker and Hutchinson (1985), in a carefully evaluated study, showed that linking work on gender issues with work in science in a primary inservice program had a significant positive effect on the attitudes of teachers, particularly women, to science, and on the attitudes and activity of girls in their science classes. It was for other curriculum practices with similar characteristics and outcomes that we were looking in this study.

Method

Information about current and past teacher education practices was obtained by contacting personally and/or by questionnaire, conveners or organizers of programs in tertiary institutions, Departments of Education and professional organizations and by advertising in professional journals. Two questionnaires were developed, one relating to preservice teacher education units and programs in science, science education or science related areas; the other to inservice teacher education programs. The purpose of the questionnaires was to identify those programs, units and curriculum practices which, in the opinion of their conveners, were productive in changing the attitude toward the teaching of science or in changing the actual mode of teaching science of women preservice or practising teachers. Responses were obtained from 51 preservice and 14 inservice conveners. Respondents who showed special interest and expertise in the area were asked to send more information about their programs and where possible, the curriculum materials used.

FINDINGS

Practices affecting attitude change

We found widespread general agreement among preservice and inservice course conveners about curriculum practices necessary for attitude change in women. Almost all women were seen as lacking in confidence prior to taking such courses. The majority of respondents described such practices as learner-centred and issue or context-centred, and only a minority referred to subject or science-centred practices. The practices must use practical hands-on, experiential, teaching-related and non-threatening learning strategies that involve gender-inclusive concepts that relate to everyday experience and emphasize human concerns. They must be integrated with learning and development theory, and be closely linked with classroom practices.

Treatment of Gender Issues

A major difference between inservice and preservice programs was in the importance conveners attached to the integration of explicit work on gender with work on science, in their programs. Gender issues tended to be treated implicitly (if at all) in preservice courses, but explicitly in inservice courses.

Many inservice conveners, but only a very few preservice conveners, regarded the inclusion of explicit work on gender with work on science as an important attitude change strategy. Most preservice conveners did not see the relevance of such work. Several were hostile to it. There were three differing perspectives on the treatment of gender issues. Gender was seen as an irrelevant variable with children being seen as individuals (a majority); as important but "added" to the normal curriculum (a third); and as crucial, interactive and transforming every aspect of the curriculum (very few).

There was thus considerable disagreement about whether girls and women should be seen as gendered persons, (in some sense affected as a group by societal influences), or as unique individuals for whom biological sex is simply one characteristic they have in common.

Models of "exemplary practice"

Using an inductive-cum-analytic process three models of exemplary preservice practice were developed, the first two from the preservice questionnaires, the third using both inservice and preservice questionnaires and additional material obtained from preservice conveners. These models were based largely on the differing explanations given for attitude change and on their implicit concepts of knowledge, of persons, and theories of learning. There was a subject-centred one (adopted by a few), a learner-centred one (the majority), and a knowledge and person-centred one (barely represented in preservice responses, strongly represented in inservice responses).

In the development of all three models we were drawing implicitly on familiar models of curriculum design such as the cultural transmission/subject-centred, liberal-progressive/child-centred, socially-critical/emancipatory division (Kemmis et. al., 1983). In the development of the third model we also drew explicitly on the extensive literature on science and science education in which gender is identified as a crucial variable, in particular on literature in which work on science is integrated with work on gender. (Bleier, 1986; Cockburn, 1985; Commonwealth Schools Commission, 1987; Fee, 1983; Gilligan, 1982; Harding, 1986; Head, 1985; Keller, 1985; Kelly, 1987; Lewis, 1987; McNeil, 1987; Mahoney, 1986; Rennie et. al., 1985; Smail, 1984; Whyte, 1986; Yates, 1986)

Using material from the preservice questionnaire responses the first two models were differentiated in terms of their central emphases, explicit or implicit concepts of science, approaches to attitude change, teaching-learning strategies and assessment procedures, integration with classroom practice, and the importance of gender as a variable.

* Model 1 Units identified as subject-centred were characterized as changing attitudes within the dominant subject-centred model. In this model the mastery of scientific concepts is emphasized. Science is seen as a body of knowledge constructed by scientists. The problem of low self-confidence of women in relation to science is attributed to insufficient or inaccurate scientific knowledge, the solution being to give women more scientific knowledge. Tertiary, not primary, teaching strategies are used. A process oriented approach is used, but no integration with, for example, units on learning theory is attempted. No explicit work on gender is included. The gender of students is seen as not relevant.

* Model 2 Units identified as learner-centred were characterized as changing attitudes by changing the model of what science and science teaching are perceived to be, viz. from a subject-centred to a learner-centred one. This model focuses on the teaching and learning of science of young children, on science as a way of knowing, and on non-threatening confidence-building activities. The problem of low self-confidence in women is seen as due to previous experience of science as a fixed body of expert knowledge or "facts", and/or to gender-role socialization. The solution is to provide a practically-oriented, teaching-related, risk-free opportunity to experience activities advocated for children; an opportunity to gain a changed perception of science. Gender is seen as either not relevant, by those who see children as unique individuals, or as relevant by those concerned with equity or career issues for girls: an issue to be "added on" to the curriculum.

* Model 3 (a gender-sensitive model) Courses identified as knowledge and person-centred can be characterized as changing attitudes to science by changing what gender is perceived to be. This model is both knowledge and person-centred. Both are seen from a gender perspective, and are seen as constructed. It is similar to an extended learner-centred model but with an explicit gender perspective integral and formative of every aspect. The model is anchored in practices which are gender-inclusive, and gender-sensitive and hence related to issues of human concern. It changes attitudes and practice through practice, and through reflection on practice/experience. It enables women to understand why their attitudes to science and themselves have changed, by reflection on their experience of inclusive and non-inclusive practices. It encourages women to value their own knowledge and experience from a critical perspective. It seeks to enable women to reproduce, and further develop, a transformed (gender-inclusive, gender-sensitive) model of science teaching and learning in schools. Change in confidence is the result of a change in consciousness, that is, a change in understanding of personal and political reality. Such a change would almost certainly be irreversible (Bearlin et al., 1990, pp 94-95). A concern for the development of confidence in women with respect to the teaching of science, is seen from such a gender perspective, as a very complex matter involving the transformation of the whole teacher education curriculum.

RECOMMENDATIONS

Although there was most support for an extended version of the second model among preservice conveners, this did not seem sufficient reason for accepting it as the model most likely to bring about lasting change in attitude to science among women primary and early childhood teachers (Note 2). This model lacked a coherent gender perspective, and many problems identified by preservice conveners when working with women students were able to be resolved, or at least better understood, by taking gender systematically into account.

There was strong support among inservice conveners for programs which were explicitly and coherently gender-sensitive. An extensive research base provided the rationale for such programs. These factors together led us to recommend research on the effectiveness of preservice programs based on similar principles, that is, programs based on the third, explicitly gender-sensitive, model.

PECSTEP

The WASTE Project Report thus recommended that research be undertaken "on the effect on the attitudes of women preservice teachers to science and science teaching, of teacher education courses in which work on gender and work in science are systematically linked or integrated with each other and with practice in schools which have wide affirmative action policies." (p. 13)

PECSTEP was set up to carry out such research and thus to attempt to create a program based on the third WASTE model. However given the dearth of primary science being taught in schools it soon became obvious that such research at the preservice level would not be possible without companion inservice programs. PECSTEP was therefore designed to link the preservice education of teachers with appropriate practice in schools by providing a special inservice program for supervising teachers.

Overview of PECSTEP

The purpose of the project is to improve teaching and learning in science and technology of girls and boys by increasing the number of early childhood and primary teachers who are effective educators.

The project involves:

* the development, teaching and evaluation of a year length inservice program involving primary and early childhood teachers;
* the modification, teaching and evaluation of an existing semester length preservice unit in science and technology education for preservice teachers;
* the establishment of regional support networks for the practising teachers taking the inservice program;
* the linking of preservice teachers with inservice teachers where possible.

All units in the programs systematically link work on gender with the learning and teaching of science and technology. A summary of outcomes and preliminary research findings for the inservice and preservice programs together with 1990 developments are presented in the paper by Hardy, Bearlin and Kirkwood (1990) in this volume.

Inservice Program

The inservice program was developed and taught by an experienced science educator and researcher, Dr. Valda Kirkwood, from the University of Waikato, using a gender-sensitive, interactive approach that was both knowledge and person-centred. Key features of the workshop program and its follow up in the school context were:

* Workshop "atmosphere" Teachers experienced support, acceptance and affirmation as they began, often anxiously, their explorations of science and science teaching and learning. Small groups, women-only groups, hearing and valuing of all contributions, and the explicit valuing of the experience of women were seen as important.
* Beginning with the familiar context Teachers began their investigations in a context with which they were familiar and secure, and from which they could develop their investigations in directions they perceived most fruitful. They were introduced to "science" through domestic technology - toasters and then breadmaking. Their very first activity was the making and eating of toast with their afternoon tea.
* Sharing in groups The sharing of explorations, reflections and progress amongst group members in workshops and in network groups encouraged the teachers to clarify their own directions and perspectives, to learn of others' journeys and to receive affirmation of their own learning.
* Connected teaching This gender-sensitive interactive approach has been named connected teaching by Belenky et al. (1986), in their study of women's ways of knowing. In this approach, which is deeply respectful of both knowledge and persons, the teacher does not focus on her own knowledge but on her students' knowledge, and the feelings associated with it. In this way, women were enabled to come to see and understand scientific knowledge and knowing as something no longer separate and alien to them. Instead they saw it as related to and connected with their everyday lives, enabling them to make sense of their experience. Science became something over which they could have control, not something which through its experts had control over them. Their learning became a demystifying and empowering experience. Their attitudes to

science were changed by changing what science and science teaching and learning were perceived to be, and experienced as being.

* Gender as explicit Explicit wo: , on gender as it connected with the teaching and learning of science and technology was included in the program. Discussion of gender issues arose spontaneously when men present "grabbed" the toasters which were to be dismantled. Explicit work built on and extended such discussions.

Among the outcomes the following can be identified:

* From both the quantitative and qualitative research data collected it is clear that as a result of undertaking the inservice program teachers are more interested in science and technology, feel more competent as teachers in these areas, and see themselves as having more background knowledge for teaching science and technology. Teachers also became more gender-sensitive. There was a positive change in their perceptions of the activity of girls in their science lessons.
* Teachers reported changes in their concepts of science and technology, and of teaching and learning; changes in their approach to other curriculum areas and changes in their personal - professional lives.
* Teachers indicated that they now saw scientific knowledge more clearly as socially constructed and were more aware of the activity of both adults and children in the construction of their own meaning and knowledge. While from group discussion it would appear that many teachers believe that gender is socially constructed, few indicated that seeing science as socially constructed meant it was also gendered. All were aware that what "counted" as technology was gender coded.
* Teachers who previously were in awe of science reported at the end of the program having a sense of power over science and a sense of control of their own learning and their lives that they had not experienced before.

<u>Summary</u>

The PECSTEP Project and in particular the inservice program can be seen to be based on the third model of exemplary practice identified in the WASTE Project Report: a model which is knowledge and person-centred and explicitly gender-sensitive. The program has been effective in enabling women teachers to change their attitudes to science and to themselves as teachers of science. As well it has made them, according to their own accounts, more gender-sensitive teachers. How effective this gender-sensitive model of teacher education is in enabling teachers actually to become more gender-sensitive as teachers is a matter for further and longtitudinal research. We have not as yet been able to extend the program to enable women (and men) to have an opportunity to explore further gender-sensitive theories of learning and teaching and knowledge. From the perspective of this model, without such exploration it will be difficult for them to construct their own gender-sensitive learning experiences for their girl and boy students, and to evaluate their empowering effect.

GENDER AND SCIENCE 'ISSUES' IN THE DISCIPLINE REVIEW

The report of the <u>Discipline Review of Teacher Education in Mathematics and Science</u>, a highly political document, is constrained by its social and political context. It struggles against the economic rationalist, reductionist, functionalist ethos which gave rise to it. It is to be commended for the emphasis placed on gender issues.

The dominant gender perspective is that related to "equity" in the context of an "equal and pluralist" society, providing equal chances for girls to learn what boys already learn. It is in some senses a victim-blaming model with implicit justifications based on social justice and economic utility, and with suggestions that scientific/technological literacy is needed for a participatory, sustainable society. Recommendations thus relate to providing gender-inclusive teaching practices, but not to changing the curriculum in the sense of changing the knowledge base.

The epistemological position of the writers is thus not coherent as it relates to gender. The writers seem to hold a constructivist view of knowledge and of the nature of the learning process. They see knowledge as humanly constructed. However they do not see it as gendered, but see it instead as gender-neutral (p. 45).

The document thus has an 'add-on' perspective with respect to gender as in the second WASTE model. Recommendations with respect to Education Studies and Curriculum Studies, will be ineffective unless both knowledge and persons (children and teachers) are seen as gendered and hence the teaching learning process is seen as gendered in every aspect and needing to be reconstructed (Note 3).

A similar criticism can be made of the position taken by Parker and Rennie in their chapter on "Gender Issues in Science Education...". They address the intractable "problem" of the need for the existing legislative and policy mandates bearing on the incorporation of gender equity issues in science teacher education to be actualized. They take the position that the change most needed in science teacher education is "that programs develop in teachers a positive attitude towards the implementation of gender-equity initiatives" (p. 235).

They are to be commended for addressing solutions to the "problem" at both the institutional and program/project level. However there seems to be a lack of coherence in the way in which issues to do with gender are approached. At the institutional level structures, including macro-pedagogical approaches, are seen as gendered. Yet issues to do with power relations are never directly addressed. Thus an argument for the transformation of power relationships, which would enable a "feminist pedagogy" to be implemented, becomes instead a plea for diversity which takes for granted the coming into being of non-hierarchical, participatory structures. While criticizing the notion that teaching could be seen structurally as a gender neutral occupation, they use, without comment terms such as "gender free" in relation to science programs. Similarly their review of research relating to the conditions necessary for bringing about attitude change in teachers lacks a gender critique.

An analysis of their pioneering and influential research on primary inservice education, (Rennie et al., 1985) in which work on gender issues was undertaken in conjunction with work on science, provides no strong indication that the way in which the science component of the research was approached was intentionally gender-sensitive. While the work on gender was explicit it could be seen in some senses as "added to" the work on science. PECSTEP findings would seem to indicate that all aspects of a program, the mode of teaching, the selection of content, and the creation of context, must all be gender sensitive. Explicit work on gender is included within this context.

This is not to say that their contribution to the Review is not of value, rather that it does not go far enough. As much recent research in science education and in gender construction now indicates, we need to look more closely at the way in which boys and girls, and men and women, are active in their own gender construction and the way in which science and science education are involved in this. (Clark, 1989; Kenway, 1990).

Overall, the report is in danger of being functionalist in a society whose direction is determined least by those to whom science and maths and technology is currently being taught. It does not clearly ask science and technology literacy for what end? Are students to be reactive or proactive? Will knowledge of science and technology enable them to work to create and sustain a just, participatory, compassionate, global society or do they need to be politically literate as well? An understanding of the political or power dimensions of the social construction of scientific knowledge would provide this. In a curriculum based on the third model, which is knowledge and person centred , such political literacy is an integral part of scientific literacy.

REFERENCE NOTES

Note 1. No distinction was made, in gathering information from conveners, between the attitudes of women to science, to the teaching of science, to themselves as teachers of science. In the questionnaires, positive attitude change in women was identified with increase in confidence in themselves as teachers of science.

Note 2. Further details of the development of these models can be found in the WASTE Project Report. Having developed models 1 and 2 from the preservice questionnaire responses, we used further material obtained from course materials and follow-up conversations with preservice conveners to build a "consensus" model. This model included what we believed most of our preservice respondents would see as the ingredients or characteristics of a preservice science education course which would be effective in changing the attitudes of women to science and to themselves as teachers of science. This model was largely an extension of learner-centred Model 2. While equity was an agreed concern, there was not agreement on the way in which gender issues should be addressed in the program.

Note 3. See Ch 12 for an example with respect to chemistry and social context. The WASTE Report (Bearlin, Annice & Elvin, 1990, Ch. 8) deals with this issue at some length. PECSTEP findings to date support this thesis strongly (Kirkwood, Bearlin & Hardy, 1989; Hardy, Bearlin & Kirkwood, 1990).

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LEARNING IN SCIENCE PROJECT (TEACHER DEVELOPMENT): THE FRAMEWORK

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ABSTRACT

The Centre for Science and Mathematics Education Research at the University of Waikato is now undertaking the fourth Learning in Science Project, LISP(Teacher Development). The project builds on the findings of the previous three projects on the nature of learning and how to improve learning of science in classrooms. This two-year project is investigating the process of teacher development (as change in behaviour and beliefs) in the context of two kinds of teacher courses that acknowledge and take into account teachers' existing ideas. This paper summarises the planning done for the first phase of the project as detailed in Bell, Kirkwood and Pearson (1990).

GENERAL AIMS OF THE PROJECT

The Learning in Science Project (Teacher Development) is a two year project, funded by the New Zealand Ministry of Education, which aims to:

* develop and investigate teacher development courses that help teachers of science implement the findings of the previous Learning in Science Projects and that are based on a constructivist view of learning for both teachers and their students.
* investigate factors that help or hinder teacher development with respect to implementing the findings of the previous Learning in Science Projects.
* develop and evaluate resource material for such teacher development courses.
* develop a constructivist model of teacher change development, and
* provide the policy makers in the Ministry of Education, members of the School Boards of Trustees, middle management in schools, and teacher educators with information on promoting teacher development in science education as well as other areas of the curriculum.

It follows on from an earlier one-year project [LISP (Teaching)] in 1988, funded by the former Department of Education.

BACKGROUND TO THE PROJECT

Previous Learning in Science Projects

The Department of Education (which in 1989 was restructured into a Ministry) has funded three Learning in Science Projects (LISP), based at the University of Waikato, to investigate how children learn science, namely: LISP(F1-4) (1979-1931) (Tasker, Freyberg, & Osborne, 1982), LISP (Primary) (1982-1984), (Osborne & Biddulph, 1985), LISP (Energy) (1985-1988) (Kirkwood & Carr, 1988).
The main outcomes of this research were:

* a review of the problems and difficulties in science education in New Zealand in 1979 (Freyberg, Osborne & Tasker, 1979);
* descriptions of children's understandings in specific concept areas, such as energy, floating and sinking, plant nutrition, electric current (Osborne & Freyberg, 1985);
* the development of a model of how students learn science (Osborne & Wittrock, 1985; Bell, 1984);
* the development and evaluation of new teaching approaches, for example, the interactive teaching approach (Biddulph & Osborne, 1984);
* the development of classroom and inservice material to accompany the above three, such as the LISP(Energy) Teachers' Guide, 1989.

A growing concern throughout the nine years of research has been the limited impact of the research findings on teachers' and students' activities in classrooms, despite evaluations indicating the effectiveness of the new approaches (White & Tisher, 1986). This concern acknowledges that the findings will only have impact on classroom teaching and learning if teacher development occurs. In taking into account the findings of the Learning in Science Projects, most teachers are challenged to change their implicit theories of students, schools, how students learn, the nature of knowing and knowledge, and the implications of these for teaching, and to change the teaching and learning activities in their classrooms (Claxton & Carr, 1987). This reinforces the view that curriculum development and the implementation of curriculum innovations (whether they be new syllabuses or new teaching approaches) are dependent on teacher's professional development (Bell, 1986).

Activities in New Zealand to promote the teacher development associated with the findings of the LISP projects have included:

* rewriting of sections of the primary science syllabus (Department of Education, 1987);
* development of a new F1-5 science syllabus and eight supporting professional development guides. One of the guides, yet to be published and titled Learning in Science, contains a series of workshops introducing the main findings of the LISP projects;
* preservice science education courses in Colleges of Education and Teachers' Colleges;
* inservice and continuing education courses for teachers. These range from one hour "advertising" sessions at teacher conferences, to half or whole day workshops and conferences, to fifty hour Advanced Study for Teachers courses, for example:
  . "jumbo" days when all the teachers in a local area attend a day-long course chosen from a wide selection organised by local teachers.
  . school-based teacher-only days, organised by the staff for themselves, sometimes with an invited resource person
  . one or two day courses organised by the former Department of Education inspectors or advisers for teachers in a local area
  . national (usually residential courses) run by the Department , by the Teacher Refresher Course Committee or by other organisations.
  . workshops of 1-6 hours at subject association meetings or conferences, eg at SCICON, the biennial conference of the Science Teachers' Association.
  . teachers college based advanced studies for teachers courses (AST) and distance education courses run for the Advanced Studies for Teachers Unit (ASTU). Typically, these are 50 hour courses spread over 25 weeks.

LISP (Teaching)

In 1988, a one-year contract project [called LISP (Teaching)] was funded by the former Department of Education, as a forerunner of the present two-year project, to investigate the concern that there has been only a limited impact of research findings on teachers' and students' activities in the classroom. It had become increasingly clear that the process of adopting the science education innovations requires of most teachers a major shift in their implicit theories about how students learn, science, the nature of knowing and knowledge and their role as teachers (Claxton & Carr, 1987). It has also become clear that the professional development of teachers is a key component in the implementation of curriculum innovations (Bell, 1986). In response to this, the one year LISP (Teaching) project investigated factors which do and do not facilitate teacher development as documented in the literature (Silvester, 1989a) and as perceived by interviewed primary and secondary teachers of science, Teachers' College lecturers, advisers and inspectors (Silvester, 1989b). The framework for the literature review is constructivist to complement the constructivist approach of learning developed by the LISP projects (Osborne & Wittrock, 1985). The literature indicated the following factors as facilitating teacher development:

* teachers understanding the change process, and the nature of the change itself (Claxton & Carr, 1987);
* teachers clarifying, investigating and reflecting on their own perceived problems and concerns (Hodson, 1988);
* time and opportunity for reflection on personal actions and their effects (Kirkwood, 1988; Baird & Mitchell, 1986; Schon, 1983);
* time and opportunities to practise new behaviours (Fullan, 1988);
* ongoing and interactive courses (Fullan, 1988);
* courses that acknowledge and take into account teacher's existing ideas (Kirkwood, 1988; Hodson, 1988);
* an atmosphere of mutual trust (Biddulph, 1987);
* collaboration with a support person (Baird & Mitchell, 1986).

In the interviews, teachers of science and science educators were asked about their own experiences, or about the experiences of teachers they had worked with, of changing their classroom behaviour and beliefs in response to the the LISP findings. The interview findings suggest that the following facilitated teacher development: support from other people; some kinds of inservice courses; involvement in LISP research; resources being available; perceptions about the process of change, and personal qualities and beliefs.

Few of the 70 people interviewed felt that teachers could develop in isolation. They commented that support and encouragement from peers, the head of department, the principal, advisers, inspectors and parents (listed in decreasing order of perceived importance) had helped the change to occur. Local or school-based courses, spread over several weeks with time for reflection and trialling of ideas in between sessions, were mentioned as promoting development, as were the group management skills and credibility of the course leader. Without exception, the teachers interviewed, who had participated in research associated with the LISP projects, either directly in the action-research or through having their students work with the researchers, reported that the experience had been a very powerful influence. Many teachers felt able to contemplate change given appropriate resources for support when changing their pedagogy.

Understanding the change process was felt to be facilitative as was understanding and accepting the need to change and what is required for the change. The interviews also indicated that the effect of their personal qualities and beliefs may well have a significant influence on their willingness and initiative to change.

Not all of these factors, described in the literature review and the interviews, have been taken into account in the few inservice and continuing education courses run on LISP findings.

A further literature review

At the beginning of the current two-year project, further factors influencing teacher development were considered. These were the professional and life histories of teachers and the school culture of the teachers.

Teacher development is influenced by the structure of teacher careers, the social context in which schooling occurs, how teachers manage in their career and the relationship between their professional and personal lives (Sikes et al., 1985). Fullan (1982, p.107) points out that "educational change depends on what teachers do and think" and this is moulded and modified by their personal life histories and career paths (Ball & Goodson, 1985; Sikes et al., 1985), their socialization into the profession (Nias, 1986) and their professional life cycle (Huberman, 1989; Levine, 1987; Oja, 1989). It has also been shown that females and males have significantly different needs at points within their own lives and career path (Krupp, 1987; Levine, 1987).

Nias (1986) suggests that the professional socialisation of teachers must be understood as an active process in which individuals seek to preserve their sense of identity. She argues that to understand teachers, attempts must be made to learn about their 'personal dispositions' that stand 'at the core of becoming a teacher' (Griffin, 1987). It can be argued that in the professional development of teachers through traditional inservice courses, the assumptions have been made that all teachers are in the same stage of development. In addition, Groundwater-Smith (1988) argues that inservice education may serve a set of knowledge interests that allows teachers to be managed and controlled, rather than knowledge-forming interests on the other hand, which are seen as emancipatory. Groundwater-Smith writes that inservice needs to emphasise the empowerment of the knower with emancipation based on reflection and self-recognition. Nias (1986) notes that this is taking a view of teacher development as being the development of the person which is rather more than just a passive view of staff development. It is also having them gaining personal and professional meanings from their work as teachers.

The literature also indicates the influence of school culture on teacher development. School culture is described as the variables that reflect norms, values, belief systems, cognitive structures and meanings of persons within the school (Tagiuri, 1968; Anderson, 1982; Leiberman, 1984; Miskel & Ogawa, 1985; Finlayson, 1987). In a study of change and effectiveness in schools (Rossman, Corbett & Firestone, 1988) show that the acceptance of improvements depends on the existing school culture. They state that the introduction of planned change challenges the status quo and teachers will respond to the change according to how well it fits with the culture in terms of 'what is good and true'. If the change is seen to be an improvement in teaching practice then it is likely to be welcomed, whereas if the change threatens the foundation of the system then it will be resisted. Rossman et al. (1988) note that three cultural change processes are relevant for a study of school culture and change: evolutionary processes where the culture acquires new content slowly with a diffusion through the system; additive processes which modify quite suddenly the norms, beliefs, or values of the culture; and transformative processes where there is a deliberate attempt to change the culture. Their research suggests these processes were operating when change was introduced into several schools.

These additional factors of personal and life histories and the culture of the school were taken into account in the research design.

RESEARCH DESIGN

Research Questions

The research will address six questions, based on the aims of the project:

1. To what extent did the teachers on the courses, set up as part of the research, change their ideas, beliefs, values and behaviour about: learners and the process of learning, including learning-to-learn and teachers as learners; the nature of science and scientific knowledge; teaching activities and the role of the teacher, amd science in the school curriculum?
2. What factors facilitate or hinder this development, particularly those relating to: the culture of the school; a knowledge of the process of change; components of the courses and personal life histories and professional career paths?
3. What resource materials were needed to support this teacher development?
4. What are the strengths and weaknesses of the two kinds of teacher development courses?
5. What model of the teacher development can be recommended to policy makers, school managers, teacher educators and teachers as a template for developing courses?
6. What are appropriate criteria for the evaluation of teacher development courses?

Initial foci of data collection

Initially, the research has two main strands:

* The change that has occurred for teachers (and their students) in terms of their views of teaching, the role of the teacher, learning (their own as well as that of their students), learners, the nature of science and the place of science in the school curriculum in their self-reports of beliefs and values. These selected areas are based on the research findings of the previous LISP related to teacher development (Kirkwood, 1988).

* The factors which inhibit or promote teacher development, with particular reference to:
  . the teachers' personal life histories and professional career paths
  . their knowledge of the change process and their reaction to change
  . the culture of the schools in which the teachers work
  . and the components of the two courses.

The initial selection of these four areas is based on the research team's own views about teacher development. These beliefs have developed from our own experiences in teacher development and from reading current literature. Other strands may arise from the on-going analysis of data as it is collected, using the grounded theory approach (Glaser & Strauss, 1967)

Courses
Two kinds of teacher development courses which will be specifically set up for the research project:

* a course developed and facilitated by a science educator for 18 teachers from several intermediate and secondary schools in the local area (called the locally-based course)
* a course developed and facilitated by a science educator in a school for the 4 science staff in a single secondary school (called the school-based course).

Both courses are based on the known research findings on teacher development and aim to help teachers implement the findings of the Learning in Science Projects related to learning and teaching science.

Teachers involved in the project
Teachers involved in the project were selected from both intermediate and secondary schools in the Hamilton region. Eighteen teachers attended the local course, with equal numbers of men and women, six teachers coming from intermediate schools and twelve from secondary schools. The school- based course involved the science department of a rural secondary school, comprising four teachers and again with equal numbers of men and women.

Nature of the courses
Both teacher development courses involved eight, two hour sessions where opportunities were made for discussion, sharing of ideas and reflection on the interactive teaching model (Biddulph & Osborne, 1984) presented by the two course facilitators. Teachers were encouraged to try out and practice new activities and reflect on their learning and experiences in a personal journal.

Methods for Collecting of Data
This research, as with previous LISP research, makes extensive use of a qualitative methodology within an action research framework. Data are being collected during 1990 in a number of ways:

Surveys All course members are being surveyed at the beginning and end of the course, focussing on biographical data, their views on teaching and learning in science, science in the school curriculum, their view of science and their thoughts on their own learning. The initial survey was based on that developed by Bearlin, Hardy and Kirkwood. (Note 1)

Preliminary Interviews All teachers on both courses were interviewed in May 1990 by the researcher before the courses began. These informal interviews explored the teachers' survey responses and enabled a rapport to be set up between the researcher, the schools and the teachers. These interviews helped in the selection of the four case study teachers.

Case Study Interviews   Weekly interviews are being conducted with the case study teachers. These interviews provide qualitative data on the ways in which the teachers' ideas on teaching and learning science, science and science in the school curriculum have been influenced by the courses. These interviews are audiotaped and transcribed. The case study teachers are given the transcripts to read and approve before the data are used (Bell & Osborne, 1981).

Case Study Classroom Observations   The researcher will also observe the classroom activities of the case study teachers towards the end of 1990. The lessons will be audiotaped and transcribed, and field notes taken (Tasker & Osborne, 1981). These transcripts and field notes will then be analysed with regard to indicators that the findings of the Learning in Science Project findings have been implemented. A list of indicators will be developed from these data to be used as a measure of teacher development in the next year of the project.

Facilitator Interviews   Interviews will also be conducted with the course facilitators after each session to record their views on the interaction occuring in the courses.

Student Interviews   Several students in the classes taught by the case study teachers are being interviewed after the courses for their views about any classroom changes occuring in response to the courses.

Course Session Observations   The researcher was present at all sessions of the two courses to take field notes on the discussions and events occuring.

Journals   All teachers on the two courses, and in particular the case study teachers, were encouraged to keep a journal throughout the course. The journals will not be directly accessed by the research team but act as a prompt during interviews and when completing the post-survey.

Final Interviews   All course members will be interviewed at the end of the course as a way of accessing the data in their personal journals.

The data collected in 1990 will inform the planning for phase 2 of the project in 1991. The two kinds of courses will be run again but with modifications suggested by the data.

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THE PUPIL AS PHILOSOPHER

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ABSTRACT

Discussion of the need for an understanding of the philosophy of science to inform classroom practice is mostly directed at clarifying the nature of science, the history of science, the nature of scientific evidence, and the nature of scientific method for curriculum developers and teachers. The discussion assumes no input from pupils.The constructivist perspective, however, assumes that pupils do not come to lessons with blank minds. What insights and questions do students bring to lessons about issues relevant to the philosophy and history of science? Can these be used to develop understanding? Classroom discussions about the energy concept imply that students have valuable ideas and questions related to the exploration of philosophical issues. Rather than developing curricula to tell students about the philosophy and history of science, this paper argues for exploration of student's ideas and questions when abstract concepts are being discussed in the classroom.

INTRODUCTION

The pupil as scientist.

Rosalind Driver (1983) used the above heading as title for her book on learning in science; complementary discussions are found in Osborne and Freyberg (1985) and Biddulph and Osborne (1984). These accounts of science classrooms emphasise two important research findings:

* that learners bring a variety of ideas to lessons;
* that learning which engages with these ideas is valuable.

Learning approaches developed from these findings can be argued to involve the pupil as scientist, and to provide a more appropriate image of science, since pupils:

* explore questions of interest to them in an open-ended manner;
* communicate their developing understandings to others;
* debate alternative ideas;
* recognise the provisional nature of their answers to questions.

The constructivist perspective inherent in this approach considers that students generate new understandings from prior ideas (Osborne & Wittrock, 1985).

The place of history and philosophy of science in science education

There has been a good deal of discussion of the need for science education to be informed by insights from the history and philosophy of science (e.g. Hodson, 1985; Matthews, 1988). They, and others, have described several problems related to current science education practice. These include:

* the development of a naive realist view of science as a body of objective knowledge. Teachers and text-book writers can easily fall into the trap of describing science as unproblematic in content, free from dissent and revision. In this view scientific knowledge exists independently of people, and can be discovered by an astute researcher rather as a successful gold-digger discovers gold.

* uncritical acceptance of the objective nature of observation. There is, in current text-books and in classroom discussion, unlikely to be any consideration of the theory-laden nature of our interaction with the world; that we see the world as we have "invented" it.

* an inappropriate understanding of the falsification of ideas in science. Despite all the evidence to the contrary in the history of science, the overwhelming impression given by most current science education practice about the process of theory change is unhelpful. This image suggests that a few crucial experiments or observations can demolish a theory. Rare incursions into history imply that Lavoisier dealt a death-blow to phlogiston theory, or that Galileo validated a heliocentric solar system, with scarcely a protest from contemporary scientists. This trivialisation of the difficulty of changing the ideas which made sense of the world does not promote a sensible approach to assisting students in their own conceptual change.

* a trivialised description of scientific method. When this topic is discussed in books or in the classroom a mechanical procedure with a bogus objectivity is usually described. Hypotheses are seen to be developed, tested and modified in a manner which is unproblematic and dehumanised. Again the difficult process of conceptual change can be presented as facile and unworthy of study.

* a false view of the relation between theory and experiment. Most practical activity implies that experiments are carried out to demonstrate the truth of theory. At the conclusion of the event there is a "right answer" available to confirm or deny its success. The concept of experiment as the critique of theory is scarcely ever a part of practical work.

Many solutions to these problems have been canvassed and curricula incorporating these solutions are now developing in some countries. The British national school science curriculum introduced in 1989 selects "The Nature of Science" as one of its attainment targets and spells out a programme of study for 11-14 year olds and for 14-16 year olds, as well as defining competence levels. In this curriculum many of the problems outlined above are addressed in a very forthright fashion, clear descriptions being given of issues to be taught by teachers to students. Contexts are seen to be important but the assumption seems clearly to be that students will come to these issues with blank minds. This assumption is apparent when the programmes of study for the age levels are described. The earlier activities focus on building up a knowledge of historical events, later activities then consider controversy and change in the ideas of science. There may be pathways to exploring the nature of science that begin with some different insights which pupils bring to science lessons.

The intention of the remainder of this paper is to consider some important bases for philosophical discussion brought to lessons on energy by students.

THE PUPIL AS PHILOSOPHER

The three year LISP(Energy) investigated how junior secondary school students in New Zealand grappled with a very difficult scientific construct (Carr, Kirkwood & Newman, 1987; Carr & Kirkwood, 1988). Three intensive case studies of classrooms revealed that energy is a concept that provides problems that focus on issues comparable to many of the philosophical issues avoided by curriculum developers and teachers as being too hard for young learners. Students' conversations about energy with the teacher, amongst themselves, and with Valda as researcher revealed a great deal about the ideas that students bring to lessons, ideas from which they could develop both an understanding of energy and a philosophical base for their understanding of science. The research also revealed very clearly the difficulties faced by students in reducing their rich world of experience to the tidier world of science. This shift in perspective is too often assumed to be straightforward, but frequently the transcripts reveal a need for more negotiation with students as to which observations are seen as relevant to the scientific construct and which others are to be ignored. This seems to us to be a fundamental philosophical issue.

The value of a direct negotiation of philosophical issues was seen when Valda talked with students about energy being an idea made up by people to organise and clarify their world. Energy is a human construct. Rather than Valda's suggestion being seen to be inaccessible philosophical talk, the students responded to it with relief and increased interest. The problems they were having in "seeing" energy became acceptable. They were relieved to find that they were not for some reason "blind" to what was apparent to others. The students also welcomed the opportunity to explore the reasons why such a construct could be useful and powerful. There were a number of occasions when classroom interactions provided an opportunity for discussion of philosophical issues. When these opportunities occur in the classroom the agenda of science lessons often does not include them.

Consider the following three episodes (A, B, and C) related to the classroom activities observed in the research:

(A) Sue (the teacher identified as S) has been tracing an energy chain from a person running, back through food as an energy source, to the sun (a typical occupation of biologists; the process has been, also typically, a hard grind). After much teacher-directed discussion the expected answer, which is nuclear energy, is finally given, but that is not the end

> S. But where did the energy itself come from? Angela?
>
> A. The sun.
>
> S. The sun. And when the energy comes from the sun it comes as what energy? (lots of replies...light heat rain)

S. What is going on in the sun that gives the light energy? B (another student) Helium changes into hydrogen.
S. Right.(sic) So how do you know helium is changing? What sort of energy in fact would it be up there (pointing to a list of energy forms). Andrew? Andrew Nuclear.
S. Good. Nuclear energy.
B. But Miss it doesn't matter how far you go back, but where does that last one come from? How was that formed?
S. When you keep on going back you're going to....you're looking at tomorrow [a reference to the intention of tackling the conservation of energy which must have been hard to understand!]. Where does it always come from? We don't quite know how the nuclear energy was formed originally. There's different theories.
B. Yeah, but nobody'll ever know how it really happened and be sure that they know.
S. I don't think we will. Not in my lifetime.

(B) Andrew was later asked what he had got from the topic, and the issue raised in (A) is still alive for him.

> For the record I'd say that what I'd learnt at this particular stage in the year so far is that energy can not be destroyed or created. I'm still not sure about energy can't be created, but I'll leave that for otherwise I'll get confused. I'm still thinking of how we got there in the first place. Because we've got all this energy and how was it? But anyway it can't be destroyed.

(C) Another teacher, John, had been tracing an energy chain back to the sun, and he ended with:

> Hydrogen is actually being converted to helium by a nuclear reaction so we can put...that there was a nuclear reaction there. And here we are virtually at the start of our nuclear flow thing. We've virtually reached the stage where we can't go much further because you then have to ask the question,"Well where did that nuclear energy come from?" and you might be getting into another field there. We won't answer that question.

It is reasonable to comment that the teachers here were less prepared to engage with philosophic considerations than the students. Sue, in reflecting on her lessons when she had tried to introduce more discussion and interaction with the students' ideas, said:

> I think part of it is this right and wrong answer type thing. I think as scientists we're basically trained to think like, this is so and that is so. I think through doing this research I've become a little less black and white. And it also makes it more difficult. We looked at a few more ramifications, side issues, which you tend to brush off. I think it's important that they are brought out if you've got the time and that we are able to discuss them, and explore them.

Curriculum development needs to reflect Sue's insight.

Experiments and observation.

Classroom activities exploring energy changes are a common feature of teaching about energy. Students are required to perform some "simple" tasks and to describe the energy changes occurring. Valda's conversations with groups of students about their activities revealed a rich ground for discussion of some issues. These issues will be outlined, and then illustrated with a transcript.

* What is the link between observation and experiment? In the following transcript, the students are uncertain whether they can "see" energy in the form of bubbles, whether they should construct a "dissolving" energy, and how they should deal with the situation where everything is potential anyway.

* What are the appropriate boundaries of a scientific experiment? In the transcript the role of the investigator who lifts a piece of calcium and drops it into water is inferred to be significant, whereas the teacher assumed that the experiment began with the calcium already (by remote control?) in the water.

* What features of the event are rejected as irrelevant to the experiment? Science takes a more reduced view of the world than the richer experience of the students. In the transcript, students correctly observe movement of water by the bubbles of gas as the calcium reacts. Here is an opportunity to discuss the nature of science and the scientific procedure. (One of us has watched a group of ten year olds add common salt solution to a solution of silver nitrate and record a vast quantity of observations, including that the solution became warm which would surprise many scientists. Their rich interaction with this activity contrasts starkly with the bald scientific construct that silver chloride is precipitated). One important aspect of learning in science is to acquire a different view of the world, to see the world through different spectacles. A proper and valuable role for philosophy of science in school classrooms would be to negotiate this different perspective. The powerful constructs which result certainly help to make better sense of the world, but only if the rules of the game are clear. The following conversation between Valda (V) and a group of 14-year- old students (P) occurred as they were attempting to describe the energy changes when a small piece of calcium was dropped into water. The teacher had "helped" their analysis by giving chemical energy as the starting energy. Her energy change which was later revealed to the class was:

chemical to heat.

The students had carried out the activity and had arrived at a sequence of energy changes:

chemical to gravitational to potential to kinetic

and were still debating their answer when Valda joined them.

V Where are you starting from?
P Chemical
V Chemical energy

P That's when you put it in, that's when you drop it. Then gravitational.
P They're close.
P What's gravitational about it?
P Yeh, it starts when it's chemical, so it only becomes chemical when it hits the water.
P No. No. Chemical is when you drop it, when you pick it up to drop it, isn't it?
P Yeh. And then gravitational pulls it down.
P Oh yeh. So body heat might..yeh, heat/
P Heat?
P No, body heat when you pick it up and then there's gravity.
P Chemical.
P Gravity. What else?
P Can you have dissolving energy?
P Potential.
V Dissolving energy?
P Can you use that?
V I want to find out what your ideas are. You think there might be dissolving energy?
P Well, when it gets kinetic it will dissolve.
V Kinetic did you say?
P Yes.
V Why? What makes you think there's kinetic?
P Because it's moving the water particles while it's bubbling. ...
V What do you think the bubbles might be of?
P Energy.
P Acid, or it might be trapped in or something like that. ...
V After that kinetic is the end?
P Hey. It could go potential couldn't it?
...
P If that's a flammable gas it's got potential.
P Everything's potential anyway.
V So you think everything is potential?
P When it's still.
...
P Well if it's a flammable gas it's got more potential to go into flames and blow up, and if it's just carbon dioxide or something it won't burn or anything..

This transcript reveals a group of students working hard to play the teacher's game but still enmeshed in problems about what are appropriate observations, what are the boundaries to an experiment, how to remove the human participant, and what aspects of their observations are relevant to the scientific view of this activity.

CONCLUSION

The opportunities for building the philosophy of science from students' insights and questions outlined above occur frequently in science lessons, and are almost as frequently ignored. A similar analysis of issues in the history of science could well be made (how often are students' alternative ideas linked to those held by earlier scientists who had thought very deeply about the concept being considered, and therefore given their due value?) This paper is intended to begin an exploration of the concept of pupil as philosopher and to caution against the development of curricula for the philosophy of science by experts without reference to the ideas and problems students bring to lessons. Engagement witht these ideas and negotiation with them may be less tidy than development of curriculum packages remote from the interests of pupils. The effort involved may well be justified by reflection on our current developing understandings of how students learn.

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NEW DATA AND PRIOR BELIEF: THE TWO FACES OF SCIENTIFIC REASONING

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ABSTRACT

Kuhn (1989) has argued that at the heart of the ability to reason scientifically is the process of differentiating existing mental models (i.e. theory) from new data. In this regard she has proposed a developmental sequence in which, in the early stages, theory and data are fully integrated and are used interchangeably. Later, when theory and data are compatible, they tend to be moulded together as 'the way things are', but when they are incompatible conflict is avoided by the use of strategies which bring the two into line: these strategies often include selective attention to the data. Only at the upper levels of this developmental spectrum are theory and data conscientiously differentiated, with each being used to reflect on the other.

This paper analyses the responses made by Year 11 students to problems which required them to evaluate a prediction based on some provided data. The problems were set in two contexts, one scientific and one social, and the predictions to be evaluated combined plausibility/implausibility and validity/invalidity.

The response patterns were very similar to those described by Kuhn, and the implications of this for teachers, especially those attempting to use conflict based teaching approaches, are developed.

INTRODUCTION

What is scientific reasoning? Over the years the concept has undergone various changes, however it is not our intention here to describe these, or to debate their various merits. Instead we will accept here that such reasoning involves a dialectic between theory or theories, and evidence, and will examine some problem solving by Year 11 students for evidence of their ability to reason scientifically in these terms.

Recently Kuhn (1989) has proposed some psychological factors which underly scientific reasoning ability and which develop with age and use. She argues that children, lay-adults and scientists differ in their increasing ability to separate and coordinate existing mental models with new evidence, and that the strategic and metastrategic skills involved have both generalizable and domain specific components.

In the early stages theory and evidence are fully integrated, and are used interchangeably. Later, where they are compatible, problem solvers tend to mould them into a single description of 'the way things are'. Where they are in conflict different strategies are adopted which may involve either a change in the mental model or, more commonly, a selective use of data. These strategies, which are performed unconsciously, serve to remove any potential conflict.

At the other end of this spectrum Kuhn (1989) suggests that the scientist is able to consciously articulate a theory which he or she accepts; knows what evidence does and could support and contradict it; and is able to justify why the coordination of available evidence and theories has led him or her to accept that theory and reject others purporting to account for the same phenomena.

In previous work (Dawson & Rowell, 1987; Rowell & Dawson, 1988) we examined how Year 11 students used provided data, together with existing knowledge and beliefs, when solving a particular class of scientific problems. In these studies we collected evidence showing that the kinds of strategies adopted were very dependent on problem context rather than only on the logical structure of the problems. This paper complements our earlier statistical analyses by directing attention to the detail of the strategies used by the 715 Year 11 students in the 1988 study, and reflecting on these strategies in the light of Kuhn's (1989) proposals.

METHOD

Framework for the study

Much work on scientific reasoning has utilized problems in semantically lean contexts, where the strategies problem solvers adopt can be assessed against ideal, often purely logical, strategies. We, though, are interested in real scientific problem solving in semantically rich contexts, where respondents already have some knowledge of the problems involved, and their overall contexts, before being provided with data. The aim in this study then was to deliberately activate relevant background knowledge to the problems set, and only then to provide relevant data. As we were interested in how students would use the data together with their prior knowledge, we deliberately encouraged them to use the data, and we also provided the opportunity for them to reflect on the interaction between the data and their theories.

715 students attempted two problems, one from each of two contexts. One problem examined the effects on the period of a pendulum of three factors: its length, the weight of the bob, and the type of string (nylon or cotton). The second problem was related to whether or not students would be likely to smoke. The factors considered were whether the students were fitness fanatics, whether their parents smoked, and whether their favourite colour was red or blue. In each problem context we anticipated that two of the identified factors would be seen as possibly relevant to the outcome, while the other (the type of string or the students' favourite colour) would be seen as irrelevant. The overall format of the problem is shown in Figure 1.

Although I'm not always very good at experimental work, I have been trying to look at the effect of three factors which may be related to whether or not school students are smokers. The factors I studied were whether they are fitness fanatics or not, whether their parents smoke, and their favourite colour.

QUESTION 1.

From whatever knowledge of students smoking that you have, which factor or factors (fitness fanaticism, whether parents smoke, favourite colour) do you expect to affect whether students smoke? (You can say none of them).

(SPACE LEFT FOR ANSWER)

I recently looked at four group of students and got the results shown:

Group 1		Group 2	
Favourite colour	Red	Favourite colour	Blue
Parents smoke	Yes	Parents smoke	No
Fitness fanatics	No	Fitness fanatics	No
STUDENTS ARE SMOKERS		STUDENTS ARE NON-SMOKERS	

Group 3		Group 4	
Favourite colour	Red	Favourite colour	Blue
Parents smoke	No	Parents smoke	Yes
Fitness fanatics	Yes	Fitness fanatics	Yes
STUDENTS ARE SMOKERS		STUDENTS ARE NON SMOKERS	

My next experiment will be to look at another group of students with the following characteristics:

Favourite colour	Red
Parents smoke	Yes
Fitness fanatics	Yes

I PREDICT THAT THESE STUDENTS WILL BE SMOKERS and I want you to comment on this prediction by answering two more questions.

****

IN THESE QUESTIONS YOU WILL NEED TO USE ALL THE DATA COLLECTED IN THE FOUR EXPERIMENTS ABOVE TO HELP YOU GET A GOOD ANSWER.

****

QUESTIONS 2 & 3

2. I predicted that the new group of students will be smokers because I worked out that the four experiments above showed that their favourite colour is related to whether they smoke, but whether parents smoke and whether they are fitness fanatics are not.

   Say in as much detail as you can whether you think I have worked correctly from the results I got in the four experiments. Start your answer with "Yes, because ------" or "No, because ------".

   (SPACE LEFT FOR ANSWER)

3. Do you believe my prediction that the students will be smokers which was based on the 'favourite colour' will be correct? Start your answer with "Yes, because ------" or "No, because ------" OR "I'm not sure, because ------"

   (SPACE LEFT FOR ANSWER)

Fig. 1. Format of a typical problem (with a valid but implausible prediction)

Using Figure 1 as an example, students were :

* told that "Although I'm not always very good at experimental work, I have been trying to look at the effect of three factors which may be related to whether or not school students are smokers" [this was to activate the notion that data are not necessarily reliable]

* given the context of the problem and asked which of the three factors might affect the outcome (Question 1) [to activate prior knowledge]

* provided with the data and outcome for four experiments

* provided with the data for a fifth experiment

* reminded that "IN THESE QUESTIONS YOU WILL NEED TO USE ALL THE DATA COLLECTED IN THE FOUR EXPERIMENTS ABOVE TO HELP YOU GET A GOOD ANSWER" [to activate a data-driven strategy]

* given a prediction and asked to "Say in as much detail as you can whether you think I have worked correctly from the results I got in the four experiments" (Question 2) [to place emphasis on using all the data]

* asked whether they believed the prediction, and to say why (Question 3) [to provide an opportunity for reflection on the data in the light of prior knowledge]

In each problem context four different problems were generated : these differed in the relationship of the prediction to the data provided and to its plausibility. We thus had predictions which were: valid/plausible, valid/implausible, invalid/plausible, invalid/implausible. For example in Figure 1 the outcome (students are/are not smokers) covaries only with the students' favourite colour (red/blue), hence the prediction that the new group of students will be smokers is a valid one; yet it is intended to be implausible. Students were randomly assigned one pendulum and one smoking problem.

Approximately 170 students attempted each of the 8 problems: of these forty answer sheets for each problem were randomly selected for detailed study of the answers to questions 2 and 3.

RESULTS

From the initial analyses, broad categorizations as to when and how respondents used data and theory were constructed: these contained most responses (Table 1).

TABLE 1
THE NUMBER OF STUDENT RESPONSES IN EACH CATEGORY

	Response categories										
	Data use				Theory use			Data & Theory use			
Problem	a	b	c	d	e	f	g	h	i	j	k
1 Pendulum	23	6	7	2	13	1	24	25/6	7	5	[illegible]
2 Pendulum	16	6	5	11	14	3	16	23/5	12	6	2
3 Pendulum	13	14	8	2	17	1	18	17/7	7	2	0
4 Pendulum	19	7	8	4	12	6	18	21/8	9	4	0
5 Smoking	18	2	19	1	30	1	9	8/19	12	6	0
6 Smoking	21	1	13	4	17	14	7	9/13	17	13	0
7 Smoking	17	7	11	4	21	1	12	14/11	11	4	0
8 Smoking	20	3	17	0	18	7	13	13/17	9	2	2

Response Categories

Data use
(a) The provided data were interpreted using a covariation strategy
(b) The data were used in a different way
(c) Data were not referred to at any point
(d) It was claimed that the data collected were valueless.

Theory use
(e) A causal theory was given
(f) Only a negative theory was given (i.e. variable x cannot affect the outcome)
(g) No theory was used

Data and theory use
(h) Only one source was used (data only/theory only)
(i) Both sources were used with no distinction being made between them
(j) Both used, and a distinction was made between the two sources
(k) Both used, and a need to fit them together was noted

DISCUSSION

In the analysis of these results we were particularly interested in seeing to what extent students would use reasoning strategies at the upper end of Kuhn's (1989) developmental spectrum. We suggest that a high level response to question 2 should include a covariation based data-driven strategy, with a comment on the logical validity of the prediction. In response to question 3 a distinction should be made between the evidence provided and any theoretically based understanding the student might have, and conclusions should be drawn about their support or conflict. Thus across the two answers it should be made obvious that the data and theoretical perspectives are being perceived as different sources of information. In fact only 42 of a total of 320 responses were at this high Kuhnian level. Typical responses were:

Q.2. "Yes, because the length or weight factors don't seem to effect (sic) the result at all, only what sort of string was used".

Q.3. "I'm not sure, because I think surely the weight of the bob and the length of string would affect the result".

And the clearest distinction of all, though this response was not amongst those randomly selected:

> I don't believe these results, and I wouldn't believe them if you repeated them 1000 times.

Despite this recognition of conflict, only one answer followed with a suggestion about how a resolution might be achieved:

> A different set of data would need to be collected to obtain a correct answer.

In contrast to these few high level responses, the majority (216/320) mentioned only the data or a theoretical view (Table 1 column h). On the pendulum problems this single source was more commonly the data (96/160 responses), on the smoking problems theoretical (60/160 responses).

The reason for the use of only one source is not clear. It is possible that students responding in this way lack the cognitive ability to make a separation, and that theory and evidence are perceived as an undifferentiated whole. On the other hand lack of performance does not necessarily mean lack of competence and possibly these respondents perceive no need to make the separation for this class of problem (a metacognitive inadequacy). If this is the case, it would be expected that a distinction between evidence and theory is more likely to be made when the two are in conflict.

Responses to the two invalid/plausible problems (problems 3 and 7) show no evidence of this. However in the responses to the two valid/implausible problems (problems 2 and 6) a higher proportion did make a conscious distinction between data and theory (6/40 on problem 2; 13/40 on problem 6) (Table 1, column j). Nevertheless, even on these problems, the number giving these high level Kuhnian responses was relatively small.

Conflict reducing strategies

Kuhn (1989) suggested that one of the first developmental steps in the differentiation of theory and data is the subconscious recognition of potential conflict between the two. This is reflected in answers which resolve conflict through the modification of theoretical perspectives or through selective use of the data.

Modification of theory

Some students did adjust existing theories, though these theories might not necessarily have been strongly held. Question 1 required students to indicate which of the three stated variables would be likely to have some role in determining the outcome. A number of students who in questions 2 and 3 accepted the evidence uncritically had expressed quite different views in question 1: thus their 'theory' had changed as a result of the evidence. But in none of the responses read was this change ever mentioned.

Data-driven Strategies

The most commonly adopted data-driven strategy (with or without an added theoretical component) recognised the covariation between the level of a single variable and the outcome. Interestingly the adoption of this strategy was relatively independent of problem context or structure, a finding which contrasts with our 1987 study, and for which the additional prompting might have been responsible. Other data-driven strategies were observed in smaller numbers, with these often serving to reduce conflict between the data and the students' probable theoretical beliefs: these strategies included selective attention to parts of the data, and the rejection of data.

Selective attention to data

In problems 3 and 7 the prediction was intended to be plausible but invalid. If a student feels a need to accept the prediction (presumably because it fits a fairly strongly held theory), the problem to be faced is that the data do not fit if the best available strategy (covariation) is used. Possibly as a subconscious attempt at conflict resolution, some students used the data as prompted, but did so selectively. The rest of the data were ignored or their importance rejected in a theory based statement.

Problem 3.

> Yes, because the Weight of Exp 2 has 100g which is double the weight of Exp 4 although the length of Exp 4 is four times as long as Exp 2. I think it is correct.

Problem 7.

> Yes, because whether or not they are fitness fanatics or not they see no harm in smoking and do it because their friends do it. Their favourite colours have nothing to do with whether or not they smoke, but parents in group 1 and 3 may have a large influence on their children smoking. In groups 2 and 4 the children probably smoke because their friends do it and it looks cool walking around the street with a fag in their hand or mouth. Also in groups 1 and 3 the children may receive some pocket money. Their parents buy everything for them so they therefore spend their money on cigarettes.

Rejection of data

In problems 2 and 6 potential conflict arises from the fact that the prediction is valid, but implausible. In solutions to problem 2, a relatively common strategy (11/40 students) was to claim that the method whereby data had been collected was flawed. (Table 1, column d)

> No, because you should have kept all but one factor constant e.g. length and material and only varied the weight until you decided whether or not the period was corrected by this factor. There is too much variation of factors to determine which is affecting the period of the pendulum.

Some of this group of respondents left it there accepting that no prediction could be made: others added a theoretical component.

> No, because for the four experiments you have used different weights or lengths of string. I'm sure if you used the same weight and same length of string you would get the same period. [presumably excluding the importance of the type of string]

Some, though fewer, responses of this type were noted for problem 6.

> No, I don't think the work was done correctly, hence the results, because there are so many other factors that cause smoking unmentioned. ...I don't think the colour has anything to do with whether or not a person smokes.

Overall, these results indicate that in their attempts to solve this type of problem, very few Year 11 students operated at the upper end of the developmental spectrum. Usually theory and evidence were not distinguished, with one or the other being used by itself, but representing both, as a full solution. Where the two were mentioned, they were often synthesized as a single, undifferentiated solution. Where there was a potential for conflict between the validity and the plausibility of the prediction, there is evidence for both theory change and, depending on the problem type, different alternative strategies for manipulating the data to fit plausible expectations. Very few students indeed demonstrated a clear separation between theory and evidence.

IMPLICATIONS FOR TEACHING

If 'being a scientist' does involve the conscious differentiation of theory and data, and if making rational choices in one's individual and social life demands the same ability, as Kuhn argues, then this study suggests that there is a need to investigate ways in which it can be improved.

There are also implications for those who adopt conflict based teaching approaches designed to change student misconceptions. Whether these are successful will depend on each learner's ability, and inclination, to separate and hold apart theoretical and evidential representations in order to compare and contrast them. This study, and others, shows that under normal circumstances school students demonstrate limitations in these skills, and while teacher based conflict approaches encourage their use, they do little to change their availability.

We have proposed a teaching methodology for changing student misconceptions (Rowell & Dawson, 1983) which depends on students being able to compare two theoretical positions with each other and with the evidence. While we have had a modest success with this method with Year 7 students in a relatively focused, though developmentally important, area (the conservation of volume and its relationship to the displacement of water) (Rowell, Dawson & Lyndon, 1990), our success was more limited in a more divergent area (that of control of variables) with much older students, for whom a higher level of strategy availability might be anticipated (Rowell & Dawson, 1985). Given that, in both of these studies, students were helped to use their available metacognitive strategies, the decreased success of the older group presumably reflects the effects of the richer problem space.

Currently we are working on a variant of our conflict based model which focuses student activity more firmly on the metacognitive aspects of the task, thereby aiming to optimize the use of these skills, though not increasing their availability. This approach has shown encouraging results with a Year 7 group, but to date only in relation to the water displacement problem (Rowell, Dawson & Lyndon, 1990).

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THE INFLUENCE OF GENDER, ETHNICITY AND RURALITY UPON PERCEPTIONS OF SCIENCE

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ABSTRACT

This paper reports an investigation into gender, ethnicity and rurality on Fijian students' perceptions of science. A questionnaire was administered to a large sample of Form 5 classes. All students had completed a four year integrated "Basic Science" course in the junior secondary school and were continuing their studies in the upper secondary school. The responses were analysed to determine the significance of gender, ethnicity and rurality on the students' perceptions of science, attitudes to science in the world and to science in the school curriculum.

INTRODUCTION

Development of scientific and technological capacity is a concern in many countries, evidenced by statements of science policy, research grants and initiatives in education (see, for example, Hawke & Jones, 1989). In developing regions, this is a particularly pressing concern, as science and technology are promoted as major contributors to national development (UNESCO, 1983). The responsibility of building national interest and expertise in these areas has fallen largely upon their education systems.

Education in science, however, is not unproblematic. There are wide ranging concerns about achievement and participation in science. Ormerod and Duckworth (1975) suggest that attitude and interest play an important part in performance in science and willingness to continue further studies. Attitudes can influence the building of national scientific and technological capacity. Much of the research on the under representation of women and girls in science in education and the workplace, is associated with these attitudinal factors (Kahle, 1985; Sjøberg & Imsen, 1989). Much of this research has been undertaken in "developed" countries, with little research elsewhere.

Research into gender issues in education arises, in part, from a concern with inequality perpetuated through schooling. Gender is only one source of inequality, and in developing countries, Bacchus (1989, p. 14) claims that other sources include rural/urban, regional, class and cultural differences. The research reported here aimed to investigate the attitudes and perceptions of upper secondary school students to science in Fiji, and to explore the influences of gender, ethnicity and rurality upon these affective characteristics.

THE FIJIAN CONTEXT

Fiji comprises about three hundred islands, covering 18 300 square kilometres in the equatorial region of the Pacific Ocean. Its population of over 700 000 people are mainly Fijian or Indian. Other ethnic groups include Chinese, Europeans and people of mixed ethnicity. In 1970, Fiji became independent and in 1987, after two military coups, it was declared a republic. It is an agricultural economy with tourism and sugar exports as the major foreign exchange earners. Additional export earnings are gained from fish, coconut products and gold.

Fijian and Hindi are the main languages, although education is in English, which is an official language and widely used. The adult illiteracy rate in 1985 was 14.5% (9.8% for males and 19.1% for females). Over the same year $F82.2m were spent on education, 22.1% of the total government spending (Europa World Yearbook, 1989). Primary school starts at age six and continues for six years. Following four years of junior secondary school in forms 1 - 4, upper secondary schooling continues in forms 5 and 6 and sometimes also in form 7. Students in form 7 are often attempting to improve their tertiary entrance chances. There are several public examinations, the most significant at the end of primary school, after junior secondary schooling in form 4, and for university entrance in form 6 (and form 7). The regional university, The University of the South Pacific, has its main campus in Suva, the capital. Other tertiary institutions in Suva include the Fiji Institute of Technology and Fiji School of Medicine.

The access of girls to schooling is equitable. In 1980-1986, with a school attendance rate reaching 95% to the end of form 4, girls comprised 50-51% of the secondary school population. In 1986, 3.2% of the population aged between 20-24 were studying at the tertiary level (4.1% of the male population, 2.3% of the females). Only 35% of students at all third level institutions were female with a representation of 31% in universities in 1986. In this year, females were 32.9% of those studying Natural Science but only 19.8% of those studying Mathematics and Computing Science (UNESCO, 1989). At the Fiji Institute of Technology (FIT), in Semester 1, 1986, there were no female enrolments in Automotive Engineering, Building and Civil Engineering, Electrical Engineering, and Mechanical Engineering. Only 4 of the 520 students in General and Secretarial Studies were male. The figures also suggest a tendency for certain ethnic groups to attend FIT and particular kinds of courses (Parliament of Fiji, 1988), for example, the majority of engineering students were Indian. In the work force female scientists and engineers involved in research and development are a minute 11%. Females comprise exactly the same proportion (11%) of technicians (UNESCO, 1989).

Given the uneven participation of students across science-related courses, this study set out to explore the perceptions of, and attitudes towards, science in a sample of form 5 students selected because they had elected to pursue further schooling. They had completed four years of an integrated science course originally based on the British Cambridge certificate for overseas students, and developed through the New Zealand School Certificate: Pacific Option. They are in a position to choose whether or not to continue science and make career choices. The study aimed to determine the influence of gender, ethnicity and rurality on the perceptions of science of Form 5 students; it examined the influence of these three variables on:

* students' perceptions of science in the curriculum, compared with their perceptions of English, mathematics and social studies;
* students' attitudes to science at school;
* students' perceptions of science in the world; and
* whether or not students would specialise in science if they could.

METHOD

The instrument

The four research questions were answered by students' responses to a questionnaire modelled on one used in Swaziland by Wheldon and Smith (1988), and subsequently adapted by Wheldon and the present authors. A pilot administration of the questionnaire was carried out in an ethnically mixed, coeducational class in a Fijian school. Respondents were also interviewed about their understanding of the items. No change was suggested to the wording of the items reported here.

The three independent variables in the study were measured by students' self-report in a biographical section of the questionnaire. Students were asked to indicate their sex, their ethnic group, and the place where they had spent most of their life. Students were identified as Indian, Fijian or other ethnicity. Rurality was defined in geographic terms. Students who had lived mostly within 5 km of a major town or city were described as urban dwellers, and those living more than 10 km away were described as rural. Those in between were described as semi-rural dwellers.

Because home background can influence students' perceptions about science, students were asked to record the level of education and occupation of their parents. These variables were investigated as possible covariates in the study. Level of education was coded on a four point scale, from 1 (up to five years of schooling) to 4 (post school training). Parental occupation was coded on a six-point scale from home duties (coded 1) to professional (6).

The sample

The research sample was designed to be a stratified random one-sixth sample of form 5 students in Fiji. The 'class' was chosen as the sampling unit for two reasons. First, the exact population of form 5 students was unknown and thus it was not possible to make a random selection of individual students. Second, the administration of the questionnaire to whole classes rather than small groups of selected students would minimise the disruption to schools.

The most recent enrolment data were for 1988 (Note 1) and these formed the basis for sample selection. There are 107 senior secondary schools in Fiji (almost all on the main island) which have form 5 students in a total of 248 classes. The schools were categorised according to whether their population was predominantly (more than 80% of students) Fijian, Indian or ethnically mixed, and whether they were located in urban or rural areas (Ministry of Education, 1987). Approximately one-sixth of the classes in each category was randomly chosen as the research sample, a total of 1097 students from 39 classes in 23 schools. Of these, 1090 completed the items relating to gender, ethnicity and rurality. The composition of the final sample is shown in Table 1.

There are 552 Indians, 458 Fijians and 80 students of other ethnic backgrounds. These students came from different countries in numbers too small to make meaningful analyses, hence the analyses in this paper were restricted to Fijian and Indian students. A question asking for place of birth indicated that almost 99% of these students were born in Fiji.

Table 1 also reveals that the majority of students are urban dwellers, living in or near towns. This is a reflection of the geography of Fiji, where schools with upper secondary classes tend to be near or in major towns. It is important to note that the sample is representative of form 5 students, not of all people of similar age living in Fiji.

TABLE 1

COMPOSITION OF RESEARCH SAMPLE

Location	Indian		Fijian		Other		Total
	Male	Female	Male	Female	Male	Female	
Urban	160	202	116	138	27	30	673
Semi-rural	56	44	21	52	2	5	180
Rural	45	45	72	59	7	9	237
Total	261	291	209	249	36	44	1090

RESULTS

Students' Perceptions of Science in the Curriculum

The first research question examined the influence of gender, ethnicity and rurality on students' perceptions of science in the curriculum, compared with their perceptions of English, mathematics and social studies. In six separate questions, students were asked to select which of the four subjects, for them, they considered to be the easiest, most difficult, most interesting, most boring, most useful for getting a job, and least useful for getting a job. For each question, a chi-square test used to determine whether the pattern of responses was significantly different between groups according to gender, ethnicity, or rurality. Rurality had no significant overall effect. To detect any interaction between variables which might be confounding the effect of rurality, the pattern of responses for each ethnic-gender group was examined. None showed an association between rurality and ranking of subjects significant at the .05 level.

The variable for which consistent significant differences were found was gender, and the results are reported in Table 2. English and Mathematics are considered to be the easiest subjects, and Mathematics and Science the most difficult. The gender differences are related to the tendency of females to rate English as the easiest and Mathematics as the most difficult subject. More males (39%) than females (31%) rated science as the most difficult subject. Science was considered to be the most interesting subject (by about one third of students) followed by English (32%). The most boring subject was perceived to be Social Studies. Mathematics was rated as boring by more females than males, and more males than females rated Science the most boring subject. English is perceived to be the most useful subject for getting a job, attracting about two-thirds of all responses. Science was considered to be the most useful subject by about 22% of students. Social Studies was widely perceived to be the least useful subject for getting a job.

TABLE 2

PERCENTAGE OF MALES AND FEMALES SELECTING SUBJECTS ACCORDING TO DIFFICULTY, INTEREST AND USEFULNESS FOR GETTING A JOB

SUBJECT	Easiest**		Most Difficult**		Most Interesting*		Most Boring**		Most Useful**		Least Useful**	
	M	F	M	F	M	F	M	F	M	F	M	F
English	31	60	14	6	28	36	16	9	57	69	4	3
Mathematics	43	26	33	47	23	20	23	32	16	9	10	17
Social Sciences	14	9	14	16	14	10	33	40	3	3	75	70
Science	12	5	39	31	35	34	28	19	23	19	11	10

** Significant difference associated with gender $p < .01$
* Significant difference associated with gender $p < .05$

Ethnicity had a significant association with the responses only on the question concerning the easiest subject. Possible interactions between ethnicity and sex were investigated by examining the responses for ethnicity, controlling for gender. There were statistically significant associations between ethnicity and the subject selected as easiest ($p<.01$) and most difficult ($p<.05$) for males. Whilst both groups of males considered Mathematics to be the easiest, 49% of Indian males selected Mathematics, compared to 34% of Fijian males. The significant ethnic effect for males choosing the most difficult subject was caused by the larger proportion of Fijian males selecting mathematics (40%) compared to Indian males (27%). There was no difference between ethnic groups in the proportion of males (12%) or females (5%) choosing science as the easiest subject. There was no association between ethnicity and any other variables.

In summary, Science is perceived by about one-third of students as the most difficult subject, about as difficult as Mathematics. However, females rate mathematics as more difficult than science. Students rate Science as an interesting subject, but many other students, particularly males, consider it to be boring. Science is perceived to be fairly useful for obtaining a job, but comes a poor second to English. Overall, there is a tendency by females to rate Mathematics less positively and English more positively than males, and this has been the main cause of the gender effects.

<u>Students' Attitudes to Science</u>

Students' attitudes to science at school and their perceptions of science in the world were each measured by four items. Items referring to science in the world were 'Success in science leads to good jobs'; 'My parents would be proud if I became a scientist'; 'Science helps to make the world a better place'; and 'The government should spend more money on science'. The response choices were strongly agree - agree - undecided - disagree - strongly disagree. Three items about science at school also used this response format: 'Science is too difficult for me'; 'There should be fewer science lessons'; and 'My teacher makes science interesting'. The response choices for the other item, 'I find that understanding science is...'- were very difficult - difficult - in between

- easy - very easy. Items were scored 1 through 5, so that a high score represented a positive attitude or perception.

Factor analysis confirmed the presence of the two hypothesised dimensions of science at school and science in the world. The four-item scales 'School Science' and 'Science in the World' had moderate alpha reliabilities of .63 and .60, respectively. The desire of students to specialise in science was measured by a single item stating 'I would specialise in science if I had the chance.' The response choices were definitely yes - very likely - maybe - not likely - definitely no, and were coded 5 through 1, respectively.

The correlations of the four home background variables (each parents' education and occupation) with the measures of School Science, Science in the World, and Science Specialisation were inspected. The correlations were consistently positive and trivial for the relationships with School Science and Science Specialisation, and negative but trivial for Science in the World. In no case did the correlation reach .10. These results suggest no reason to consider these variables as covariates in further analysis.

A three-way analysis of variance was employed to investigate the relationships between gender, ethnicity and rurality with the three science variables. There were consistent significant effects associated with rurality and some interaction effects related to ethnicity. The mean item scores for each ethnic-gender group are graphed for the three locations in Figure 1. The scores in all cases are positive in that the results are above the response midpoint of 3. There is only one significant effect for Science in the World, a main effect for rurality ($p<.05$). For each variable, Indian students from the semi-rural location tend to be the most positive in their perceptions, and this has resulted in the significant interaction effects ($p<.05$) between rurality and ethnicity for School Science and Science Specialisation. For Science Specialisation, there is a significant interaction between ethnicity and gender ($p<.05$). Fijian females tend to hold the more positive attitudes than males, whilst Indian females are the most positive group in semi-rural areas and the least positive in urban and rural areas.

Perhaps the most remarkable result from the analysis is the small amount of variance accounted for by all three variables, including their interactions. The 3.6% of variance accounted for by gender, ethnicity and rurality for Science Specialisation is the largest result, and Figure 1 indicates quite complex interactions. For all variables, gender has the least effect.

DISCUSSION

This study examined the influence of gender, ethnicity and rurality on the attitudes towards, and perceptions about, science held by form 5 students in Fiji. Compared with other subjects in the curriculum, science was rated by about one third of students as the most difficult, but also the most interesting subject. More males than females perceived science to be the most difficult subject, and also the most boring. Other gender effects were related to males (particularly Indian males) perceiving mathematics to be easy, and to females rating English much easier than did males. Science was considered useful for getting a job, but much less useful than English. Rurality was not related to subject ratings.

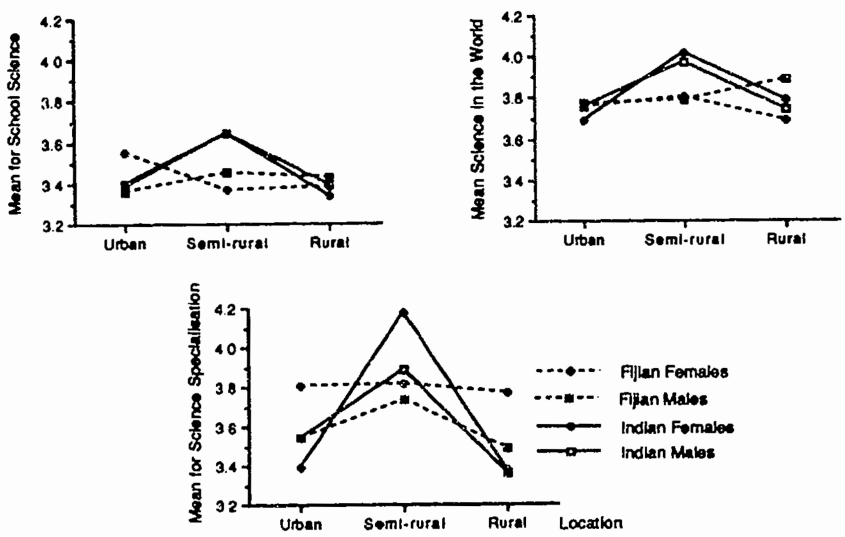

Fig. 1 Mean Scores for Science at School, Science in the World and Science Specialisation

Students perceive science rather positively, with overall means of 3.44, 3.76 and 3.63, respectively, on the five point scales relating to science at school, science in the world and a desire to specialise in science. Small significant effects were found for rurality, with Indian students in semi-rural areas having the most positive attitudes or perceptions. Indian males and females have similar perceptions, but there are some inconsistent differences between Fijian males and females.

The findings of this study can be summarised in three points. First, there is evidence that, in general, science at the upper secondary level is perceived as relatively difficult, but interesting, a finding consonant with the results of studies in many developed countries. Wheldon and Smith (1988) found the same perceptions were held by students in Swaziland. Second, the assumption that rurality, gender and ethnicity are important influences on students' attitudes about science has been shown to be unfounded. Only a very small amount of variance can be attributed to relationships with gender, ethnicity and rurality. Third, the investigation of both parents' educational backgrounds and occupations revealed no relationships of any practical importance. However, other indicators of social, economic and cultural background, such as family size and family income, may be important and could be investigated in other research.

The finding that the fixed variables of gender and ethnicity and parents' educational and occupational background have no consistent relationship with students' attitudes to science suggests that schools have the potential to be major factors in the formation of students' attitudes. By the time students reach form 5, it is likely that their attitudes about science are well-formed, and school effects may be more significant in the early years. There seems to be no particular negative effect of girls compared to boys, and yet in Fiji females are underrepresented in post school science-related courses and careers. Indian males perceive mathematics to be easier than do Fijians, and this may be associated with their higher enrolment in engineering courses. Data about public examinations are not recorded by sex, nor ethnicity, and it is not possible to describe gender or ethnic differences in performance. The results gave no indication that females rather than males consider science to be difficult, in fact the opposite was found.

In terms of development of a national capacity in science and technology, this study found that science is thought to be important and interesting, and there is little evidence that gender, ethnicity or rurality provide an additional barrier to participation in careers in science. A reason for the underrepresentation of females in science-related careers may be associated with students' and teachers' attitudes relating to appropriate career choices, and advice about careers. Research is under way in this area. Although this sample is representative of students of form 5 age, it is not representative of all school students. Another sample including younger students would provide further information about attitudes to science, perhaps to include some rural locations on the outer islands or in the interior where communities operate in a largely subsistence economy. The effect of school factors in the formation of attitudes may also be investigated. Reasons for career choices may need to be gathered from those already in the workforce. More precise implications may then be drawn for the successful development and implementation of scientific and technological development projects.

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REDISCOVERING IGNORANCE

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ABSTRACT

Science teachers tend to operate as if knowledge is the major area and ignorance is a minor appendage. In fact, ignorance is the dominant, and rapidly expanding, area. This paper argues for greater emphasis on helping students to recognise and deal productively with ignorance, uncertainty and the unknown.

INTRODUCTION

When listening to science researchers, teachers and students, it is becoming increasingly rare to find people who believe strongly in the type of science education commonly offered in schools. Students have seldom been strong believers and, along with parents, employers and institutions of higher education, have commonly expressed dissatisfaction. The big change has been amongst teachers. The idea of force-feeding large indigestible chunks of science curriculum into students seems to be becoming increasingly unpalatable for science teachers.

So, where to go with a system that trains science teachers rigorously in the scientific disciplines and then surrounds them with narrow academic texts and curricula based on the logic of those disciplines? Ann Kerwin, Marilys Witte and their co-workers at the University of Arizona College of Medicine have implemented one solution: their Curriculum on Medical Ignorance. They are operating in a field where recent reports have indicted medical education for failing to prepare students to meet the challenge of the uncertain nature of current science and the inevitable ambiguities, complexities and weaknesses of medical practice. Margaret Brumby's (1982) investigation of medical students at Monash University revealed such problems with stark clarity. The pages of Research in Science Education have been filled with similar telling reports on the limitations of our current science teaching practices for almost fifteen years. So, maybe we can learn from the work of Kerwin and Witte, and their catalyst, Lewis Thomas (1988):

> The only solid piece of scientific truth about which I feel totally confident is that we are profoundly ignorant about nature. Indeed, I regard this as the major discovery of the past hundred years of biology .... It is this sudden confrontation with the depth and scope of ignorance that represents the most significant contribution of twentieth-century science to the human intellect. (p. 197).

GETTING IN TOUCH WITH SCIENTIFIC IGNORANCE

Why do we sleep? What is the function of sleep? The almost universally held response is: in order to rest, to recover or restore ourselves. Webb (1977) reports that intensive research on the mechanics of sleep has failed to find what, if anything, is being restored. To date no substance has been found in the blood or brain that builds up or restores during sleep. Webb suggests that sleep is an adaptive process that evolved out of species-environment interaction. Only those humanoids that remained inactive and relatively safe during the hours of darkness survived to reproduce our species that sleeps as it does. Such a view gives different insights into so-called sleep disorders than the more traditional restorative view.

Such examples abound in the sciences, and the Encyclopaedia of Ignorance (Duncan & Weston-Smith, 1977) is one valuable source. Here many of the world's leading physical and biological scientists write about their own ignorance, and ignorance in their field. Some of these issues have been dealt with in an earlier paper (Edwards, 1985). What follows below is a brief exposure to some areas and issues involving scientific ignorance.

To begin with physics, Davies (1977) reports that:

> During the last 20 years, mammoth efforts have been made to formulate a rigorous theory of quantum gravity .... Unfortunately, not only does success seem very far away, but some physicists even doubt whether the quantum theory is compatible at all with the general theory of relativity. Such an incompatibility would presage a new theory more fundamental than either of the old .... To find out just what these concepts might be, and what strange new perspectives they will provide on the nature of the Universe, we must await tomorrow's discoveries (p. 83).

Such a statement would not surprise most physicists or science educators but the spirit embodied in it seldom plays a significant part in science teaching. Moving to a more contentious area of physics, it is instructive to compare two hypotheses about forces on objects.

* Hypothesis A: Where a similarity of pattern exists between the thought patterns produced by a person, and the structure of a physical object, at a microscopic or quantum level, then the object can be strongly influenced by the person.
* Hypothesis B: A body generates in the space around it an abstract quantity which can act on another body at a distance from it without the mediation of anything else.

It is interesting to consider one's own reaction to the two hypotheses. The first is Bastin's (1977) tentative theory of psychokinesis, which will be dismissed summarily by most as related to Uri Geller's spoon bending. The second hypothesis produces a range of reactions. Newton ('87) suggests that the hypothesis is:

> To me so great an absurdity that I believe no man, who has in philosophical matters a competent faculty for thinking, can ever fall into it.

(That was 1687, by the way, not 1987 and was Isaac Newton's response to the concept of 'action at a distance', the basis of his universal laws of gravitation, as cited in Bertotti, 1977, p. 93.)

While not suggesting that Bastin's theory of psychokinesis should be given equal status with the universal laws of gravitation, Bastin (1977) does make a significant point (by the way, the comparison to Newton is this author's, not Bastin's):

> Familiarity may make us see a reasonable coherence where in fact there are great areas of ignorance while denying any coherence to unfamiliar ideas which may be no worse in their incoherence (p. 126).

The status quo is often given a status it does not necessarily deserve, both in the sciences and in education. One example from medical research, cited by Wall (1977), makes the point well. Wall reports on a trial of a new therapy for treating slipped discs by direct injection of an enzyme into the disc. Seventy percent of patients responded to the injection of an inactive compound in a double blind trial.

> In spite of their repeated observation of the placebo response, thoughtful and humane doctors still cannot believe their eyes and tend to fall back on the assumption that their initial diagnosis must have been wrong. If a patient responds to an inactive compound, then the pain could not have been 'real' and must have been psychogenic. Such a statement is a completely unjustified conclusion which attempts to prop up an outmoded dualism (p. 365).

A similar issue is that of undue faith in science. Much of this comes from misconceptions about the certainty of scientific knowledge, particularly in the areas of empirical research and statistical analysis. Tracey (1977) refers to Weinberg's concept of 'trans-science'. This field consists of the questions which can be asked in the language of science but which cannot be answered by science. Weinberg (1972) cites an example concerning the biological effects of low-level radiation insults. A matter of important public policy is to determine the acceptable level for humans, and experiments on mice are a common starting point.

> Now, to determine at the 95 percent confidence level by a direct experiment whether 150 millirems will increase the mutation rate by 1/2 percent requires about 8,000,000,000 mice! Of course this number falls if one reduces the confidence level; at 60 percent confidence level, the number is 195,000,000. Nevertheless, the number is so staggeringly large that, as a practical matter, the question is unanswerable by direct scientific investigation (in Tracey, 1977, p.358).

Tracey, then Chief of the CSIRO Division of Food Research in Australia, went on to point out we cannot do experiments in nutrition on humans that have much validity. One can go on to cite similar examples and statements from leading researchers in such diverse areas as pain (Wall, 1977), ecology (Holdgate & Beament, 1977), sleep (Webb, 1977) and physics (Bondi, 1977). One final example, from the well-known biologist Crick (1977):

> The first major gap in our knowledge is that while we understand a gene in a very simple organism, such as a bacterial cell, we are uncertain exactly what is in a higher organism. Our chromosomes appear to have much more DNA (deoxyribonucleic acid) than we would expect. Also they have much more protein associated with them than we find associated with bacterial chromosomes. The primary gene product appears too large for a simple messenger function and much of it is broken down rather quickly and never leaves the nucleus of the cell - why, we do not yet know (p. 301).

This is the way science is. We are profoundly ignorant. This has seldom been a problem for top scientific researchers. From the days of Socratic ignorance to the forefronts of current physics, as embodied in the ideas of Einstein, Feynman, and Hawking, acceptance of ignorance has been central. As Einstein puts it:

> The most beautiful thing we can experience is the mysterious. It is the source of all true art and science. He to whom the emotion is a stranger, who can no longer pause and stand wrapped in awe, is as good as dead; his eyes are closed (cited in Witte et al., 1989, p. 45).

THE CURRICULUM ON MEDICAL IGNORANCE

The Curriculum on Medical Ignorance was introduced at the University of Arizona College of Medicine in 1985. It is outlined briefly here to show one way in which a central role for ignorance has been embodied in a science education program.

The three central goals of the program are:

* To enlarge students' understanding of the shifting domain of knowledge, ignorance, uncertainty, and the unknown through the examination of philosophical and psychological foundations and approaches, the study of the history of the evolution of selected ideas and practices, and the exploration of a timely medical topic.

* To assist students in recognising and dealing productively with ignorance, uncertainty and the unknown, by teaching them to question critically and creatively from different points of view, communicate clearly in different media, and to collaborate effectively to tap and mobilise relevant resources.

* To reinforce Socratic attitudes and values of curiosity, optimism, humility, self-confidence and constructive skepticism. (Witte et al., 1989, p. 4)

The program includes an accredited elective consisting of seminars and clinics for third- and fourth-year medical students, a summer institute for entering first-and second-year medical students, and special conferences with Visiting Professors of Ignorance.
The seminars and clinics involve analysing relevant clinical cases through questioning. Staff provide guidance in evaluating relevant literature, examining the type of questions asked, and illustrate different ways of analysing cases or formulating questions. The

sessions involve student participation and involve formats such as: short lectures, case-study analyses, group-centred discussions, Socratic inquiry, brainstorming, problem-identifying and problem-solving practice, simulation exercises, and student presentations.

The summer institutes involve input from staff who discuss the philosophical, psychological, and historical frameworks of the unknown, describe the evolution and shortcomings of current ideas, and pinpoint unanswered questions in their field of expertise. Students then formulate questions about their own research topics, keep a weekly log of questions, and prepare oral and written reports focussing on unanswered and newly-formulated questions about basic biology, clinical aspects, and ethical issues surrounding their research topics.

The Visiting Professors of Ignorance are leading practitioners. They trace the influence of ignorance as a career determinant and the use of questioning as a tool for discovery in challenging accepted dogma in textbooks, research and practice. In their presentations they focus on the great unknowns in their field and how they have gone about answering questions in the laboratory and clinic.

Results from the course have been impressive in terms of student ratings, faculty evaluations, student publications, and acceptances of abstracts for State and Federal research meetings (Witte et al., 1989).

Witte et al. (1989) sum up their experience:

> Some may fear that encouraging widespread admission of ignorance serves only to excuse sloth, ineptitude, quiescence, and other dispositions antithetical to intellectual progress. These detractors, however, might consider Socrates' counter-argument that uncovering greater ignorance skillfully enlarges our field of study, increasing opportunities, capacities and responsibilities to better the present and future .... Students as well as teachers who develop rigorous,imaginative and systematic inquiry skills and the courage to use them are the ones best suited to move beyond the knowledge of the day and meet the challenges of the rapidly evolving high technology in the century ahead (p. 8 - 9).

The approach taken here fits within Kerwin's (1986) map of the terrain of ignorance. This consists of four areas:

* The things we know we don't know - such as a cure for AIDS.
* The things we don't know we don't know - these are the things yet to be discovered.
* The things we think we know, but don't - either through misconceptions or where knowledge will change.
* The things we think we don't know, but do - either implicit or intuitive knowledge.

Such a model is a valuable framework for anyone planning a course in ignorance.

IMPLICATIONS FOR SCIENCE TEACHING

There are many ways in which an emphasis on ignorance could affect science curricula, science teacher education, and science classroom practice. Below is a list of some of the major implications.

Reduce coverage

Science curricula and work programs are heavily over-stuffed in a way that leads many teachers to abandon the search for understanding in favour of getting through the work. Much of science teaching involves teaching the supposed fundamental facts of the discipline. There is a need to let go of this perceived need for content coverage, for knowledge transmission. There needs to be a better balance between knowledge and ignorance as foci for science teaching.

Learning for oneself

There should be greater concentration on how to proceed when one does not know the answers. This would shift the emphasis back onto the questions rather than the answers. Students can learn how to ask better questions and search for their own answers. Instruction in thinking skills (Edwards, 1987) would play a significant role here. Designing and implementing one's own experiments are valuable skills. Here students look closely at their procedures and results to find tentative answers to their questions, rather than concentrating on a cook-book approach to getting the right answers to someone else's questions.

Reintegrate with humanities

Scientific disciplines do have their particular logic and there is value in learning about the structure of disciplines. This can be balanced against a rediscovery of the links with the humanities. Some science programs, texts and teachers manifest an arrogance towards the humanities. They view their subject as more objective, based on solid empirical facts, more immutable than the 'softer' subjects such as English and History. The links and similarities need to be re-established and explicated. In some schools students are beginning to learn more about scientific language and writing. Through unpacking genres students are gaining new insights into how science is written and spoken. Replacing moribund science texts with vital publications such as the New Scientist can help in this area.

Science for all

In our culture the critical decision-makers are seldom scientists or even particularly scientifically literate. The types of science programs on offer are unpalatable and mostly of little value to a significant proportion of students. Science needs to be opened up in a meaningful way to all students. Starting from their own ignorance, and own questions, would be a good way to begin.

Joy in studying science

For most senior students science has become a slog on the way to achieving a high tertiary entrance score. Students need to get back in touch with the mysteries and paradoxes of science, to enjoy being confused and trying to find ways out, to blunder, trip and explore. By looking at the cutting edges of science students can get a feel for the excitement, arguments, and uncertainties of science. They need to know how little we know and to see their learning in the context of our ignorance. This has already begun with the current emphasis on constructivist approaches.

Fallibility of science

The public mostly have a belief that scientists can solve everything. President Bush's recent public oath of faith that scientists will find the answers to the problems of carbon dioxide emissions, took advantage of that. Most people believe in a few loose ends rather than massive ignorance. Let students see what science can and cannot do at present, and arm them with inbuilt 'crap-detectors' from an early age.

History of science

If only the great scientists could read what is preached in their names! Let students have access to the writings of these great scientists, let them see their humanity, their humility, their self-doubt, their pomposity, their strengths and weaknesses. What we practice in current science teaching is almost the opposite to what they preached. Those who have translated the ideas of these great scientists into school curricula and texts have generally got it sadly wrong. Students need to understand the contexts for our beliefs in current theories, to marvel at the advances, and be challenged by the mysteries. By reference to the history of science and the current cutting edges, students can see how their learning fits as one transitory step on the way.

Challenge the status quo

Encourage students to challenge what they see and read. Popper's conjectures and refutations are one place to start. By constantly turning upside-down the world's of our students we encourage them to deal more openly and realistically with their world and their understandings of it. Students can be in touch with major current scientific debates, and generate debates of their own.

Lewis Thomas (1983) sums up the situation well:

> And maybe, just maybe, a new set of courses dealing systematically with ignorance in science might take hold. The scientists might discover in it a new and subversive technique for catching the attention of students driven by curiosity, delighted and surprised to learn that science is exactly as (Vannevar) Bush described it: an "endless frontier".
>
> The humanists, for their part, might take considerable satisfaction watching their scientific colleagues confess openly to not knowing everything about everything. And the poets, on whose shoulders the future rests, might, late nights, thinking things over, begin to see some meanings that elude the rest of us. It is worth a try (p. 155).

CONCLUSIONS

There is much to be gained by redressing the balance between knowledge and ignorance as foci for science learning. Greater emphasis on ignorance would result in students being aware of their own understandings and able to ask when they do not know. It could readmit joy, paradox and mystery into science education. Such a more honest confrontation with science as it is practised may result in a community less willing to accept the status quo unquestioningly and with less blind faith in the ability of science to solve our problems.

Such a change in emphasis would need to permeate science teaching at all levels from primary to tertiary, and would need to impact science teacher education programs and state science syllabi.

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PRACTICALIZING PIAGET AT THE ASEP GUIDELINES CONFERENCE 1970

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ABSTRACT

'To understand is to invent' (Piaget, 1968). This paper examines the attempt of Les Dale, the Assistant Director of the Australian Science Education Project, to apply Piagetian theory to describing a theory of instruction for the Project. The historiographical method consists in examining and comparing instances of curriculum invention in science education in Australia starting with contemporary and retrospective accounts of the key figures (Fawns 1988a). This paper is a case record (Stenhouse, 1978) which synthesises public and personal material in the files collected by the author. It has been subjected to review by Dale and others including those to whom it was presented at A.S.E.R.A. It accompanies an earlier paper (Fawns, 1989) which assessed the social context of the Debate at the Guidelines Conference 20 years on.

On the second morning of the Guidelines Conference, Tuesday January 20 1970, Les Dale, Assistant Director of the Australian Science Education Project, presented a formal paper entitled "The Purposes and Aims of ASEP" (Note 1). He saw these aims to be markedly different from the local Junior Secondary Science Project (JSSP) in which he was involved and the American project Probing the Natural World (ISCS). That latter project attended to children's frameworks more than earlier American projects but still began by asking scientists how scientists operate and sought to identify those procedures that have contributed most to scientific progress. The procedures that were identified as critical were the ability to "operationally define and measure" and the "ability to build models" (ISCS Teacher Guide, 1970). Dale describes these projects as based on mechanistic theory in which the progression from childhood to adulthood proceeded by the acquisition of increasingly complex skills and information which was accepted as learning. The basic proposition was that the environment (in this case the course material) directly changes the behaviour and shapes beliefs of the learner. Dale who had just completed his MEd and was soon to undertake his PhD in Piagetian Theory proposed a contrasting view. His organicistic account of his ASEP Scheme proposes that cognitive structures are the result of an inherent property of the organism by which it adapts itself to circumstances. It was the child's environment that could provide the trigger but the development is internal. The Conference syndicates endorsed his recommendations that, in advising teachers when and how to teach particular scientific concepts, Piaget's characterization of the stages of intellectual development be employed rather than grade level. The syndicates also endorsed the general principles he "derived from Piaget for dealing with subject matter".

Fig. 1 shows the distribution of intellectual development which Fensham (1975), a keynote speaker at the Conference, later reported was taken as the basic assumption for the construction of ASEP Units

Aspect	Stage 1	Stage 2	Stage 3
Need for Concrete Situations	Can solve problems, if actual objects are involved. Perception not dominant so he copes with optical illusions.	Can extend from actual situations to consider possibilities, but doesn't see all possibilities in an abstract situation.	Not tied to concrete situations. Can solve abstract problems. Can manipulate words or symbols. Used all possible situations.
Implications	Observation needs to be directed. Use actual specimens and objects.	Possibilities should be be presented in concrete form.	Some concrete experience necessary - prior to abstractions - in considering possibilities.

Fig. 1 Features of children's thinking at each stage

The derived pedagogical principles Dale quoted from Ginsburg and Opper (1969) in the Guide to ASEP are shown below.

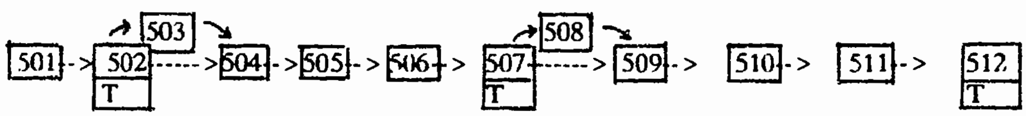
Pedagogical Principles Derived From Piaget's Biological Theory

* New ideas and knowledge should be presented at the level of a child's present thinking and language.
* A major source of learning is the activity of the child. Children must be able to try out things for themselves, to manipulate objects, words and symbols, ask questions, find their own answers, and discuss their findings with other children.
* Classroom materials should be tailored to the needs of individuals and should present moderately novel situations. Children differ greatly in their levels of thinking, their approach to problems, their interests, and the time taken to accomplish tasks. Interest and learning are facilitated if the new experiences are moderately different from what is known.
* Children should be given considerable control over their own learning. The normal child should be given a rich environment containing many things of potential interest (ASEP, 1974)

The JSSP Junior Secondary Science Project was the first laboratory based programme produced in Australia. Robert Wilkinson, a Melbourne University physicist, had with Dale organized the funding and development of the JSSP from 1964, based on American instructional units brought back by Mervyn Turner, a member of the ACER staff. Wilkinson (Note 2) had written and coordinated the original approach from the States to the Commonwealth Government to fund a thorough revision and extension of the JSSP materials into Years 9-10. Turner and Wilkinson sought "to provide for differences in pupils of prior experience and in various abilities and aptitudes and to engage them actively in the instruction - learning process and in ways of investigation"

(Cohen & Fraser, 1987). In this view the child's behaviour presented itself directly and simply to common sense observation.
Compared to earlier courses, JSSP was less formal in pedagogy but more formal in its science. Like PSSC and BSCS Courses it was to develop skills and attitudes - habits of scientific thought. The JSSP cards were expected to define instructional procedure and compensate for weak teaching. Wilkinson and others at the Conference felt strongly that the ASEP endorsement of teacher autonomy underpinned by a constructivist theory of learning was impractical, irrational and extremely ill advised.

At the Conference two of the ACER Staff, Turner and Bennett (1970), criticised the adoption of Dale's three stages model. In Dale's proposals as they saw them "Pupils did not have to acquire any knowledge which they did not already possess." The aim of the Project, they argued "should be to promote transition rather than accept the stages in every piece of material." Their position was closer to Wilkinson's. The JSSP Units were seen by Dale as "cybernetic" or steering mechanisms guiding students at their own rate of learning through a series of work card investigations, diagnostic tests, remedial loops and extended research activities to the correct scientific understanding. The units were perceived and presented as shown in Fig. 2 for Unit 5.



T = test, (Self administered and recorded).

RESEARCH ACTIVITIES:

1	2	3	4	5	6	7	8	9	10	11	12
13	14	15	16	17	18	19	20	21	22	23	24

(JSSP 1968)

Fig. 2 JSSP Unit 5 Flow Sheet

The JSSP Units were packaged like the American SRA remedial reading cards which were endorsed by ACER. ACER accommodated and drew royalties from the JSSP and ASEP materials and has acted as a conduit for American thought in Science Curriculum reform from its establishment (Fawns 1988a).
The sequenced activities, diagnostic tests and optional research activities in JSSP were interventions designed to deliver laboratory centred junior science to all classrooms and cater for individual differences. They were also incorporated in ASEP and it was ASEP that came to be identified with the new professionalism in science education (McCullagh, 1974). Change in learners became change in curriculum and in teachers and in schooling. ASEP became briefly synonymous with curricular change, curriculum innovation and implementation in schools. It made new demands upon teachers. They became curriculum makers rather than curriculum followers. They had to work in a fashion that maintained the essential tension between the learner's structures and those in the public domain. Dale felt the Core (public) and Option (learner) design of each unit supported this tension. He felt that the limits and the logic of student lived experience could be followed in each unit. Dale's metamorphosis of the JSSP programme of instruction to the ASEP Scheme is important. This had to do with his sustained belief that piagetian theory provided a "sound basis for development of a progressive approach in schools" (Dale, 1975). This belief was sustained despite the

implication he drew from his own research studies on combinational thinking about the age equivalence of the Piagetian stages.

The research sounds a cautionary warning to all who feel inclined to generalize from Piaget's findings (on the age of) transition from concrete for formal thinking to other countries. It indicates that the use of concrete materials as precursors to abstract thinking is necessary throughout the years of secondary schooling and could extend beyond. (Dale, 1971)

This latter conclusion about the external use of concrete methods was central to his practical reasoning and was supported at the Conference as the key feature of children's thinking. (See Fig. 1) Vickery, leader of the West Australian delegates, had worked with the I.S.C.S. Project in Florida. He observed that the aims of personal development, special skills of sociability, the relevance of the children's experience and their immediate environment, enjoyed a consensus at the Conference, and were very persuasive. However, he was uneasy about the disturbing resemblance of the proposed aims to the "Education for Living" programmes of the 1930s (Vickery, 1970). The Conference proposals however did not have the utilitarian orientation of the American schemes which inspired the young Stanhope to seek an Australian General Science in the 1930s (Fawns, 1988a).

On the problems of legitimating content, the discussions made clear that any science concept was to be justified in the curriculum only by its contribution to the intellectual, social and emotional development of students. Dale felt strongly that because children are unique individuals, influenced in different ways by the curriculum and maturing physically and mentally at different rates, the teacher should find out important things about each child. For example, he suggested in the ASEP Guide a teacher needed to closely observe

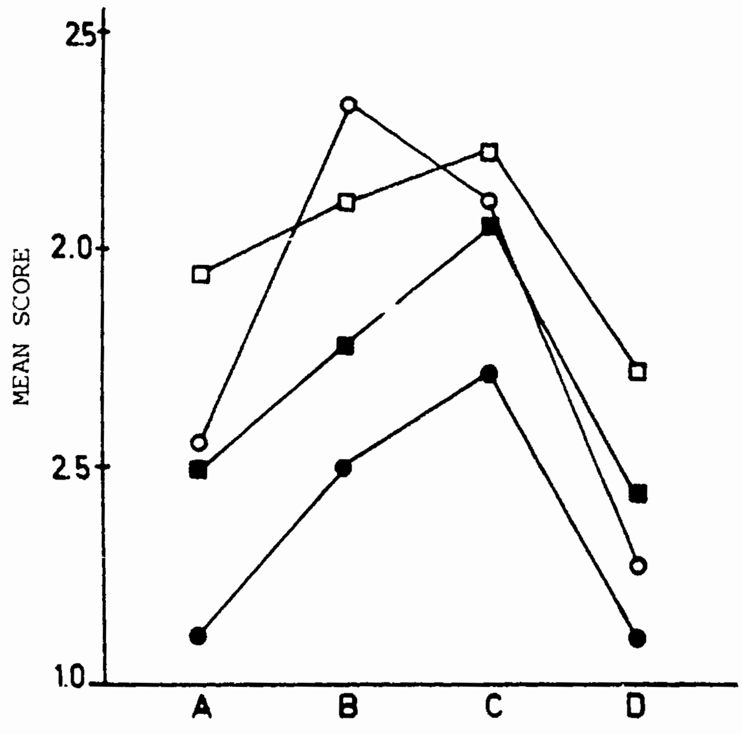
* their behaviour in certain circumstances;
* the rate at which they absorb information;
* the questions that they ask; and
* how they answer questions.

Dale described this as the sort of information Piaget collected in determining the level at which a child was operating. The role of the teacher was to choose material based on close observation of the student rather than simply to test whether the student was prepared for the next scientific activity. Teachers' ability to match student and materials was obviously an issue for Dale. Tisher and Dale (1975) later produced for teachers and others a pencil and paper test of developmental level. Many participants at the Conference accepted that there were many paths to knowledge and much subsequent research has supported this biological view (Rowell, 1984). The teacher training problem was to become a persistent issue. Rowell and Dawson (1977) raised doubts for example about the soundness of ASEP's assumption of teachers' optimal matching in classrooms. Dale recognized this issue. He became critical of the time and resources that were allocated to the formative evaluation process which was to run out in 1974. Whilst acknowledging that the testing process improved the Units he argued that an overemphasis reduced the opportunities and potency of the Project in professional re-education specifically in the biological theory of intelligence.

TEACHING SCIENTIFIC INQUIRY

The Conference endorsed the Inquiry Approach consistent with the principles Dale devised from Piagetian theory. The great success of the "Web of Life" course rewritten in Australia from BSCS material inspired confidence in the aims and methods of the approach.

Critical questions about the revolutionary "Web of Life" Biology course had focussed in its early years upon the significance of the aim of developing skills and attitudes of scientific enquiry. The pragmatic question was whether this was practically achieved and therefore a valid aim. This was not initially posed in the context of stages of development. Lucas (1968, 1969) for example compared students who had not studied biology with students who had done the Web of Life Course on aspects of scientific enquiry (Fig. 3). His results and those of Batten (Note 3) suggested some success but also the significance of an "ability" factor.



Open symbols: Upper ability group Circles: Non Biology students
Solid symbols: Lower ability group Squares: Biology students

A. biological prediction (multiple choice)
B. chemical prediction (multiple choice) (extended answer)
C. biological control (multiple choice)
D. errors of inference

Fig. 3 The Validity Of Teaching "Content Free" Objectives

Morgan (Note 4) in reply to Lucas later confided that the course had been less successful than he hoped in this area and explained this failure in terms of the Piagetian stages. His data showed that many senior students had not achieved formal operations (Blake 1978). Morgan changed the course objectives for subsequent editions to be more in line with Schwab's conception of a broader historical appreciation of biological explanation rather than a training in scientific method.

In ASEP, success in the inquiry approach had to be achieved by all students. For Dale, Piaget's organismic theory which made logic submit to life seemed to provide more flexibility than mechanical logical systems which made life submit to logic. In this he was supported by Eldridge, a Tasmanian delegate at the Conference who proposed that the "slow" learner was not adequately catered for in the JSSP material. "At this point we cannot put our finger on it but it seems to be largely a matter of reading ability." Vickery concurred: "We are not considering a two year extension of JSSP because the objectives and instructional procedures are different to the ones I have brought from W.A".

ORGANISMIC THEORY

The organismic assumptions of importance in development of the pedagogical principles of ASEP were:

* a belief that living organisms are qualitatively different from each other.
* a belief that in looking at living organisms it is systematic organisation - the hierarchical and the interactional - which should be stressed.
* a belief in and commitment to the notion of homeostatic regulation as a framework encompassing the essential development. The external environment is a necessary trigger to change, but development itself is internal.

The ideas of epigenesis, equilibration and auto-regulation were present in scientific intellectual arguments of the 1920s and 1930s. They were developed by Dewey and reintroduced by Schwab (1956) in his characterisation of both the growth of biological knowledge and biology teaching (Fawns, 1988b). The pedagogic implication of the shift from an empirical behaviourist framework to an idealist-structuralist one are important and not discernible in arguments about science curricula in Australia much before The Web of Life. In the Web of Life materials a number of Conference speakers saw the development of broadly transforming habits of classroom discussion which would lead students to understand scientific thought as the continuous restructuring of public knowledge and not merely scientific reasoning.

Piaget's notion of intelligence, like Dewey's, as an active process of construction, generic in species, with knowledge resulting from construction or invention, was clearly a challenge to frameworks of permanence and mechanical determinism. Behind the disavowal of the need for a theory of intellectual development in the behaviourist tradition was the assumption that the child presented itself directly and simply to common sense observation.

Dale claims to have been attracted to the philosophy of Kant in his undergraduate studies, in which he majored in biological sciences. He saw the curriculum as a framework by which to alter the epistemology of students and to facilitate change in teaching styles to accomplish this. As a successor to the synoptic textbook which defined a simplified unchanging world JSSP attempted to build in a purposive mechanism guided by logical rules. The JSSP design was intended to shape and change behaviour in classrooms by accommodating ability differences in different rates of progress. Science remained invariant. In marked contrast, the ASEP Unit, required the child to be invariant, proceeding through integrated patterns of thought called stages.

As an explanatory device, Dale was able to use Piagetian theory in opposition to both vitalism (nature study) and mechanism (programmed instruction) in the teaching of general science. In the 1930s it had turned out to be very difficult for Stanhope and Turner in Australia and Lauwerys and Shelton in England to define which analysis of technical and scientific principles or behaviour organised the themes for the General Science courses they attempted to promote. Dale's ASEP unit offered its own solution. Each unit was viewed as having a systematic life of its own. A major advantage of this organismic system for Dale was its very adaptability. While the state and pattern of the whole could be unequivocally defined as known, stable and common, the detailed state and pathways of relationship of the parts could be treated as undefinable, unique and non-recurrent, without loss of plausibility. Dale took the structural parts from the JSSP unit but rejected the Newtonian and Darwinian determinancy and behavioural causality, in favour of a more dialectical structure.

Criticisms Revisited

Piaget's organismic theory will still seem to many science teachers to dangle on the edge of mysticism. Dale saw the theory was underdeveloped at certain points. He is still convinced however of its value as a practical scheme. Organicism, holism, vitalism have varying degrees of "mystical" elements in them in that there is in these a certain searching for para-scientific transcendence. Piaget in Biology and Knowledge (1971) drew on the writings of other organicist biologists of the 1930s like Waddington, Weiss and Cannon, who opened up the field of cybernetics based on central notions of information and direction or autocontrol. He drew powerful historical analogies between the knowledge of the biologist and the epistemologist to discuss the changes in biological explanation from genetic predeterminism to developmental interactionism. Some critics since 1970 have read Piaget and hence the ASEP model in the purely maturational terms of presenting an inevitable development via natural internal forces. There was never a sense of inevitability in Dale's organismic view. Much of his PhD is concerned with training (Dale 1975). He indicated his concern that Piaget's descriptions of formal operations were often ambiguous and seemed to equate logical operations with reasoning. He sought to include psychological elements like field dependence and independence in his major study. Some of the critics have emphasized that learning is a radical reconstructive and reflective actitivity. The teacher's role as they see it is to help the children step back and interact with their own activity rather than with the structures of the discipline as the teacher "sees" them. Other critics have asserted that the use of a discipline's structure should be beneficial in providing contrast and organisation for the student's own reflections. Emphasis on the power of contrast to help the individual go beyond the information given brings to mind Bruner's theory of instruction and the curriculum reform movement of the sixties.

The organicists have argued that an organism interacting with its environment (a stimulus) should be studied in a systematic manner. Pedagogically this means that "mistakes" in arithmetic or scientific explanation should be looked upon not in isolation, but as part of a large more coherent whole. Mis ,kes should be viewed as real attempts by the children to order their universe. Thus, we look beyond the immediacy of the mistake itself to see the logical or semi-logical underlying pattern of prior knowledge which as Fensham (1970) early observed would not necessarily have a positive relation to mental restructuring. What appears as chaos at one level of systematic organisation shows signs of order at the next. The assumption that a dialectical searching with the child is likely to be far more beneficial than the didactic manoeuvre or a quick correcting of the error has strengthened since 1970. A dialectic relationship is sought between the levels of the child's structures and those of the discipline studied. Many critics have argued that this dialectic relationship must have a strong constructivist thrust claiming that transformation will occur to the degree that the individual is able to fashion particular elements into a coherent, logical and productive framework. This framework adds to reflection a quality that Dewey did not see.

A number of critics have argued that Piaget and ASEP ignored individual experience and the social dynamics of change by not paying sufficient attention to the role of language in learning. ASEP classrooms were organised around talking groups but paid little attention to the quality of communication in the groups. Critics asking for greater emphasis upon personal and social experiences often call for alternative curricula.

Munby (1983) observed that most theorists and critics dealing with Piaget have ignored his organicist background and have attempted to force an organicist world view into a mechanistic plan. To practicalize Piaget or ASEP this biological framework must be recognised and understood. What then of teachers? How can they make ASEP practical if they have not been trained and do not work in schools where this framework is valued, desired or even recognised and where the mechanistic tradition is dominant? Dale asked these questions twenty years ago. His attempt at a solution was the ASEP guide and the 44 core and option Units. He concluded that the teacher as decision maker is not something that schools seem to want. Critics ask whether a teacher can have the range of autonomy which would, in a period of crisis and uncertainty, permit the transition from curriculum user to curriculum maker? Can teachers accept the perfectly defensible position that typical reactions of students are not fragmentary and that the conceptual or abstract level of psychological functioning is the normal level of human functioning? Dale observed that restrictions on teachers in the classroom resided in rules of the game of schooling - rules which dictate a general level of functioning that moves directly and without processing from student behaviours to assumptions about intellectual potential. He sought to "invent", in Piaget's sense of understanding, a scientific theory to underpin a progressive approach in schools through the Project and the idea of the ASEP unit (Dale, 1975). By so doing he elevated theory from the Social Sciences to a new status as a method of analysis of both the pedagogy and children's learning of science in Australia.

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THE QUALITY OF TEACHER EDUCATION PROGRAMS: METHODOLOGICAL AND PROCEDURAL ISSUES FOR REVIEWERS

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ABSTRACT

The National Disciplinary Review was charged with reporting on the quality of the mathematics and science teacher education programs in universities and C.A.E.'s in Australia. Given the limited direct contact that such a review could have with these programs, the reviewers chose to use a grounded theory approach as much as possible. They were informed about the courses, by exit students from each of them, by official handbooks and additional explanatory information, and by data from interviews with key members of staff. These, with help from the research literature, commissioned papers and particularly the practices encountered during the visits to institutions, enabled descriptions and some criteria of quality practice to be developed.

INTRODUCTION

Evaluation is now a major field of educational study and practice. One subset of this field is exemplified by the Disciplinary Reviews that have been established by the Ministry responsible for higher education in Australia.

These reviews are intended to be both a means of monitoring the state of practice in a discrete sector of higher education, and of establishing processes of reformation inside universities and colleges of advanced education, and outside, in appropriate governmental departments and other bodies which employ its graduates. Accordingly, it is not unexpected nor unreasonable to find reference to the quality of the educational programs in the terms of reference provided to the review panel.

The four-person panel, who accepted the task of the Disciplinary Review of Teacher Education in Mathematics and Science, had three terms of reference that related to quality (DEET, 1989) :

1(b) The Review Panel shall examine the quality of teacher preparation in mathematics and science, in mathematics and science education and in other aspects of the professional development at each higher education institution, with particular reference to the levels of attainment expected of students by institutions;

2(a) The Review Panel shall report on the nature and quality of pre-service and post experience courses in higher education institutions for teachers of mathematics and science;

2(c) The Review Panel shall report on the quality and efficiency of teaching and where appropriate research in higher education institutions relating to mathematics and science teacher education.

While such terms are reasonable in the sense that they relate to obvious questions and hopes to which the review process should contribute, they are much less reasonable and obvious when it comes to providing answers and related recommendations. A research investigation of quality in these programs may have chosen to sample them and so extend the direct experience that its investigators would have had with the selected programs. The reference to "each institution" in l(b) above precluded this option and, in fact, set a limit on the depth and extent of contact the Review Panel could have with any one program. Australia, in 1988 when the Review began, had 52 institutions involved in the preparation of teachers. In them, there were 135 distinct programs to be reviewed - 18 early childhood, 55 primary and 62 secondary. A two day visit to each institution was what could be managed and afforded.

Pirsig (1976) in his exploration of quality was struck by the paradox that while it is impossible to describe what quality is, everybody can recognise it when they see it. It is not difficult to get wide agreement that a particular film, for example, is of high quality. But to distil from that a set of characteristics of quality films is not very helpful. Another film, also judged to be of high quality, may be rated poorly on each of those characteristics and acquire its quality judgement from its excellence on some other characteristics.

Linke (1984) and Bourke (1986) have reported on the matter of the quality of institutions of higher education in Australia. More recently considerable attention has been given to the issue of performance indicators (AVCC/ACDP, 1989). This has shifted the focus of attention to the department or the appropriate unit of aggregation for performance indicators. For sustained improvement of teaching, Elton (1987) also argued that the academic department (or sub-departmental group) responsible for the teaching of a course of studies is the critical unit. It is just such a group of staff with which the Review was concerned, but even in this situation, the Review Panel was able to gain access to this group (or most of it) for only some parts of a whole teacher education program.

The Review Panel rejected an approach based on a priori definitions of quality characteristics followed by their measurement. In this paper we describe how it did evaluate quality in the programs it encountered. To simplify the paper and enable more detail to be provided we will use secondary pre-service science programs of the degree plus Dip. Ed. type to illustrate our approach. Similar reports can be provided for each of the other "types" of programs we identified, although not all those responsible in the institutions agree with these identifications and see their program as more distinctive.

SOURCES OF INFORMATION RE QUALITY

Three separate sources of information were used - exit students, staff, and program details. Our basic intention was to allow the meaning and the indications of quality to emerge from the data the Review gathered and unearthed - a naturalistic or grounded theory approach. The timetable of events did not, however, always allow this to happen.

Students

For example, we would like to have explored in exit students their acquisition of a number of pointers to quality that had emerged through the Review. These could have been both those things that the staff of an institution claimed to be the quality features of their courses and other things that had emerged more generally. As it happened, our only chance to survey exit students extensively was very early in the project's life, namely, in September-October 1988. Accordingly, the project team made lists of three sorts of knowledge that were associated respectively with knowledge in the disciplines of science, knowledge of curriculum, and knowledge of pedagogical procedures. The particular items were derived from the panel's previous experience, the literature on teacher education for mathematics and science, the current trends in curriculum in these fields, and the directions the terms of reference provided. These were checked and refined with advice from its management group and consultants. The sorts of knowledge in these categories are listed below and the specific descriptions are provided in Volume 2 of the Review Report (DEET 1989).

Discipline Knowledge: (a) broad content knowledge, (b) specific knowledge related to years 9 - 10, and (c) specific knowledge to teach years 11 - 12 by major science studied.

Curriculum Knowledge: (a) of the relevant state curricula, (b) of national and international trends in curriculum, (c) to develop a small teaching/learning unit, (d) of how science can link to other parts of the curricula, and (e) of gender factors and science content.

Pedagogical Knowledge: (a) of a number of well known approaches in science, e.g. expository, inquiry, project-based excursions, laboratory and problem-based, (b) of strategies associated with special groups, e.g. girls, disabled students, and individual differences, (c) of constructivist or meta-cognitive approaches, and (d) of computer-based methods.

A preliminary analysis of these data from the exit students was made available in advance of the team's visit to each institution along with the team's summary of the structural features of its courses. Statistical analysis provided direct comparisons between a particular group of students' responses concerning the learning outcomes and the national or state average of students in similar programs. In reporting on the individual institutions, these student data were used but, in recognition of their incompleteness and other limitations in the survey procedures, our comments were never based on the student data alone. This early concentration on some learning outcomes that might be expected from an initial education for mathematics and science teaching did, of course, colour to some extent both the team's sense of the possible and the scope of the discussions during the institutional visits.

Staff

If characteristics of staff were to be used to suggest quality, the question of which staff immediately arose. The panel chose what seemed to be the obvious group for each institution from the individual curricula vitae submitted to it. In some cases, the composition was changed if the institution made a case for doing so. In general the staff were full-time and directly involved in teaching Methods and Practice of science teaching. These staff provided details concerning themselves, such as age, gender, qualifications and teaching experience. While these structural variables were important for other aspects of the Review, they have, we believe, little direct linkage to quality, although it may, indeed, be hard to develop an adequate dimension of gender inclusiveness in the total absence of either women or men in the staff group.

The involvement of staff in professional activities with science teachers and curricula and their research record seemed to be more likely pointers to the quality of the courses (and its maintenance) for which these persons are responsible. The assumptions behind this are that contacts with the current practices in schools or with the growing edge of thinking about and studying them are likely to lead to more effective teaching, particularly when it is the program or sub-program as a whole rather than the individual staff member that is under scrutiny. The data collected on these two aspects of the staff's work were as follows:

Professional activities (time spent over last five years): (a) consultancies in science education, (b) contributions to school science, and (c) non-award inservice involvement in school science.

Research (over last five years): (a) internal grants (b) external grants, and (c) publications (books, edited books, articles in journals, book chapters, reports, etc.)

The raw data were self-declared by the designated staff persons and they were usually accepted as such by the team, except in cases where the definition of the data seemed clearly to have been misunderstood and unusually high values (days or publications per year) were reported. Direct communication with the institution either confirmed these values or led to revisions.

These data were analysed in a number of ways. For the group of staff in each institution, totals for each sub-index were calculated and a mean value (days, grants, publications) per staff member was derived, as well as a sense of the distribution of performance among the group including the number and proportion of staff with zero values.

Combinations of the data led to indices of "overall professional activities" per person, and of "composite publications rate" corresponding to an equivalent single author paper per year (West, Hore and Boon, 1980). The data were also factor analysed and two factors emerged which could be associated with "professional activity" and "research". The component indices and the factor values for each institution were, respectively, plotted against each other (see page 107, volume 2, DEET, 1989).

The striking findings from these analyses are (i) the correlation between "involvement in professional activities" and "research output", (ii) the not unexpected prominence of the better known groups of science educators in some of the universities, and (iii) the inconspicuous role of most of the groups in the CAEs, not only in research but also in professional activities. The sometimes presented argument of involvement with the profession (the applied or socially-relevant argument that was used in the binary system for CAEs as "equal but different") was certainly not sustained by the review's findings. Rather, it seems that those who are well known through their publications tend to be those who are invited to participate in professional activities. Pursuing the assumptions that were made in this matter by the reviewers, these findings suggest that encouragement of research among the enlarged group of science education staff in Australia's new unified universities should be a high priority if the quality of courses in the next decade are to be maintained by the stimuli that involvement with the profession can provide. This will be a real challenge to deans of these enlarged schools or faculties since they are also under pressure to develop the two cultures of research and teaching separately among their staff.

Programs

The information about programs developed as the Review proceeded. It began with handbooks and other print materials that added detail to the often cryptic descriptions of a course and its component parts in the handbook. The process of analysing these descriptions often led to further information being required from the liaison person each institution had established for the panel to contact. By the time the team visited an institution it had made a draft summary of the information provided and this was left for factual revision by the staff concerned.

It was important to contain the Review and not let it stray to the whole of teacher education. The panel, reluctantly, thus could gain only cursory information about the more general studies of education foundational studies in the programs. We can, accordingly, only report on our approaches to quality in relation to the science and science education components.

After the rich and variegated experiences of the 52 visits were concluded and the many other sets of data had been assimilated, at least at an initial level, the Review panel made some decisions about how to report on what they had learnt about quality. In chapter 4 of Volume 1 they set out a set of desirable features that a quality course of science teacher education needed. They also described a number of qualitative aspects of courses that they believed led to high quality preparation of teachers.

In the case of the academic science in each course, it would have been presumptuous of the panel to evaluate its content in other than structural terms. Two sorts of structural features were, however, developed. Those concerning the depth and breadth of the science provided were determined by the fact that Australian science teachers are expected to teach a disciplinary science curriculum in the senior secondary levels and one of the world's most integrated forms of science in the lower and middle secondary ones. Accordingly a major study in one science over three years (of the weight available in the older universities) and the opportunity to include at least one year of study of the three other science areas, was taken as a necessary condition for quality.

A number of courses in the CAEs met the second criterion more definitely by requiring these three minor science studies, but their so-called major science study had little more weight than the first two years of study in a university albeit that it occurred over three years.

The second set of structural criteria was derived from some of the subsidiary characteristics that employers are seeking in science graduates entering industry or applied research. The ones chosen were those which also seemed to be useful to future teachers in the light of the contemporary trends in science curriculum content and pedagogy. This approach seemed to be reasonable since a majority of science graduates will enter these fields of employment. Employment as teachers was a prospect for such a small proportion (less than 10% in most universities) of the university science graduates, that it was unreasonable to expect to find features in these tertiary science curricula that were specially catering for such a minority. The criteria were :

* Nature of Science - how knowledge is generated in a particular science, what are some of its characteristic concepts, methods and arguments, how its experimental procedures have been developed, and how they can be put into practice to design an investigation of a problem (as distinct from doing set experiments).

* Communication - how knowledge is stored in science, how it can be accessed, and how these scientists communicate to each other and to non-scientists.

* Computers - how are these being used to improve teaching and learning and what new aspects of the science are now amenable to undergraduate science because computers are available.

* Applied Science and Technology - how applications of science, and particularly Australian ones, form a significant component of the course.

In the Panel's discussions with science staff, information was sought about whether these sorts of features were present and when they were introduced in a substantial way for students.

In the case of science education a number of the qualitative aspects of the courses could be extracted and described as dimensions along which a course of study can be developed. In order to assist staff locate their own programs along the dimensions and to enable them to gain a sense of dimensional direction three sorts of categories (A, B, C) were described for each dimension. The dimensions are listed in Table 1 and the three descriptions for each one are given in Appendix I. The numbers of courses that were rated as A, B and C are also shown in Table 1.

TABLE 1

DIMENSIONS OF COURSES IN SCIENCE EDUCATION

	A	B	C
Curriculum Knowledge	24	14	0
Pedagogical Knowledge	21	15	2
Contemporary Perspectives	14	15	9
Gender	6	22	10
Applications of Science to Society	18	18	2
Methods - Practicum Relationship	20	13	5

The members of the panel independently rated the programs for which they had full familiarity (data file and visit), and found a high level of concordance. Each program could thus be given a "quality profile", A C A B - -, on these dimensions of content. These quality gradings, it should be noted, are subject not only to the limit of the dimensions included but also to the limitations of the information about them that was available to the panel. The panel sought advice from the Review steering committee about reporting these dimensions and the individual program profiles. It was agreed that the descriptions of the dimensions should be included, but the individual profiles were to be communicated only to the dean and liaison person in each institution. In fact, in the last minute flurry to meet the deadline for the report to be delivered to Canberra, the descriptions of the dimensions were inadvertently omitted. The profiles have not, accordingly, been transmitted as planned. This paper provides a useful opportunity to report this aspect of the panel's response to its quality terms of reference.

REFLECTIONS

Despite Pirsig's warnings, the Review did produce a description of quality of teacher education programs. The description took several forms : a form of minimum quality definition of teacher education programs (described in chapter 4 of Volume 1 of the report as "desirable features", but interpreted by some commentators as minimum standards); evaluative judgements about various programs, their staff and their students; and a set of performance indicators concerning programs, graduates and staff.

The emergence of these descriptions is not easily described, hampered by the linear nature of writing which does not match the cyclic nature of the analysis itself. As the panel examined the sources of information about a particular department/group and its programs, some characteristics of quality were identified. Examination of another department/group and its programs sometimes reinforced these characteristics, sometimes added new aspects, and sometimes led to a re-evaluation of previous judgements. The commissioned papers (and, indeed, the panel members' own conceptions about quality of teacher education) also provide more than static theoretical framework for the Review. Deeper meanings emerged for interpreting aspects of departments/ groups and their programs as ideas were distilled from these papers.

Others will judge the success of the Review's approach. The panel remains convinced of the superiority of their approach over the alternative of specifying fully a set of characteristics of quality in teacher education programs and then gathering a priori data to rate them on those characteristics.

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APPENDIX I

CATEGORIES FOR DIMENSIONS OF SCIENCE EDUCATION COURSES

Curriculum Knowledge

A Programs which provided adequate coverage of the local (state) school science curriculum and the major national curricula, provided students with an opportunity to develop a small curriculum unit themselves, and provided some framework of national and international curriculum movements within which the local curriculum could be interpreted.

B Programs which provided adequate coverage of local school curricula only.

C Programs which did not provide adequate coverage of local school curricula, or did not have such coverage in compulsory units.

Pedagogical Knowledge

A Programs which provided instruction in and opportunities to practise the teaching of a range of traditional and contemporary approaches to the teaching of science.

B Programs which provided instruction in the teaching of a range of traditional and contemporary approaches to the teaching of science but no related opportunities to practise. Or programs that provided instruction in a limited range of teaching approaches (eg traditional approaches only) even if opportunities to practise were available.

C Programs which provided instruction in a narrow range of approaches to teaching science and no related opportunities for practise. Or programs that had no instruction in pedagogy that was specific to science.

Contemporary Perspectives

A Programs in which science curriculum and pedagogy units provided access to a range of contemporary thinking and writing in science learning and teaching.

B Programs in which science curriculum and pedagogy units provided access to only a limited range of contemporary thinking in science learning and teaching (eg. to Gagné and Piaget only).

C Programs in which the science curriculum and pedagogy units were essentially theoretical.

Methods - Practicum Relationship

A Programs in which there was a substantial relationship between the science curriculum and pedagogy units and the teaching that students undertook in science in their teaching practice. Such relationships sometimes included set teaching tasks prepared in the curriculum and pedagogy units and discussed in subsequent classes.

B Programs in which there was a limited link between science and curriculum pedagogy units and students' teaching practice. Such links included for example some set tasks but no follow up.

C Programs in which there was little or no relationship between the science curriculum and pedagogy units and the students' teaching practice.

Use of Technology in Teaching of Science

A Programs in which instruction was given in ways in which computers can be used in teaching science, and in which practice in them was provided.

B Programs in which the use of computers in teaching science was included as a topic in curriculum and pedagogy units but these approaches were not used.

C Programs in which the use of computers were not included in the curriculum and pedagogy units.

Application of Science to Society

A Programs in which the science curriculum and pedagogy units included an introduction to ways in which applications of science can be taught.

B Programs in which applications of science were not a significant component of the science curriculum and pedagogy units.

Gender

A Programs in which gender and science/science education were included as a topic and as integral parts of the curriculum and pedagogy of the program - that is gender inclusiveness was both included and practised.

B Programs in which gender and science/science education were included as a topic but not integrated into the program.

C Programs in which gender and science/science education were not included or were very marginal.

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LEARNING ENVIRONMENT, LEARNING STYLES AND CONCEPTUAL UNDERSTANDING

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ABSTRACT

In recent years there have been many studies on learners developing conceptions of natural phenomena. However, so far there have been few attempts to investigate how the characteristics of the learners and their environment influence such conceptions.

This study began with an attempt to use an instrument developed by McCarthy (1981) to describe learners in Malaysian primary schools. This proved inappropriate as Asian primary classrooms do not provide the same kind of environment as US classrooms. It was decided to develop a learning style checklist to suit the local context and which could be used to describe differences between learners which teachers could appreciate and use. The checklist included four dimensions - perceptual, process, self-confidence and motivation. The validated instrument was used to determine the learning style preferences of primary four pupils in Penang, Malaysia.

Later, an analysis was made regarding the influence of learning environment and learning styles on conceptual understanding in the topics of food, respiration and excretion. This study was replicated in the Philippines with the purpose of investigating the relationship between learning styles and achievement in science, where the topics of food, respiration and excretion have been taken up. A number of significant relationships were observed in these two studies.

INTRODUCTION

This paper synthesises the results of two studies on learning styles and children's understanding which are part of the Teaching-Learning Project in Malaysia conducted at the Regional Centre for Education in Science and Mathematics (RECSAM) and a replication study conducted in the Philippines. Although there have been a number of studies in these two fields, it is the cultural setting and its corresponding learning environment which make this work different.

Learning environment is a factor that can influence how learning occurs in the classroom. It refers to the number and kinds of alternatives made available to the pupils and the "provision made for mobility and multilevel resources when they are needed" (Dunn & Dunn, 1979).

Learning styles pertain to the cognitive, affective and physiological elements in the overt behaviours of pupils which may indicate how they learn best (Ferrer & Leong, 1990). They refer to a kind of home base where one feels most comfortable in coping with a learning situation. Learning styles refer, more specifically, to individuals' preferences in effecting and acquiring behavioural changes. There are occasions however, when out of necessity, pupils develop styles that suit the prescribed learning environment and learning occurs (not necessarily understanding) through using ways that are not congruent with their own preferences. For example, when we teach our pupils a lot of science content and drill them on conceptual labels in revision, is there any understanding taking place? This kind of environment may serve a few whose intention is simply to pass examinations, but not those who want to learn and understand.

Understanding of a concept is not only a function of the extent of knowledge about it but also of the integration of that knowledge (White, 1988). The understanding of a concept thus requires the acquisition of fundamental knowledge and skills and the establishment of relationships between the elements which go to make up that concept and its relationship with the concepts in that area. Teachers can help pupils develop concepts by accommodating the different ways they prefer to learn. Their learning style preferences, somehow, exercise control over understanding and influence other knowledge, skills and attitudes.

INSTRUMENTATION

There are two main ways of describing how children approach learning. One method is to describe pupils in terms of a limited number of broad categories (McCarthy, 1981). Another is to describe pupils in terms of their profiles on a limited number of parameters (Dunn, Dunn & Price, 1987).

The first instrument used in this study was an adaptation of the 4 Mat system which is an eight-step cycle of instruction that capitalises on students' learning styles and brain dominance processing strengths (McCarthy, 1981). The instrument was tried out with 80 primary four pupils from two schools in Penang, Malaysia. The analysis of children's responses yielded low reliability coefficients. Interviews of children and observations of classes in science were conducted to determine the suitability of the items to the existing conditions in Malaysian classrooms as evidenced in the teaching behaviours and pupils' reactions to learning situations. The findings revealed that existing conditions in Malaysian classrooms do not match the conceptual framework of McCarthy's model which was basically meant for American students. The learning environment in US and in other countries where McCarthy's instrument was tried out is different from the learning environment experienced by pupils in Malaysia. This explains the low reliability of the first generation instrument.

There was a need, therefore, to develop an instrument that truly describes the reality of the learning environment of the target clientele. An instrument that would establish the learning style profiles of individuals was necessary. A series of interviews was conducted with primary school children from different ability groups to determine modes of coping with learning difficulties and various ways of approaching learning situations in primary science. The children were also asked to describe the activities they do in the science class to probe into the kind of learning environment set up by the teacher. Various ways of reacting to the learning environment were likewise sought. The children's responses were incorporated in the new instrument that describes children's approaches to learning in terms of their profiles on four dimensions - modes of perceiving and processing information for the cognitive domain, and self-confidence/self-esteem as well as motivation for the affective domain.

Following are the four learning style dimensions and the descriptions of the scales in each:

Perceptual dimension describes a learner as concrete or abstract in terms of perceiving information. Concrete-abstract characterises the learner's tendency to use sensory modes of perceiving information such as visual and tactile for concrete, and auditory and verbal for abstract.

Process dimension describes a learner as passive or active in terms of processing information. Passive-active shows the extent of understanding a learner gives to a task. A passive processor needs external aids in understanding and limits targets to bare essentials. An active processor engages in deep reading and active mental tasks to understand meanings and welcomes opportunities to discuss details.

Personality dimension indicates attributes of the personality of the learner pertaining to self-confidence/self-esteem, whether low or high. Low-high self-confidence/self-esteem shows the level of arousal or activation manifested by the learner as he/she approaches a learning situation, whether low or high in terms of confidence, dependency and anxiety. A learner with low confidence does not feel clever, works dependently, and is afraid to leave unfinished tasks. This works the other way around for a learner with high confidence.

Motivation dimension identifies the approach to learning preferred by the learner, whether superficial or deep. Superficial-deep indicates commitment of the learner to a standard of achievement, whether superficial or deep. Preferences for external stimuli that are more appealing, familiar and less complex characterise superficial commitment while concerns for more thinking tasks for the sake of understanding describe deep commitment.

Below is a sample item for the perceptual dimension.

I usually like a lesson in which
A. I can see, touch and discuss things being learned.
B. the teacher demonstrates to the class things that are being learned.
C. I listen to the teacher and copy notes from the board.
D. I listen to the teacher and read about it.

The new instrument called Learning Style Checklist (LSC) was administered to 224 primary pupils who were randomly selected from six primary schools in the Island of Penang. The results on the 20 items were subjected to analysis to test the validity of the scales derived from the responses obtained with an earlier sample of 80 pupils using a clustering procedure. After a series of try-outs and factor analyses, the LSC was reduced to 10 items. Internal consistency reliabilities and criterion-related validity were established.

To determine the consistency of LSC scores, two indices of reliability were utilised: test-retest and internal consistency. Table 1 gives a list of reliabilities per dimension.

TABLE 1

RELIABILITY COEFFICIENTS OF THE LSC

Dimension	Test-retest	Internal Consistency
Self-Confidence (Low-High)	.76	.54
Perceptual (Concrete-Abstract)	.48	.54
Process (Passive-Active)	.73	.57
Motivation ((Surface-Deep),	.59	.58

High test-retest reliabilities are reported in the areas of personality, process and motivation with r greater than .50. In modes of perceiving information change over time is expected to happen depending upon the complexity of the learning tasks being undertaken.

Expressed as Cronbach alpha coefficients, the internal consistency reliabilities of the four components are .50 and above. A low alpha (less than .40) suggests that the scale in question reflects more than one underlying attribute, which is not a satisfactory situation because a score on such a scale is difficult to interpret (Biggs, 1987). The present values are most satisfactory considering the number of items in each category is very small.

TABLE 2
CORRELATIONS BETWEEN TEACHERS' RATINGS
AND PUPILS' LSC SCORES

Dimension	Correlation Coefficient
Personality (Low-High Self-Confidence)	.80
Perceptual (Concrete-Abstract)	.62
Process (Passive-Active)	.77
Motivation (Superficial-Deep)	.76
Overall	.68

Another important task performed was the determination of the degree to which the LSC scores are systematically related to one or more outcome criteria. In this study, teachers' ratings were used as the criterion variable. They were correlated with the pupils' LSC scores. Table 2 reports the validity coefficients after correction for attenuation.

To determine children's understanding, a Test of Understanding of Concepts (TUC) was developed for the concepts of food, respiration and excretion, the three topics identified as difficult to teach and learn by teachers and pupils. These are some of the topics covered in the science component of the subject, Man and Environment where children spend about 16% of their academic time in school. The test was constructed out of the results of the interviews-about-instances (Osborne & Gilbert, 1980) carried out with primary pupils who have studied the three areas under investigation. Content and criterion-related validity as well as internal consistency reliabilities were established. The criterion variable used to correlate with pupils' scores on the TUC was pupils' rating in the subject, Man and Environment. The correlation coefficients after correction for attenuation were .55 for the section on food, .64 for respiration and .65 for excretion. The overall correlation coefficient was .71.

To determine the internal consistency reliability, a sample of 60 pupils was used. Table 3 shows the Cronbach alpha coefficients for each of the three sections of the test and the overall index of internal consistency.

TABLE 3
INTERNAL CONSISTENCY RELIABILITY OF THE TUC

Test Section	Reliability Coefficient
Food	.68
Respiration	.84
Excretion	.93
Overall	.88

PROCEDURE

Subjects

The sample used in this study consisted of 200 primary four pupils randomly selected from a total population of 900 pupils from six primary schools in the Island of Penang. These six schools comprised more than 10% of the total number of national primary schools in Penang Island. They were chosen on the basis of the following criteria: (1) they are the typical average suburban primary schools, (2) they have average student population, and (3) they use the national language as medium of instruction.

The primary four pupils who comprised the sample belonged to the nine to ten age group and were studying science for the first time. Science is a component of the subject Man and Environment which is introduced in the primary level in year four. Between the administration of the LSC and TUC instruments, the pupils in this study had several months of exposure to Man and Environment.

Data Collection

The 200 pupils used with the final ten-item version of the LSC were used to norm the instrument. The use of norms allows teachers to compare their pupils with a larger population. Table 4 gives a profile scoring based on a local norm which utilised a 33.3 percentile range for each of the -, 0, and + levels.

An average scale score identifies the child as (0) which is between the two opposite levels of a scale, e.g. low (-) and high (+). A score less than the average places the child on the left of the area measured, e.g. low self-confidence, while a score above the average places the child on the right of the area, e.g. high self-confidence.

TABLE 4
PROFILE SCORING

Dimension	No. of Items	Profiles -	0	+
Self-confidence (Low-High)	4	4-8	9- 11	12-18
Perceptual(Concrete-Abstract)	2	2-3	4 - 5	6 - 8
Process (Passive-Active)	2	2-5	6 - 7	8
Motivation (Superficial-Deep)	2	2-4	5 - 6	7 - 8

The TUC was likewise administered to the same pupils who were given the LSC. Out of the 200 primary four pupils tested on the concepts of food, respiration and excretion, the bottom 60 students on the test which represent the lower 30% of the total sample were involved in a study to determine if a relationship between learning style and conceptual understanding existed. The learning styles of these children were analysed.

In addition to the data collected from the LSC and the TUC, interviews with 16 (27%) of the subjects were conducted to validate results. The interview sought to ascertain the children's preferred learning styles and also determine their preferred science activities and materials in learning food, respiration and excretion.

FINDINGS

The following statements are based on the analysis of the learning styles of children with conceptual difficulties in primary four science. They are substantiated by interview results.

Children with problems in understanding some difficult concepts in science had low to average self confidence. They liked more peer interactions and less of hands-on activities on their own.

The mode of perceiving information by these children with conceptual difficulties was a blend of concrete and abstract. They preferred to work with concrete objects. They required more explanations about things they didn't understand in the lesson.

A leaning toward active processing was firmly established. The children who expressed preference for this mode of processing information liked practical work and discussion (class and small group).

The children who experienced conceptual difficulties were predominantly motivated deeply. They preferred to read and understand by themselves. They didn't want games, puzzles and other similar unfamiliar classroom activities for "they are just a waste of time".

DISCUSSION

Children with low to average self-confidence would probably hold to ideas they believed to be correct rather than attempt to construct new untried understandings that they are less confident about. An effective change strategy would utilise these ideas as starting point for instruction and gradually lead the pupils to extend themselves by considering other ideas and modifying theirs in the light of some satisfactory views. This strategy is proposed since the common classroom practice fails to identify children's existing ideas prior to instruction. Observation of classes and interviews conducted with some science inspectors reveal the lack of opportunities for interaction provided by teachers in the classroom (Ferrer, Leong & Liau, 1989).

Well defined models are required to be constructed at every stage of development of the concept. Children should be assisted in constructing their own mental models. Breaking up a proposition into episodes may be particularly important in helping children understand as this produces feeling of confidence in the accuracy of the knowledge. For example, the proposition that energy is used to perform an activity can be demonstrated by making children run around and asking them later what they feel immediately after performing the activity. Children's association of energy with movement can be utilised as one model on which to base class discussion. The importance of such episodes in understanding is the theoretical justification for the emphasis placed on demonstration (as in the preceding example), practical work and field trips in science teaching (White, 1988). The need to present models in the form that suit the children's perceptual preferences should be considered by teachers and developers of instructional materials. These materials should be complemented by reading or discussion exercises which will enable the children to think about the concept more deeply. It is necessary to concretise instruction first before proceeding to more abstract presentations for this group of children with conceptual difficulties. However, in the case of the present study, the lack of instructional materials, cited as a major cause of teaching-learning difficulties by Malaysian primary school teachers (Ferrer, Leong & Liau, 1989), hinders effective concrete instruction. Thus, the tendency to short circuit teaching and learning through chalk and talk becomes quite evident.

Because the learning environment does not cater for active learning, the active processors of information are left behind. The trend towards active processing identified for children with conceptual difficulties suggests that these pupils should be assisted in forming links between elements or models they construct. Better still, they should be helped to bind into a coherent mass the many shared terms and elements they encounter. This pattern of association represents better understanding according to White (1988). Without assistance the children may impose their own structure of knowledge organisation and in doing inaccuracies may occur resulting to misunderstandings/misconceptions.

In normal learning situations, children of this age (10-11) are as yet unaware of their own learning processes. The tendency to use a strategy that is incongruent with their own motivation is very likely to occur, for example, the use of rote learning to satisfy an intrinsic curiosity (Biggs, 1987). A syllabus-oriented learning environment which emphasises the accomplishment of a minimum amount of essential learning per grading period increases the likelihood of a mismatch between the learning strategy needed for success and the children's own motives and preferences. There is a need, therefore, to make children aware of not only the content to be learned but also the process of learning how to learn according to their own motives and to understand their own learning.

THE REPLICATION STUDY

This replication study was done by Totica (Note 1) in the Philippines. The subjects consisted of 480 primary six pupils randomly selected by stratified sampling from six districts in Northern, Central and Southern Negros in the division of Negros Occidental, Philippines. These pupils came from two types of schools: central and barangay. A central school has a bigger population than the other schools in the district in an urban community. A barangay school is a rural school with a small population. The pupils from both types of schools study science as a separate subject starting from primary three. They follow a science syllabus that is more content than practical skills oriented.

Two instruments were used in this study. One was the national science achievement test and the other, the LSC developed by RECSAM's Teaching-Learning Project team. The former is a content-oriented test with a predominance of knowledge items while the latter is a preference-oriented checklist. Both instruments have been validated and their reliabilities established. The relevance of the LSC to Philippine context was sought by subjecting the instrument for evaluation by 34 primary six science teachers teaching in the division of Negros Occidental. The average index of relevance was 97.2% which may be considered as very relevant. To make it more applicable for the Filipino pupils, a new set of norms was established.

The data from the two instruments administered to the 480 subjects were correlated using Pearson r. The results reveal a significant negative relationship between mode of processing information and science achievement. Those who got high scores in the test were passive processors of information (children who obtained low scores in the process dimension of the LSC).

Significant findings were also observed in the analysis of the children's learning style scores, such as:

The mode of perceiving information preferred was mainly abstract.

Many were passive processors of information. The active ones were those who did not perform well in the test.

Majority of the children were deeply motivated in learning.

Children with low to average self-confidence/self-esteem did not perform well in the test. Most of them were also active processors of information.

CONCLUSIONS

A number of important points were noted in these two studies:

Pupils with low to average self-confidence/self-esteem are more likely to have conceptual difficulties.

Pupils who have a preference for active learning may have difficulties in learning in traditional classrooms, such as the case in Malaysia and the Philippines.

Pupils with difficulties in understanding, although motivated deeply, may be expected to approach learning in ways that are not congruent with their own motives.

The difficulties of these children might have been caused by a learning environment that puts heavy premium on examinations and fulfilment of rigid syllabus requirements. Rote learning which is encouraged by circumstances in the environment does not suit the learning styles of learners who are active processors of information. Pupils who memorise what the teacher says may do well initially and may even get high scores in the test as in the case of the Philippines study where the children were tested on mostly knowledge items with only a few comprehension questions. Eventually, these pupils will be limited in understanding. Pupils who search for meaning may well appear confused initially, but with effective teaching, they will progress much further. Ideally, teachers should teach all children in a way that promotes conceptual development, and not allow those who simply try to memorise facts and procedures to do so. They should try to minimise (if they cannot totally eradicate) such activities as organised note-taking, teacher-directed explorations and scheduled study times for they only create undesirable pressures on these pupils to concentrate on bare essentials rather than on deep thinking to which they are more inclined.

Another difficulty which affects conceptual understanding lies in the mismatch of the learning environment with the motivational approaches to learning by the pupils. Because the environment caters for rote learning the deeply motivated pupils have to approach learning along this path. This situation induces the emergence of "schizophrenics" in the classroom where children prefer to do one thing and actually do another thing.

FURTHER RESEARCH CONCERNS

Some further research questions that are pertinent are whether children's preferences in learning as revealed in what they write and say are consistent with what they do in terms of their behaviours in class and whether these preferences are persistent for all situations or only with certain situations.

An excellent follow-up study could be to administer the same instrument to the same children being taught by another teacher in a different learning environment. This would give an idea of a possible relationship between preferred learning style and teaching style, and learning style and school environment.

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MISCONCEPTIONS AND LIGHT: A CURRICULUM APPROACH

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ABSTRACT

This paper describes the method used by the author to teach a class of Year 8 students about light and its properties so that the students' own ideas were considered and their misconceptions addressed. To achieve this a series of teaching modules were designed using a model of conceptual change suggested by Posner and his colleagues at Cornell University. Students' prior misconceptions about light were identified using a pretest developed by the author. After teaching a posttest was used to determine if the teaching method resulted in a lower level of misconceptions. Interviews from seven students selected at random and the observations gathered by a participant observor were used to verify results.

It was found that the teaching method resulted in a lower level of misconceptions in the sample and this was confirmed by the results of the interviews and participant observation. This paper concentrates on the design and content of one of the teaching modules.

INTRODUCTION

Many ideas, which students have prior to instruction or develop during instruction, have been well documented in physics content areas such as heat, motion, the particulate nature of matter, and light. If the student's ideas conflict with generally scientifically accepted ideas they are labelled variously as misconceptions, preconceptions, childrens' science, alternative conceptions or alternative frameworks depending upon the researcher's view of the nature of knowledge.

Students' misconceptions are often strongly held, resistant to change and can hinder further learning; learned school science may have little effect upon students' misconceptions and students may undergo instruction in an area in science, perform reasonably well in a test on that subject, yet not undergo any meaningful change in their beliefs regarding the phenomena being investigated. Various studies (Anderson & Smith, 1984; Eaton, Harding & Anderson, 1983; Goldberg & McDermott, 1983; Guesne, Sere & Tiberghien, 1983; Karrqvist & Andersson, 1983; Rice & Feher, 1987; Shapiro, 1988; Stead & Osborne, 1980) used interviews and/or questionnaires to obtain student data and concluded that students did not use concepts systematically, that the particular situation determines the conception that is relevant, that many student conceptions were misconceptions and that these misconceptions were difficult to change through regular instruction. Only the studies by Anderson and Smith and by Eaton et al. produced learning materials that could be used by teachers to help students develop a better understanding of light. The topic of light, which is initially taught in Western Australian schools in grade 9 (aged 14-15 years), presented the author with similar concerns that instruction in the regular curriculum resulted in many students constructing knowledge which was not congruent with acceptable scientific understanding.

Conceptual change

According to Posner et al. (1982) and Hewson and Hewson (1983), whether or not a student will experience conceptual change as a result of instruction depends on the following four conditions being met:

* there must be dissatisfaction with existing conceptions;
* a new concept must be intelligible and be able to restructure experience to give meaning to the learner;
* the new concept must appear initially plausible; and
* the new concept should offer the possibility of extension to new applications and further conceptual growth.

Constructivism provides a theoretical base for the design of the materials used in instruction. Constructivists state that students' ideas should be considered before instruction is commenced. Practical work should enable students to reflect, construct meaning and experience conceptual change. Constructivists also suggest that learning must be considered from a developmental point of view and that teachers should consider conceptions that are useful for students.

The research literature provided a theoretical perspective for this study. An intervention was designed to teach the topic of light and its properties by initially considering the students' current state of knowledge. Then students were involved in practical activities to enable reflection on their ideas and experience dissonance and dissatisfaction with existing ideas. Conceptual change was encouraged through the reconstruction of meanings.

METHOD

Teaching materials and treatment.

Four teaching modules about light and its properties were developed primarily according to the model proposed by Posner et al. (1982). Hewson and Hewson (1983) suggested a teaching scheme which contains the following four elements:

* time should be spent diagnosing errors in student thinking;
* teaching procedures should be developed that create conflict;
* teaching strategies should be developed to deal with student thinking which is different to the scientifically acceptable explanation; and
* evaluation techniques should be developed to track the progress of conceptual change.

The four modules developed as part of this research incorporated these four conditions and were part of the regular curriculum which addressed State-required teaching objectives. The modules were:

(1) How does light travel?
(2) How do we see?
(3) How is light reflected?
(4) How do lenses work?

Module 3 is used to illustrate the teaching approach and results.

Instrumentation

A 16-item diagnostic test was used to collect data on student understanding of light and its properties and addressed identified misconceptions in the literature (Fetherstonhaugh, Happs & Treagust, 1987). Twelve of the items were presented in the form of multiple choice questions with four distractors plus an open response to provide a reason for c·.osing the distractor. Four items required an open response only. Using this test, the following misconceptions were identified in the sample. These misconceptions are listed in Table 1 along with their percentage frequency of occurence.

TABLE 1

MISCONCEPTIONS ABOUT LIGHT AND ITS PROPERTIES HELD BY YEAR 8 STUDENTS BEFORE INSTRUCTION AND PERCENTAGE FREQUENCY OF OCCURENCE.

Misconception	Percentage (n=20)
Light travels a different distance depending upon whether it is day or night.	35
Light does not travel during the day.	20
Light does not travel at all during the night.	15
We see by looking (visual ray idea), not by light being reflected to our eyes.	75
People can just see in the dark.	10
Cats can see in the dark.	42
Light stays on mirrors	25
Images can be in two places	56
Lenses are not necessary to form images	83
A whole lens is necessary to form an image	94

Subjects

The students involved in this study were grade 8 students from a regular non-streamed science class in a country senior high school in Western Australia. The class comprised 11 girls and nine boys.

Students' Ideas

Seven students selected at random from the sample were interviewed before and after the teaching intervention. The questions that they were asked relevant to module 3 were

"What is an image ? Does light carry images ?"
"What does light do when it hits a mirror ?"
"In how many places is an image ?"

The ideas espoused by the students were imaginative and diverse. For example Brendon was sure that "light reflects images" and images can be in an infinite number of places. Brian exhibited an egocentric view in stating that light only travels as far as you after

reflecting off a mirror. He also thought that we see images in mirrors because light reflects off the mirror to the object and that images were on mirrors. This incorrect order of events was not uncommon amongst students and needs further investigation. His lack of a logical model about reflection was further evidenced by his conviction that images are just reflections and can be in many spots. Clearly he had thought about the instances in question and was able on his own to evince credible (to him) solutions to explain the phenomena. His ideas also were not stable across instances. For example he believed that light reflects to the object and light reflects as far as you.
Sharon was less imaginative but still clear-cut in her ideas about images. She stated that images are on mirrors and can be in many spots. Nathan also was unclear about the order of events as he was sure that we see an image in the mirror because light hits the mirror and then the object. He was sure that images can be in several spots. Paul thought that images are in front of mirrors but wasn't sure and he also thought images could be in several spots. Judith thought that images are in front of or on mirrors. Peta thought that images were only in two places and images were on mirrors. These students' ideas were also held in common amongst the sample.

Development of the teaching module
Ideas about the location and number of images formed by mirrors were addressed in module 3.

The teaching objectives of this module were:

* state that an image is a pattern of light.
* describe that images do not travel, only light travels.
* explain that images can only be in one place.

The misconceptions addressed in the module were:

* light stays on mirrors.
* images can be in two places at once.

Teaching Activities In Module Three
The commencing point for instruction in this module was the presentation to students of a scientifically correct model establishing that light does bounce off objects (including mirrors) and an image is formed when light enters the eye. The pretest and interviews had determined that few students had ideas about what an image is.or what kind of objects form images. Students were presented with two information sheets titled "What is an Image ?" and "How Are Images Formed ?" Only the latter sheet is discussed in detail below.

The information sheet "How Are Images Formed ?" presented the model that smooth surfaces reflect light in a regular fashion while rough surfaces let light bounce off in all directions. The model that an image is formed when light enters the eye and the brain interprets the pattern of light was also presented.

After the initial presentation of information it was necessary to allow students to integrate and differentiate the information. This was done through the use of worksheets which allowed continual comparisons between scientists' and students' views. Questions such as :

"Why can't you see your reflection in the page you are writing on ?"
"What is the difference between your idea of an image and the scientists idea of an image ?"
"Does light have to enter your eye for you to see an image ?"
"Does light have to bounce off an object before you can see an image ?"

An overhead projector transparency of the situation of light bouncing off a mirror compared with light bouncing off a rougher surface provided another instance to reinforce these ideas.

Analogies and anomalies are suggested by Posner et al. (1982) as features of a conceptual ecology that influence the selection of a new concept so the analogy of light bouncing off a desk and the desk being seen, and the light bouncing off a mirror and an image being seen, was drawn. The anomaly that we can see the image but some people think light does not travel is pointed out.

In summary, if students did not have a concept about how images are formed then they were given the opportunity to integrate or differentiate the scientifically correct idea aided by the use of analogies and anomalies. If students did possess incorrect ideas then these were brought into conflict with the correct idea of light travelling off the mirror and hence the image being seen.

Following this introduction the issue of the location of images was addressed. Students were asked to write down on a worksheet where they thought they could find an image formed by a mirror and alternatives such as in front of, on or behind the mirror were suggested. On the same worksheet students read that scientists believed that images formed by mirrors were located behind the mirror and students were then asked in how many different places they thought they could find an image.

An activity involving a pin placed in front of a small mirror was commenced. Students were asked to look into the mirror from one end and describe where, in terms of the mirror, they thought the image was located. Then they were asked to predict where the image might be if they looked from the other end of the mirror and these predictions were written down, They checked their prediction by placing their finger where they thought the image was and sketched in the position of the image. This activity brought students' own ideas into direct confrontation with the real situation. Students were asked on the worksheet about whether they thought the image looked like it was always in the same place. The scientists' model that images are always in the same place no matter from where you look and that the only time the image moves is when the object moves, was stated. Students were invited to test this idea by placing the pin in a number of different places and locating the approximate position of the image by looking in the mirror.

The situation was posed that if two people looked at the same image at the same time would they see the image in the same spot? After writing down their ideas about this situation, students teamed up with a partner to test the idea by both looking at the image from opposite ends of the mirror at the same time and locating the image. They were asked to write down if they thought images could be in two spots at the same time to conclude this particular activity.

The final activity in this module repeated the above activities but with people substituted for pins and a much larger mirror (about 1.5 metres long) used. Students were presented with the following situation as a diagram and were asked "If Jack looks in the mirror at the image of the box, how many images does he see ? Where is the image located ?

They were also asked to draw the location of the image if Jack moved to the other side of the box. Students were writing down their own ideas which were being applied in a more egocentric context than the previous section and they were not given the opportunity to check their ideas. Jack was joined by Jill in the next diagram and students were asked how many images of the box there were now and to draw the location of the images. Jill was then allowed to walk across the front of the mirror as in Fig. 1.

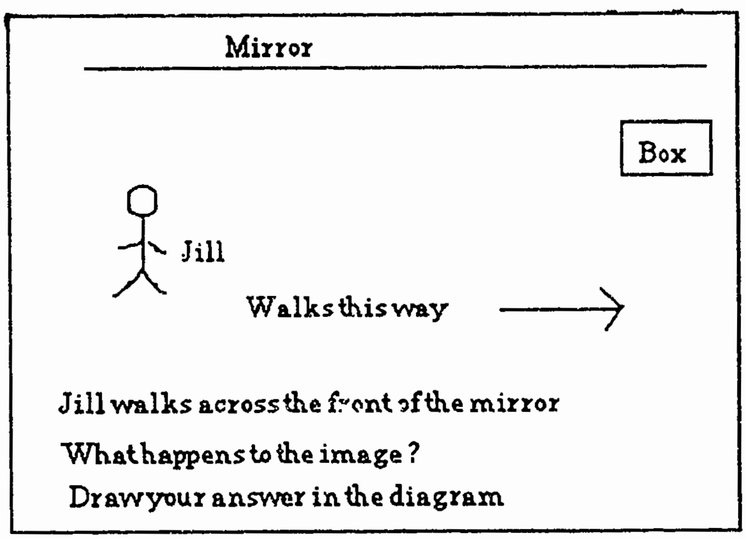

Fig. 1. What happens to the image as Jill walks ?

Finally students were asked in how many places they thought images could be. Students were then given the opportunity to individually check their answers to the above questions by actually being a Jack or a Jill in front of a mirror. This allowed them the opportunity to experience the real situation rather than the abs racted diagram and also gave the opportunity to discuss their ideas with the teacher. At this stage most students were quite convinced that images were located in only one spot and this last activity proved a little boring producing no real surprises for the students but serving to reinforce correct ideas.

Summary

Module 3 presented the opportunity for students to integrate, differentiate or exchange their ideas about images and reflection. Module 3 attempted to present the correct model so that it could be seen as more plausible (it explains the fact that two people see the image in the same spot, that images don't move....) and more intelligible than other models. The misconceptions that students possess in this particular area were easily brought into conflict by concrete methods. Integration and differentiation were aided by students' incorrect ideas being bought directly into conflict with the real and directly observable correct model, by discussion of instances portrayed and by discussion of written answers to questions on a worksheet. Discussion was an integral part of this activity.

RESULTS AND DISCUSSION

Following the teaching of all four modules students were again presented with the 16-item diagnostic instrument and the data were analysed. The mean number of acceptable responses rose from 6.60 (sd=2.64) to 10.50 (sd=2.66) ($t=4.35$; $p< 0.001$). The percentage of students who displayed the scientifically acceptable concept of reflection before and after the teaching intervention are presented in Table 2.

TABLE 2
MISCONCEPTIONS ABOUT LIGHT HELD BY
GRADE 8 STUDENTS,

Misconception	Percentage of students Pretest (n =20)	Posttest (n =16)
Light travels a different distance depending upon whether it is day or night.	35	13
Light does not travel during the day.	20	6
Light does not travel at all during the night.	15	6
We see by looking (visual ray idea), not by light being reflected to our eyes.	75	25
People can just see in the dark.	10	0
Cats can see in the dark.	42	13
Light stays on mirrors	25	6
Images can be in two places	56	81
Lenses are not necessary to form images	83	31
A whole lens is necessary to form an image	94	25

(Fetherstonhaugh & Treagust, Note 1).

The teaching method was deemed to be successful in that students were able to construct significantly more scientifically acceptable answers on the posttest after instruction than they had on the pretest. In all of the misconceptions addressed by the teaching modules, except for one, the level of student misconceptions was less following the teaching method. The interviews and participant observer data supported these findings.

The same students were interviewed after the teaching of the four modules. Brian and Peta still insisted that light hits the mirror, then the object and then to the observers, eyes. None of the other students displayed any misconceptions. All students interviewed believed that images could only be in one place. This contrasts markedly with the results from the diagnostic test where the number of students believing that images could be in two places rose from 56% to 81%. These results appear to be be an artifact of the testing instrument. With the question concerning the way in which light travels after hitting a mirror, only one student who had undergone instruction in the whole module (two were absent for most of the treatment) held the incorrect idea about light. This student knew that light travelled till it hit something in both day and night time but thought light would only come out as far as him after hitting a mirror. This misconception, exhibited in a new situation, indicates how firmly held some students' ideas can be.

Students enjoyed learning about light this way. Previously uninterested students became involved in learning when their own ideas were taken into consideration. The essence of the method and its utility in the classroom can best be summed up by the student who wrote 'I thought learning about light was better than usual lessons because it was interesting and you could have your own ideas.'

The teaching method described in this study appeared to be successful in changing students' ideas about most situations to do with the fundamental ideas of light and its properties and is comparable to the outcomes of the conceptual change teaching described by Anderson and Smith (1984) with fifth graders. At this stage it is impossible to say if the results are long lasting and research suggests that students' ideas tend to revert to their own ideas after a period of time. However, for a science teacher in a normal teaching situation, the conceptual change intervention strategy used in this study about light did result in changing many students' ideas from those which may be considered misconceptions to those which are scientifically acceptable. This is an improvement over usual teaching methods which, according to the literature, leave students' own ideas unaddressed and unaffected. The use of a diagnostic instrument and the teaching method used in this study could be applied to the teaching of science topics other than light.

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SCAFFOLDING CONCEPTUAL CHANGE IN EARLY CHILDHOOD

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ABSTRACT

The general educational literature draws our attention to the limitations of Piaget's work and presents a number of interesting ideas that science educators and researchers could consider. Of interest are Soviet psychologist Lev Vygotsky's writings on the zone of proximal development and the more recent writings of Jerome Bruner on scaffolding. The notion of learning as a a socially constructed process in opposition to the more individualistic orientation of Piaget has challenged much of our educational practice.

This paper will briefly explore the basic tenets of constructivism and contrast the theories developed from within this paradigm to the work of Vygotsky and Bruner through an analysis of classroom discourse collected from a number of early childhood classes involved in the interactive teaching approach to science.

Transcripts of teacher-child discourse are presented as evidence to support the proposition that when the teacher's role is not clearly defined, the range of teacher-child interactions will vary enormously, and the subsequent learning outcomes for children will be quite different.

INTRODUCTION

The general educational literature has in recent times been influenced by Soviet psychologist Lev Vygotsky (Wertsch, 1985). Of particular interest has been his concept of the zone of proximal development (actual potential as determined through problem solving under adult guidance, Wertsch, 1985). The notion of learning as a socially constructed process, in opposition to the more individualistic orientation of Piaget, has challenged much of our educational practice (Wood, 1986; 1988; Bruner & Haste, 1987; Light, 1986, 1987).

The writings of Jerome Bruner (1983) on scaffolding have detailed the process of social construction of learning further and allowed for the direct application of Vygotsky's theory of the social construction of knowledge to the classroom context. Whilst these writings in relation to scaffolding have not permeated the science education research literature, there are indicators that learning as a socially constructed process may complement, and offer new insights into, the current research into children's understandings of scientific phenomena. Many of the techniques advocated by for example, the interactive teaching approach to science (Biddulph & Osborne,1984), demonstrate a sensitivity to ascertaining children's understanding of scientific phenomena and assisting children to move from one level of thinking to the next: not unlike scaffolding. This process is facilitated by and through language, and it will be argued that it is the documentation and analysis of classroom discourse that provides the indicators of children's conceptual changes.

This paper will first, briefly outline the work of Vygotsky and Bruner with a view to discussing the scaffolding metaphor introduced by Bruner, as a description of the teacher-child interaction that successfully facilitates conceptual change. Second it will present data collected from a study of early childhood teachers all using the interactive approach to teaching science. Here it will be demonstrated that when the role of the teacher is not clearly stated, the types of teacher-child interactions that occur will vary enormously and the resultant learning for children will be significantly different.

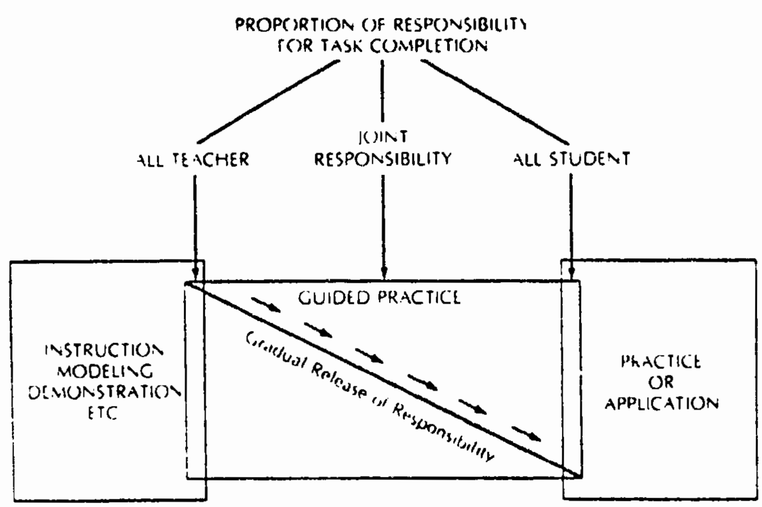
THE SOCIAL CONSTRUCTION OF LEARNING

Educationalists have recognized and validated the educational benefits to the learner of teacher generated questions, specifically higher-order questions (as opposed to recall type questions) (Redfield & Rousseau, 1982). However, within this understanding is also the recognition of the importance of the optimal placement of these higher-order questions in teacher discourse. Cognitive competence can be optimally facilitated when the teacher has the skills to not only carefully construct learning experience, and introduce questioning at opportune times, but share responsibility for completing a task with children through initially modeling the learning process and gradually releasing responsibility (Bruner, 1983).

It is this social construction of learning that has attracted attention among cognitive psychologists:

> <u>The Soviet psychologist Vygotsky... has argued that cognition begins in social situations in which a child shares responsibility for producing a complete performance with an adult. The child does what he or she can, the adult the rest.</u> In this way, practice on components occurs in the context of the full performance. In naturally occurring interactions of this kind, the adult will gradually increase expectations of how much of the full performance the child can be responsible for. (In Cazden, 1988, pp 101-102, emphasis added).

This process has been termed <u>scaffolding</u> and is shown below in Figure 1 (J. Campione, in Pearson & Gallagher, 1983, as cited in Cazden, 1988, p 104).



<u>Fig. 1 A model of scaffolding.</u>

The scaffolding metaphor makes explicit the role the teacher takes during the teaching-learning process. Here the teacher does more than simply organize resources (both human and physical), in which interactions are predominantly procedural, or which encourage cognitive conflict. The teacher actively models or instructs and assists children based on a shared understanding of their present scientific knowledge. The teaching-learning process is shared to facilitate optimum learning. Learning is viewed, not as an individual construction of knowledge, but rather through the joint construction of knowledge within historical and culturally defined contexts.

It is through explicit scaffolding on the part of the teacher, that the child is moved through its zone of proximal development which is "the distance between the actual developmental level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers" (Wertsch, 1985, pp 67-68).

Bruner (1983) demonstrated that children are able to work on tasks well above the level at which they could normally funtion (if left to their own resources) if they worked together with an adult. In these instances, it was reported by Bruner (1983) that the adult does not act in an arbitrary manner, but draws on shared knowedge held by the adult and the child. The adult prompts or reminds the child of prior experiences which are helpful for understanding present tasks. The adult progressively extends the learning demands on the child by giving the child more and more control over the interactions and then by progressively extending the scope and nature of the tasks.

The scaffolding metaphor is particularly useful for identifying support structures or techniques used by teachers to develop children's understanding of scientific phenomena.

THE STUDY

Through analysing children's and teachers' discourse whilst they engage in scientific investigations it is possible to recognise successful and ineffective scaffolding. One can then document how teachers structure their learning tasks and lead children into alternative ways of thinking.

Transcripts from two classrooms are presented here, representing typical transcripts collected from a study designed to investigate children's scientific understandings and the conceptual change that occurs during the teaching of science. One hundred hours of video tape and 190 hours of audio tape were collected over a period of six months. In each case the teachers' science lessons were video taped and children interviewed about their scientific understandings at the commencement of, during, and at the completion of the science units. Ongoing transcription of audio tapes and most video tapes occurred throughout the data collection phase.

Three sites were involved in the study, a pre-school centre (4 year olds), a transition/Year 1 classroom (5 and 6 year olds) and a Year 2/3 classroom (7 and 8 year olds). Only the two classrooms are presented in this paper. The two teachers were well versed in the interactive approach to teaching science and both indicated that they were using this approach in their teaching. However, the discourse indicates differing levels of scaffolding. In the first transcript, the teacher's discourse is predominantly procedural. In the second, the teacher engages in successful discourse (as measured by the number of discussions that are on-task which generate learning outcomes for the children) and scaffolds conceptual change more readily.

Both teachers claimed to be following the interactive approach to teaching science as detailed by Biddulph and Osborne (1984). The overriding framework and procedures adopted by each teacher were almost identical. The transcripts provide an interesting contrast and demonstrate the dangers associated with using models that have not explicitly detailed the types of interactions that are important in the conceptual change process during the teaching of science. The transcripts presented were typical of the type of interaction occurring in each of the classrooms.

Teacher-child discourse

The following transcript represents a typical example of the type of teacher-child discourse that occurred during Year 2/3 children's investigations of radios. After a whole group session, where children shared their news as it related to radios, the children worked in small groups dismantling the radios. Teacher A moved around freely assisting groups, interacting as is depicted below. This routine occurred over the whole unit of science. Variations in technique occurred in only one instance, where a visitor to the class presented information on how a radio works and interacted with children in small groups following the whole group demonstration. The following transcript typifies the interactions between Teacher A and the children during the science lessons.

Teacher A (Year 2 and 3)

T: Now Anne and Sam I need you. Anne can I have a look at your book once more, I forgot to look at your questions.
T: Righto what question are you going to use to find out when you open the radio, what do you want to find out when you open the radio?
C: Um, I don't know
T: Well you better check and see if you've got some there, if you haven't you better write some.

C: Well I haven't been trying to find out how they do it but I can't.
T: How they what? That?
C: Mm
T: Oh well we're going to have to do that.

C: Miss A
T: I'm going to have to do one job for Jane and Sarah next, you'll just have to wait.
T: What
C: I'm trying to find out that
T: That's what you're pulling the radio apart for?
Wait Simon.

T: Now excuse me, have we got a problem here?
C: Yes
T: Move out Henry

C: This one here we can't open and I'd quite like to know what's inside.

C: You need to push it in and out
C: Miss A
T: Is Miss A busy or is she not busy?
Well I don't girls. I'd prise that one open and do that one, I think that's the best one to do, you're right.

T: Now what's your problem?
C: . . . which bits were mine.
T: Which bits were your's please? Is this radio all your radio?
C: No that's all mine
T: Where is your bag? Off you go.

T: Where's your question mark?
T: You'll just have to wait Anne, I know there's a problem.

It is evident from the teacher's interaction with the children in the class that most of her language is procedural in nature. Limited extension or facilitation of children's thinking occurs during teacher-child interactions. She predominantly assists children with the physical difficulties associated with the task at hand. At times she prompts thinking by asking questions about what they are doing, or trying to find out. She does not follow through her questions or enquire about their findings.

The transcripts reveal that her interaction with students are more related to the process of recording questions and findings rather than with individual thinking. She does not intervene in their investigations, make suggestions, or model how they may proceed. Her directions relate mostly to the efficient and smooth running of the activities during the science lesson. There is little evidence to suggest that Teacher A has given herself the opportunity to develop a shared understanding of the children's ideas, experiences or investigations. Consequently Teacher A was not in a position to know to what degree learning occurred, what ideas the children had, or indeed if any of their ideas were inconsistent with the scientific view of radios. Student interviews throughout the term of data collection, and comparisons between concept maps, prior to, and at the end of the unit on radios, indicated that the learning outcomes for the children were minimal.

The children in Teacher A's classroom did not work together with the teacher to develop a shared understanding of how radios work. The children were left to their own devices to attempt to find out what they could by first, dismantling the radios, and second going to the library to locate source books. The dismantling did little to develop their thinking, since the children were not focused in their task. They did not know what to look at or how to experiment further once the radios were opened.

The second transcript demonstrates a more successful approach to direction and focussing of children's thinking so that their scientific conceptions are changed to match the scientists' explanation of electricity. Three factors have emerged in Teacher B's interaction, first there is shared understanding of the children's ideas, second, the teacher carefully scaffolded children's understanding of electricity through the careful structuring of the activity, modelling and shared responsibility for the completion of the circuitry necessary to construct a torch. Finally, a social framework was evident throughout. The teacher introduced a familiar experience to them - torches, and framed the

the investigations within socially accepted rules of 'when you dismantle, you must be able to re-assemble all pieces, so that the item will still function'.

Teacher B

In introducing the unit on torches, Teacher B organized a group time at the commencement and completion of each lesson. During these times she provided instruction, revised the investigatable questions and encourages children to share their ideas, investigation procedures and results. During non-group time, the children worked in small groups either recording their ideas and results, or conducting their experiments At these times Teacher B interacted with individual children or with small groups of children. The transcripts presented in this section are typical of the type and range of interaction that occurred during the three units of science observed.

In the following transcript Teacher B interacts with Jonus to determine his ideas about the circuit he has drawn in his science book. Once the ideas begin to emerge, Teacher B carefully draws from Jonus his ideas about the current flow. When he indicates a battery to globe path only, Teacher B draws his attention to the second wire. Because his learning of the circuit involved initially an incomplete circuit without success, to eventually adding the second wire to complete the circuit, the carefully guided interaction leads to conceptual change.

Section One

T: Jonus, tell me about this picture?
C: The battery's there and this goes there and it's going up to there
T: What's going up to there?
C: The power from the wires, into there
T: The power is going where?
C: Up to the wire
T: Up the wire, where to?
C: To the light, and when it goes there the light comes on.
T: Where does the power go then?
C: Into the light bulb
T: Does it go anywhere else as well?
C: Yes into the light
T: Does it go anywhere else Jonus or does all the power get used up on the light?
C: It gets used up in the light

In Section One Teacher B asks Jonus to explain the circuit he has drawn in his science book. Her questioning encourages Jonus to clarify his statements, and consider not only the sequence, but the overall idea he is expressing. For example, Teacher B asks "The power is going where?", to which Jonus responds "Up the wire". Teacher B then encourages Jonus to consider the implications of this by asking "Up the wire, where to?" This leads to an explanation of the circuit being a battery to globe path only.

Section Two

T: So it goes out of here and up to the light, and why do you have to have this bit joined on do you think? C: Um because if you don't then it won't go
T: Mmm but I wonder why not?

C: Um because if you don't have the battery and you have a light on there it won't go because it hasn't got any power
T: And what if you haven't got this part? Does it have power if you haven't got this wire on?
C: No
T: So what do you think, you think the power just goes up there and stops at the light?
C: Yes

In Section Two, Teacher B revises the correct ideas that Jonus has expressed about the movement of electricity along the circuit. She then points out the second wire in the circuit that Jonus has drawn. She allows Jonus to see the need for this second wire by encouraging Jonus to draw on his past learning experience, in which the circuit had not worked until the second wire had been introduced.

Section Three

T: Then why do we need this piece on as well do you think?
C: Um, because it needs to go up this one as well
T: Oh, so you think the power is going up this one and that one?
C: Yes
T: Why do you think it has to go up both wires?
C: Um, because when it goes up it is power, it needs power in both sides, and if it doesn't it won't work, the light won't go on.

In the third section of this transcript, Jonus is helped to understand the significance of the second wire in the circuit by considering the consequences of its absence. In thinking through this problem he considers the electrical flow to move from the battery up both wires to the globe. This tentative view is followed up by Teacher B in Section Four.

Section Four

T: Do you think the power could be going down that way at all?
C: No
T: Why not?
C: Only the light power can go down that one
T: The light power can go down this one? So the power going up this one can make the light turn on and then the light power can go down this one?
C: Yes
T: And what happens to it then?
C: Um, then this one gets more electricity
T: The battery does?
C: Yeah
T: So some light power can come down this one?
C: Yeah

In Section Four, Teacher B asks Jonus to consider an alternative current flow in the circuit. Here Jonus expresses a conflicting view to his previous statement by stating that the light power moves down the wire to the battery. Teacher B immediately uses this statement by restating it within the context of the previous correct ideas expressed by Jonus in Section Two. This reinforces previous and present correct views about the movement of electricity through a circuit. Further interaction is needed to determine what Jonus means by 'light power' so that consolidation or the scaffolding of further conceptual change can occur. Indeed this transcript indicates the fluid nature of Jonus' thinking, since his ideas changed markedly as a result of Teacher B's interactions. Here Teacher B could have reinforced Jonus' correct ideas by introducing a book on electricity and reading the scientists' view of electrical circuits, thus helping firm up Jonus' rather fluid ideas.

The scaffolding metaphor used here in science education, was not applied as directly as intended by Bruner for language acquisition, since children need to be first sensitized to accepting information from the teacher, book or video, before they are ready to undergo conceptual change. This is more pronounced when the ideas children are grappling with (e.g. electricity) are not directly observeable.

The science education literature indicates that telling children the correct answer does not necessarily result in children accepting and changing their ideas (Happs 1985; Gauld, 1988). As shared understanding of children's prior and present scientific experiences are gained, the teacher is able to determine and plan for children's sensitization towards particular scientific concepts such as electricity, so that explicit often non-observable information can be given, in the hope that they are ready to incorporate these ideas.

CONCLUSION

It is evident that although the two teachers were all following the interactive approach to teaching science and were all implementing it within the framework detailed by Biddulph and Osborne (1984), both had differing types of interaction occurring within their classrooms. When the teacher's role is examined in the interactive approach, it would seem that the teacher's role is to:

> ...listen to a child to know what is on the child's mind, what the child is thinking. The teacher must interact with the child to learn what are the child's ideas, and then sympathetically challenge the child to modify, develop or extend those ideas... Acting as a naive fellow investigator helps in this role (p. 11).

There is little explicit information given by the interactive approach as to how to interact with children. Yet it is the interaction between the child and the teacher that is crucial in furthering a child's understanding. Whilst the approach explicitly outlines the importance of interaction, it give little guidance to teachers as to how this interaction should proceed for maximum learning. As a result, teachers may interact in what ever way they wish. Consequently, significantly different learning contexts are created for children, as was evidenced by this study.

Discourse analysis has identified a number of techniques that Teacher B used in the teaching-learning process. The scaffolding adopted by Teacher B is not detailed in the interactive approach to teaching science, nor indeed is it explicit in any of the models and approaches developed within the constructivist's paradigm. It would seem that if teachers are to successfully scaffold learning, then the type of teacher-child interaction evident in Teacher B's classroom, need to be made clear in the models advocated in the science education literature. Otherwise teachers who subscribe to a constructivist approach to teaching, may indeed be providing learning experiences which provide few opportunities for conceptual change.

Science education research is tending to work from within a constructivist's paradigm. This paper has identified a number of problems with this approach in facilitating conceptual change in children. Reframing research from a constructivists' perspective to a social construction of learning as occurred in this study, has been useful in identifying teacher-child interaction that induces conceptual change. Vygotsky's theory of the social construction of learning, and Bruner's further development of those ideas into a practical context - namely scaffolding, have provided a tool for the analysis of the discourse collected. This type of analysis revealed a range of techniques that have not been detailed in the science education literature to date.

The identification of the types of teacher-child interaction which elicit conceptual change in children is of vital importance in developing teaching models which will maximize learning during children's scientific encounters in the classroom. If conceptual change is to be facilitated during the teaching-learning process then the approaches outlined in the literature need to state clearly the exact role of the teacher. It cannot be assumed that conceptual change will just occur if teachers are provided with teaching models that instruct the teacher to interact. The type of interaction which causes conceptual change must be stated.

It has been demonstrated in this paper that when the role of the teacher is not clearly stated, the types of teacher-child interactions that occur will vary enormously, and the resultant learning for children will be significantly different. The use of the scaffolding metaphor in science education makes clear to practitioners the role of the teacher in facilitating conceptual change in children. The next important stage of this research involves determining if scaffolding is indeed a successful approach in establishing long term change in children's learning of science concepts.

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THE TECHNOLOGY-SCIENCE RELATIONSHIP: SOME CURRICULUM IMPLICATIONS

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ABSTRACT

Technology encompasses the goods and services which people make and provide to meet human needs, and the processes and systems used for their development and delivery. Although technology and science are related, a distinction can be made between their purposes and outcomes. This paper considers four possible approaches to teaching students about the relationship between technology and science. A technology-as-illustration approach treats technology as if it were applied science; artefacts are presented to illustrate scientific principles. A cognitive-motivational approach also treats technology as applied science, but presents technology early in the instructional sequence in order to promote student interest and understanding. In an artefact approach, learners study artefacts as systems in order to understand the scientific principles which explain their workings. Finally, a technology-as-process approach emphasises the role of technological capability; in this approach, scientific concepts do not have privileged status as a basis for selecting curriculum content.

INTRODUCTION

Technology education

Technology education has been defined as "the comprehensive curriculum area ...concerned with technology, its evolution, utilization and significance;... its organization, personnel, systems, techniques, resources, and products; and their combined social and cultural impacts" (ITEA, 1985, p 25). During the past few years, Australian education systems have been introducing technology education into the curriculum. One pressure for this is economic, arising from a recognition that Australian industry must become more innovative. Other pressures come from liberal concerns: technology touches upon virtually all aspects of modern life, and all citizens ought to develop some technological understanding. In the 1990s, given adequate resource support, technology education could develop into a major curriculum innovation.

Many writers emphasise the importance of education in technology, arguing (rightly, in this writer's view) that the technology curriculum should be principally concerned with developing learners' capabilities. However, there is also value in learning about technology; this includes encouraging learners to explore the links between technology and other areas of knowledge.

Technology is being introduced into schools by teachers with experience in fields such as industrial arts, art and craft, home economics and computer studies. Science teachers can also make an important contribution, although many, lacking industrial experience and design and manufacturing skills, may feel hesitant about doing so. This paper is concerned with the relationship between technology and science; it has been written with science educators in mind. Its purpose is not to offer a detailed analysis of the nature and philosophy of technology or a broad set of principles of technology curriculum design. The aim is much narrower, namely to compare various instructional approaches which have been used in teaching about technology and science.

The nature of technology

Technology encompasses the goods and services which people make and provide to meet human needs, and the knowledge, organisational systems and processes used to develop and deliver those goods and services. Technology meets human needs through a marriage of thought and action, a combination called technological capability. Technology has been described (Black & Harrison, 1985, p 5) as

> the practical method which has enabled us to raise ourselves above the animals and to create not only our habitats, our food supply, our comfort and our means of health, travel and communication, but also our arts -- painting, sculpture, music and literature. These are the results of human capability for action. They do not come about by mere academic study, wishful thinking or speculation. Technology has always been called upon when practical solutions to problems have been called for. Technology is thus an essential part of human culture because it is concerned with the achievement of a wide range of human purposes.

Technological capability requires problem-solving ability. It involves a synthesis of the many skills needed for technological development: the ability to conceive of a product or service, and then to design, make, use, disseminate and improve it. Technological development has been described as a process of invention, refinement, innovation, diffusion and transfer (Mensch, 1979; Baklien, Note 1; Staudenmaier, 1985; Gardner, Penna & Brass, Note 2). Some writers have discussed technological development in terms of the personal characteristics of creative problem-solvers (e.g. Crosby, 1968); some have written about it in systems-analysis terms (Robertshaw, Mecca & Rerick, 1978); others have emphasised the importance of societal influences (Bereano, 1976; Boyle, Elliott & Roy, 1977).

Technology and science

What is the relationship between technology and science? The terms are often mentioned in the same breath (especially by non-technologists), implying a close link between the two. The Oxford English Dictionary (Vol XI, p 137) gives one definition of technology as "the scientific study of the practical or industrial arts", which clearly assumes such a link. A British curriculum guide for science teachers (Holman, 1986, p 23) defines technology as "the enabling process by which science is applied to satisfy our needs". The Penguin Dictionary of Economics (Bannock, Baxter & Rees, 1978. p 433) also recognises that technology is linked to science, but that other forms of knowledge are also important: technology is "the sum of knowledge of the means of producing goods and services. Technology is not merely applied science...things are often done without precise knowledge of how or why they are done except that they are effective."

These descriptions by non-technologists all omit mentioning that science is often the product of technology, that doing frequently precedes understanding. However, as McCann et al. (1984, p 101) point out,

> Historically, technology has often been the parent of science, rather than the reverse. The principles of geometry, for example, succeeded the practices of surveying. It is important to appreciate that technology may often include effective techniques for which satisfactory understanding at any deep theoretical level is lacking.

Practical techniques which serve useful ends do not always require scientific understanding. For example, the use of heat treatment in canning food preceded Pasteur's research on micro-organisms. (Of course, as McCann et al. note, modern 'high' technology does depend upon theoretical understanding.)

For Scriven (1985, 1987), technology and science have differing histories, goals, products and methods. For example, the Iron Age began in the Near East and south-eastern Europe around 1200 BC (New Encyclopaedia Brittanica, Vol 6, p 388). During the next two centuries, there was a rapid spread of practical knowledge of the metallurgy and uses of iron. The subsequent history of iron extraction (ibid., Vol 21, pp 360-388) is mostly a story of thoughtful trial and error. Scientific understanding of the chemistry of the process has developed only during the past two centuries, exemplifying what Scriven calls "the historical seniority of technology". The development of iron extraction undoubtedly involved problem solving, directed trial and error, and evaluation of results, but, Scriven argues, this was not science because "neither its main aim nor its principal product was an understanding of natural and social phenomena". Science aims primarily at generating ideas, explanations and understanding; Scriven considers that "the great scientific breakthrough is the idea, but in the case of technology the ideas are just the beginning of creating a new or improved technology". Hacker and Barden (1987, p 3), in a school textbook on technology, make a simple but effective distinction: "Science is the study of why natural things happen the way they do. Technology is the use of knowledge to turn resources into the goods and services that society needs." Fensham (Note 3) drew upon the work of the National Curriculum Committee (1988) in England to argue that science is analytic, concerned with discovery, understanding and generalised knowledge; technology is synthetic, concerned with invention and manufacture, with whatever specific knowledge is useful to solve a problem.

This epistemological analysis portrays science and technology as different but equal, a perception not universally shared: science tends to be accorded higher status. Observe how we say, 'science and technology' rather than 'technology and science', thus unconsciously emphasising science, and possibly implying that technology is an offshoot of science. Storer's (1966, p 2) whimsical comment that achievements in space are regarded as scientific triumphs, while unsuccessful launches are due to engineering failures, can be interpreted as an attempt by scientists to pretend to higher status.

INSTRUCTIONAL APPROACHES

Analyses by the author of science textbooks and research papers reveal four approaches to the question of how to present instructional content on the relationship between technology and science to learners:

* technological applications are presented after an instructional sequence based on scientific concepts and principles; this can be called a technology-as-illustration approach;

* technological applications are introduced early in an instructional sequence in order to stimulate student interest and enhance meaningful learning of scientific concepts (a cognitive-motivational approach);
* technological artefacts (real or simulated) are disassembled in order to develop understanding of the various parts of the artefact, how they interact, and the principles involved, (an artefact approach); and
* technology is regarded as a process of problem-solving (inventing, designing, making ...); scientific ideas are relevant if they contribute to this (a process approach).

Other approaches are possible. For example, STS (Science, Technology and Society) approaches tend to place less emphasis on both scientific content and technological capability and more emphasis upon the problematic nature of scientific knowledge, and upon the interdisciplinary nature of knowledge, in an attempt to show how science and technology are shaped by social forces and how they affect society. Solomon (1988) comprehensively reviews these approaches.

Technology as illustration

A common approach to teaching about technology in science courses is to introduce a phenomenon (e.g. the reflection of light or the behaviour of an electromagnet), present relevant experiences (laboratory work, photographs, etc) and scientific principles which are then illustrated by referring to technological applications. This approach, which treats technology as applied science, is often found in school texts. Chapter 2 of PSSC Physics (Haber-Schaim et al., 1976) introduces the laws of reflection, presents photographs of reflected beams and develops the concepts of ray geometry and virtual images. Plane mirrors are dealt with first, and then parabolic mirrors. The text then displays a photograph of the parabolic telescope at Mt Palomar, and describes the mechanical mounting needed to track the apparent motion of stars.

An Australian science text to which the writer contributed some years ago (Baldock et al., 1970) contains similar sequences; e.g. students are introduced to the magnetic effects of electric currents through labwork; they make a solenoid, study its properties and the effect on a compass needle of reversing the current. Students compile a list of devices utilising electromagnets, and then examine an electric bell and propose explanations of how it works.

A recent American Association for the Advancement of Science report on technology education (Johnson, 1989) clearly regards artefacts as illustrations of scientific ideas:

> The principles of energy and its use should be taught in science courses, but their application must be thoroughly experienced or demonstrated in technology activities in elementary and secondary school. Concepts of work, kinetic and potential energy, storage of energy, and thermodynamics and entropy, among others, should be accompanied by purposeful experiences...(e.g.) water wheels, windmills, and simple solar heaters (p 15).

When technology is treated as applied science, the science content of the curriculum is usually taken for granted; choices about the technology content are made subsequently, by selecting artefacts whose workings can be understood in terms of this science content. The laws of reflection and refraction, for example, are standard components of a physics course; a physics teacher seeking a modern illustration of an artefact in which reflection and refraction are important might offer the photocopier as an example, by discussing how an image of a document is formed on a cylindrical photo-receptor drum. A teacher discussing the properties of sulphur and selenium, both Group VI non-metals, might mention that they are photo-conductive: they can be electrically charged, but will hold that charge only in the dark. Shine a light on part of a photo-conductive surface, and that part becomes discharged. It is this property of photo-conductivity which is central to the photo-copying process; modern photocopiers contain a selenium-coated drum.

Rennie (1987) has reported that science teachers (but not technical teachers) frequently regard technology as an embodiment of scientific ideas. Perhaps such teachers hold to an implicit learning theory which advocates the teaching of general principles before specific illustrations. This is not irrational: scientific understanding of a reflecting telescope, electric bell or photo-copier does require understanding of the relevant scientific principles. Some science educators, however, have come to recognise the limitations of this approach. Holman (1986, p 23) cites an English comprehensive school which "decided that the traditional methods of presenting the science first and then throwing in a quick word on applications was too pure and unsuitable as a motivator of 14-16 year olds".

A cognitive-motivational approach

A second approach also treats technology as applied science, but adopts a different rationale and sequence of presentation, in an attempt to stimulate interest and understanding. The technological application is intended to serve a motivational and cognitive function and is introduced early.

This early introduction could be done superficially, with the teacher using an interesting artefact merely to capture students' attention. The artefact may then be put aside, with subsequent instruction concentrating upon the real agenda: the science content. Most writers who adopt a cognitive-motivational approach, however, argue for a more central role for the artefact, by making it the focus throughout the instructional sequence. Violino (1987), an Italian writer, advocates introducing technology into the primary school to provide "concrete experience which leads children to an understanding of an important scientific concept". He suggests using an espresso coffee-pot and a plywood overshot water wheel to model a steam turbine. Children can then be encouraged to build other machines - which, he claims, they do enthusiastically -- and as a result of these activities, their ideas about energy can be developed.

Jones and Kirk (1989) adopt the same justification for introducing technology into secondary school physics. They point out that physics "is often remote from the students' real world ... one method of bridging this gap is to introduce technological applications". They argue that the approach can enhance learning: "a technological focus which is perceived by students as being relevant should enable the students both to attend to the learning situation (engagement) and to generate more adequately links between the new and existing ideas" (p 165). They advocate a five-stage teaching/learning sequence of focussing, exploring, reporting, formalising and applying, in which a technological application (or some other real world phenomenon) serves as the focus, and offer examples of this sequence in practice. The predominant goal (understandable in a physics course) is to develop students' understanding of the physics. This resembles the technology-as-illustration approach, but the place of technology in the script changes from epilogue to prologue and theme.

One of their units starts with a flash-gun, which the students disassemble. The goal is primarily to help students understand the concept of capacitance, and not to provide them with details of all the physics involved in a flash-gun/camera system. Their paper presents data (teachers' and students' reactions) indicating strong evaluative support to the approach. They also report a difficulty: physics teachers were frequently so concerned about syllabus demands that they believed that there was "not enough time available for the introduction of technological applications ... Thus teaching packages had to develop concepts required by the syllabus while not increasing the amount of time spent on the topic." If the aim is to teach science, as it was in this case, this may be sensible, pragmatic solution to a real instructional problem. But if the aim is to teach technology, the approach is open to epistemological challenge.

Technology as artefact

A third approach involves studying artefacts to learn how they work, a kind of technological equivalent of anatomy and physiology. Artefacts are taken apart (either literally or intellectually) to study the parts, their functions and how they inter-relate. This approach is common in children's encyclopedias when they explain, in terms of scientific laws and principles, how some familiar object such as a car engine, or electric power generator, works. In Germany, Dahncke and colleagues (Note 4) have developed instructional approaches in which children disassemble household artefacts in order to understand their workings. This approach treats artefacts as systems; the aim is to help learners understand how a system works in toto. While the capacitors in a flash-gun are obviously vital to its successful operation, scientific understanding of how a flash-gun works also requires understanding of the electronics of the flash-tube, the optics of the reflector and the shutter system of the camera. Similarly, while the photo-receptor drum of the photocopier is undoubtedly the most creative invention in the system, the whole system would not operate without an optical sub-system, a paper-feed sub-system, an ink-feed sub-system, an ink-paper fusion sub-system....

This approach shifts the emphasis away from specified topics in a science curriculum to the artefact itself, viewed as a system. But the science is still there: scientific principles are drawn upon by the teacher to explain how the artefact works, or are formulated by learners seeking further explanations. Newman, Cosgrove and Forret (1988) have adopted this approach, utilising constructivist teaching strategies, in a unit on refrigeration.

Technology as process

None of these approaches, however, provides a faithful representation of the nature of technology: learning the science which explains how something works is not synonymous with learning how technologists design solutions to practical problems.

Pressing technology into the service of science education may help students to learn science, but it may do little to develop their technological capabilities. The Royal Society for the Encouragement of the Arts, Manufactures and Commerce (RSA), which sponsored the Education for Capability movement in the UK in the early 1980s, was critical of curricula in which learners "acquire knowledge of particular subjects but are not equipped to use knowledge in ways that are relevant to the world outside the education system" (RSA, 1986). The society called for an emphasis on the culture of doing, on creativity, competence at making things, decision-making ability, and the capacity to work co-operatively with others, all of which are central to the technological development process.

Approaches which treat technology as applied science, which present artefacts to learners as objects of scientific study, do little to illuminate the process of technological development. The three approaches may lead to misrepresentation of the historical and epistemological relationships between technology and science; all of them fail to present an accurate portrait of the nature of technological capability as a process involving problem-solving, invention, design, making....

A study of the principles which scientists would use to describe the workings of an artefact tells us little of the nature of the problems that the technologist had to overcome in inventing, designing and manufacturing that artefact. Yet it is the identification and surmounting of those problems which are at the heart of the technological development process. Any curriculum which fails to present this aspect of technology to learners is not teaching technology at all, but something else: applied science, perhaps, or technical skills.

Learners can be helped to understand the process of technological development, through direct involvement, or vicariously (e.g. through case studies of technological innovations). Whichever approach is used (they may of course be used together), the emphasis is upon confronting problems, upon using whatever resources are available to attain an adequate solution. Scientific knowledge may be important, but it does not have privileged status: any knowledge, skill or resource is relevant if it contributes to a solution of the problem at hand.

Secondary school students can be directly involved in technological problem-solving. Black et al. (1988, p 14) offer illustrations of tasks that might be tackled by students:

* Develop an aid for drivers reversing a large vehicle
* What can be done to provide villages in Peru with a continuous water supply?
* Decide on best energy source for a purpose chosen by each student
* Toy manufacturer needs a small-scale paint drying device
* Design and make a hypothermia-avoidance kit for old people

Such direct attempts at problem-solving can be complemented by vicarious experiences e.g. through case studies of the technological development process. The history of the photocopier provides the basis for a fascinating case study. Owen (1986) offers an account of the technological development process in action. He describes the 22 years of struggle by Chester Carlson, following his discovery in 1938 of the principle of xerography ("dry writing"), to develop the first Haloid XeroX 914 office copier. Science played an important role in this story: knowledge of the photo-conductive properties of sulphur and selenium was crucial to the development of the technology. (The first experiments were with sulphur-coated surfaces but selenium was later found to be more durable.) Other problems -- human, technical and economic -- had to be surmounted as well. One problem was that of finding an efficient method of wiping excess toner (powdered ink) off the photo-receptor drum after each copy had been made. What branch of science could possibly predict that the belly fur of Australian rabbits had just the right consistency? (Beaver and raccoon pelts were tried, but could not be easily cut to the right tolerances.) Carlson's difficulties in obtaining funds illustrate how social factors foster (or hinder) technological development. He was near the bottom of his bank account when he received a $3000 grant from a private research foundation, after IBM, RCA and General Electric had all turned him down. Even after the prototype had been made, IBM accepted consultants' advice that the market for such machines would be small, and declined to become involved.

Selected case studies of this type in the curriculum, in conjunction with direct involvement by learners in tackling more tractable problems, might help to illuminate the complexity of the technological development process. Such studies may serve to indicate that the creative technologist must be able to synthesise many sources of knowledge and skill, not just scientific, in order to develop technological capability. Some ideas for suitable topics might be obtained from contributions to the Fourth International Symposium on World Trends in Science and Technology Education (Riquarts, 1987). If the potential value of this curriculum approach is accepted, the next steps would be for curriculum developers to investigate the history of the particular area of technology chosen for study, develop instructional materials for students and support materials for teachers, and try them out in classroom settings.

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Note 3. P J Fensham, presentation at the 1989 CONASTA (Australian Science Teachers' Association annual conference).

Note 4. Professor Dahncke is the leader of a national group based at the Pedagogical Institute in Kiel. He described the group's work at a seminar at Monash University in 1989.

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YEAR 12 STUDENTS' ATTAINMENT OF SCIENTIFIC INVESTIGATION SKILLS

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ABSTRACT

One of the main goals of science education is the development of scientific investigation skills (Bryce & Robertson, 1985; Woolnough & Allsop, 1985). This paper describes a practical test instrument developed to assess students' attainment of skills associated with problem analysis and planning experiments, collecting information, organizing and interpreting information, and concluding. During administration of the test, students verbalized their thoughts as they worked on the task and their performance was videotaped for analysis. Preliminary results reveal important areas of student weakness and lead to recommendations for curriculum reform.

INTRODUCTION

Laboratory work is an integral part of the scientific enterprise, and the teaching and learning of science in schools and universities. Typically 40-60% of class time is spent on practical work in lower secondary science classes (Beatty & Woolnough, 1982).

The effectiveness of laboratory work has been questioned because teachers often mismatch their aims and the type of laboratory activity used to achieve those aims (Lunetta & Tamir, 1979; Friedler & Tamir, 1984; Woolnough & Allsop, 1985). Woolnough and Allsop (1985) have identified three aims that can validly be achieved through laboratory work: the development of process skills and laboratory techniques; getting a feel for phenomena; and being a problem-solving scientist. The development of scientific problem-solving skills can be achieved through inquiry oriented or investigation style laboratory work that gives students opportunities to practise the skills of problem analysis and planning experiments, collecting data, organizing and interpreting data (Tamir & Lunetta, 1981; Woolnough & Allsop, 1985; Tamir 1989).

Successful problem solvers bring extensive domain specific schema knowledge to the task which enables them to generate high quality problem representations which guide the selection of efficient solution processes (Chi, Feltovich & Glaser, 1981). Expert problem solvers spend more time on problem analysis (Larkin, 1979), do more high level metaplanning (Hayes-Roth & Hayes-Roth, 1979), and demonstrate greater metacognitive control over processing than novices (Schoenfeld, 1986). This paper reports on a study that is part of a larger research programme which examines the development of scientific investigation skills through primary, secondary and tertiary science education.

PURPOSE AND RESEARCH QUESTIONS

The purpose of this study was to examine the problem-solving processes used by Year 12 science students when conducting a laboratory based scientific investigation. More specifically, the study addressed two research questions:

1. Which process skills are Year 12 science students able to apply in the problem analysis and planning, data collection, data interpretation and concluding phases of a laboratory investigation?

2. What factors appear to limit students' success on practical problem-solving tasks?

METHOD

Subjects

A total of ten Year 12 science students was selected from seven different classes and six schools in the Perth metropolitan area. Subjects were selected on a random stratified basis so that there was equal representation from males and females, and from students studying the biological and physical sciences.

Procedure

The open-ended problem-solving task was administered to subjects individually. Subjects were required to investigate the factors that influence the bending of a beam under load. No time limit was imposed on the students' work. Students worked on the task with concurrent verbalization (Ericsson & Simon, 1980; Larkin & Rainard, 1984). There was minimal interruption from the experimenter except for encouragement to verbalize and for the debriefing session at the end of the task. Subjects' verbalizations and apparatus manipulations were recorded on audio and videotape. A coding manual guided the dual and independent coding of the videotapes by two trained coders. Coding discrepancies were resolved at meetings between the coders and the investigator.

Instrument

Context. The task was set in the context of the need for engineers who design and build bridges to understand the factors that influence the bending of beams under load. Subjects were shown a picture of a truck passing over a bridge.

The Task. Think-aloud procedures were modelled for the subject by the investigator and subjects practised verbalizing on two arithmetic problems. The task was explained to the subject and then the subject commenced work by reading out-loud the task statement presented in Figure 1.

THE TASK

FIND OUT WHAT FACTORS INFLUENCE THE BENDING OF BEAMS UNDER LOAD

REMEMBER

I would like you to
plan and carry-out experiments,
record and interpret your results,
and state your conclusions

Fig 1. The Task Statement

Apparatus. Figure 2 illustrates the experimental set-up provided for the subject at the start of the session. A wooden beam was supported by two retort stands and a load of slotted masses was suspended from the centre of the beam. A 1 m rule and a 50 cm rule lay on the bench, and a 30 cm plastic rule held vertical by a retort stand was placed next to the beam. Additional slotted masses were available on the bench. A pencil, pad and graph paper were placed to the side of the beam. The subject was shown a large plastic tube containing a range of other beams of different diameters, cross-sectional shapes and materials that the investigator would supply to the subject on request. Subjects were not permitted to examine the types of beams in the tube so that they had to generate beam variables themselves rather than just cue-in to variables displayed by the collection of beams.

Fig. 2. The Experimental Set-up

RESULTS

Results are presented in terms of the process skills displayed by subjects during the four phases of the investigation: (1) Analysis of the problem and planning, (2) collecting information, (3) organizing and interpreting information, and (4) concluding.

Analysis of the Problem and Planning

One of the most distinct features of the students' problem solving was the limited amount of problem analysis and planning done before manipulating the equipment and collecting data. Most students (7 of 10) commenced by identifying a few potential independent variables, although most independent variables (24 of 40) were identified while students were involved with experimenting. Only four of the subjects stated a purpose or an hypothesis for their experiments. Six subjects described how they would apply or measure variables in their experiments. None of the subjects verbalized an intention to control variables. Only two subjects planned their data recording before commencing data collection.

Collecting Information

On average the subjects conducted 3.3 experiments. The number of experiments ranged from a minimum of one to a maximum of seven experiments per subject. An experiment consisted of tests of a particular independent variable. There were six main independent variables that could be tested: Beam length, thickness, cross-sectional shape and material; load size, and the location of the load along the beam.

Four of the subjects made no measurements of the dependent variable, they relied on qualitative comparisons of the amount of bending of different beams. Of the six subjects who measured the dependent variable all measured zero values and took care to avoid parallax error. Five of the six subjects also measured beam bending at the point of maximum deflection. Most subjects collected data over a rather small range of values for the independent variables.

Control of variables could be demonstrated in three situations in this investigation. First, students could standardize their measurement procedures. For example measuring bending in the centre of the beam, using standard loads and beam lengths when comparing different beams. All subjects who measured bending standardized their measurement procedures in this way. Second, subjects could demonstrate control of variables when they changed beams. For example when testing the independent variable of beam thickness, subjects could request a thicker beam of the same material and cross-sectional shape. Only five of the ten subjects demonstrated control of variables at this level. Third, when summarizing their findings, subjects could demonstrate control of variables when comparing the bending observed in different experiments. Only five of the ten subjects restricted such comparisons to experiments that differed in terms of the one variable. Only one subject was aware that a comparison of beams of different cross-sectional shape had to be performed using beams of the same cross-sectional area.

Organizing and Interpreting Information

Five of the seven subjects who recorded data did so in an unstructured form, i.e. the data were not recorded in ruled-up tables although column headings and units were used. Two of the subjects only recorded raw data for the dependent variable, that is the original and final position of the beam. Three subjects only recorded the derived scores for amount of bending.

Three subjects transformed their data into a form that would help them identify patterns in the data; two subjects collated their data into restructured tables, and one subject constructed a graph to help determine the relationship between the independent and dependent variables. All subjects were able to interpret their experimental findings in terms of variables that influenced beam bending under load.

Concluding

When prompted in the debriefing, all subjects were able to apply their experimental findings to the problem of designing a bridge that would withstand heavy loads. Most subjects identified the need for thick beams and supporting columns placed close together. Many subjects went beyond their data when recommending beams of particular cross-sectional shapes.

In the debriefing, subjects were also asked how they would improve their approach to the investigation if given another opportunity to work on the problem. All subjects demonstrated little awareness of the methodological limitations of their investigations. Two subjects said they would take more care with measurements, one subject said he would do more written planning, another said she would test one variable at a time, and another said he would test more beams.

DISCUSSION

The subjects were confronted with a novel problem-solving task set in a real-world context. Expert problem solvers analyze problems and identify cues that activate relevant knowledge schemas to create a mental representation of the task that can facilitate the planning of appropriate solution processes (Chi et al., 1981). Extended periods of problem analysis and solution planning ultimately lead to efficient problem solutions (Larkin, 1979; Voss, Tyler & Yengo, 1983). The most typical response of the Year 12 students was to identify two or three potential independent variables and then almost immediately commence manipulating the apparatus to test one of the variables they had identified. There was no high level up-front metaplanning (Hayes-Roth & Hayes-Roth, 1979) of an overall approach to the problem. In fact most planning was low level, task specific planning in response to circumstances that arose during experimental work, typical of that revealed by previous research into adolescents' planning (Lawrence, Dodds & Volet, 1983). Some students demonstrated little metacognitive control over processing (Schoenfeld, 1986). One subject performed the same repetitive measurement routine for 25 minutes without any overt monitoring or reflection on the usefulness of the process he was performing.

The students appeared to lack a well-developed schema for the structure of a controlled experiment. Only three subjects used the term hypothesis and no subjects used the terms variable, independent variable, dependent variable, control of variables, repeated trials or sample size while working on the problem. None of the subjects verbalized an intention to control variables. Miller & Driver (1987) and Rowell & Dawson (1989) would argue that reasoning skills such as control of variables are developed in particular contexts and are difficult to abstract and generalize to the level where they can be applied easily to novel tasks in unfamiliar domains. Students did however control variables at the level of being systematic in measurement procedures of which they would have had extensive experience.

The students' poor performance on the higher level skills of problem analysis, planning and control of variables was not reflected in the area of measurement. Subjects were generally systematic and took care with zero values and parallax error. Students relative success on the data collection phase of the investigation versus the planning and analysis phase is likely to be a reflection of the style of laboratory work to which students have been exposed. Analyses of the implemented curriculum in the USA (Tamir & Lunetta, 1981), Israel (Friedler & Tamir, 1984) and Australia (Tobin, 1986) indicate that most school practical work is of the recipe style and is at the lowest level of openness to student planning (Tamir, 1989).

Johnstone and Wham (1982), Friedler and Tamir (1986) and Rubin and Tamir (1988) have argued that inquiry oriented, investigation style laboratory work is cognitively demanding and that informational inputs may overload working memory capacity. Attempts have therefore been made to teach process skills in a non laboratory situation without the additional information burdens from working with apparatus. Thes· lessons have been followed with laboratory activities where students can then apply tl skills in familiar contexts. Experts cope more easily in these high information situations as they have developed automated, proceduralized routines for common processing tasks thus freeing-up working memory capacity for dealing with novel aspects of the problem, planning, monitoring and control of processing (McGaw & Lawrence, 1984; Anderson, 1985).

CONCLUSIONS

When faced with a laboratory-based, problem-solving task most of the Year 12 students were able to successfully apply the process skills associated with measurement, data recording and some aspects of data interpretation. Their success on the problem-solving task was limited by ineffective problem analysis, planning and control of variables.

If science students are to develop effective practical problem-solving skills there is a need to modify the implemented curriculum to include more investigation style laboratory activities through which students can have the opportunity to practise the higher level process skills. There is also a need to explicitly teach the conceptual knowledge regarding the structure of controlled experiments, particularly the concepts of hypothesis, independent, dependent and controlled variables and how they relate to each other, and concepts of sample size and repeated trials.

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OUTCOMES OF THE PRIMARY AND EARLY CHILDHOOD SCIENCE AND TECHNOLOGY EDUCATION PROJECT AT THE UNIVERSITY OF CANBERRA

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ABSTRACT

The aim of the Primary and Early Childhood Science and Technology Education Project (PECSTEP) is to improve teaching and learning in science and technology of by increasing the number of early childhood and primary teachers who are effective educators. PECSTEP is based on an interactive model of teaching and systematically links work on gender with the learning and teaching of science and technology. The project involves: a year-long inservice program which includes the development of a science curriculum unit by teachers in their schools; linking of the preservice and inservice programs; and the development of support networks for teachers. Each phase of PECSTEP has been researched by means of surveys, interviews and the use of diaries. Research questions have focussed particularly on changes in: teachers' and student teachers' attitudes to teaching science and technology; their perceptions of science and technology; their perceptions of their students' responses and their understandings of how gender relates to these areas.

INTRODUCTION

The Primary and Early Childhood Science and Technology Education project (PECSTEP) is directed at identifying teacher education practices successful in changing the attitude of (women) primary and early childhood teachers to science. PECSTEP has built on the WASTE (Women and Science Teacher Education) Project which identified three models of exemplary science teacher education practice, of which only one (Model 3) integrated work on gender with the teaching and learning of science (Bearlin, Annice & Elvin, 1990). Since the research by Rennie et al. (1985) had been done at the inservice level and because little similar work was being done at the preservice level, the WASTE Project Report recommended that research be undertaken "on the effect on the attitudes of women preservice teachers to science and science teaching, of teacher education courses in which work on gender and work in science are systematically linked or integrated with each other and with practice in schools which have wide affirmative action policies." (Bearlin, Annice & Elvin, 1990, p. 13)

The PECSTEP Project attempted to create a program based on WASTE Model 3. However given the dearth of primary science being taught in schools it soon became obvious that research at the preservice level would not be possible without companion inservice programs. PECSTEP was designed to link preservice education with appropriate practice in schools by providing a special inservice program for supervising teachers.

OVERVIEW OF PECSTEP

The purpose of the project is to improve teaching and learning in science and technology of girls and boys by increasing the number of early childhood and primary teachers who are effective educators.

The project involves:

* the development, teaching and evaluation of a year length inservice program involving primary and early childhood teachers;
* the modification,teaching and evaluation of an existing semester length preservice unit in science and technology education for preservice teachers;
* the establishment of regional support networks for the practising teachers taking the inservice program; and
* the linking of preservice teachers with inservice teachers where possible.

All programs and units systematically link work on gender with the learning and teaching of science and technology.

THE PROJECT SO FAR

The project began in 1989 with a grant from the ACT Education and Training Council and support from the ACT Department of Education. In 1990 it has continued with support from the ACT Department of Education, the University of Canberra Research Fund and a DEET Infrastructure Grant. A summary of outcomes and preliminary research findings for the inservice and preservice programs in 1989 only will be given here. Fuller reports on the 1989 inservice program can be found in Kirkwood, Bearlin & Hardy (1989). Developments in the PECSTEP program in 1990 are also outlined.

In 1989, three groups of primary and early childhood teachers (altogether 60 women and 10 men) undertook in their own time, the year-long inservice course. About one-third of the teachers were either upgrading or doing a Masters course associated with the Project. Sixty student teachers were enrolled in the preservice course.

The aims of the inservice program were to enable teachers to:

* extend their understanding of children's learning in science and technology;
* explore ways of assisting children with such learning;
* extend their understanding of the importance of and the skills in science and technology to the lives of girls and boys;
* extend their understanding of their own learning in science and technology;
* extend their understanding of and skills in gender-inclusive science curriculum development and teaching;
* develop further skills in teaching science and technology; and
* supervise the work of preservice teachers in this area.

The program consisted of 14 two-hour workshops in semester 1. In semester 2 the teachers developed, taught and evaluated a curriculum unit of their own choice based on the understandings of semester 1 and with support from the tutor and regional network groups.

THE TEACHING APPROACH

Dr. Valda Kirkwood, an experienced science educator and researcher, developed and taught the inservice program. She chose to role-model an interactive teaching approach (Biddulph & Osborne, 1984) developed at the University of Waikato.

The inservice program began with a series of workshops on toasters. Teachers began by writing down everything they knew about toasters and what they would like to know. They then set about investigating their own questions (e.g. how does a toaster really work?) by taking toasters apart, setting up electrical circuits etc. Teachers worked in small groups of their own choice (or individually) for both practical work and discussion, and came together as a whole for sharing sessions. A second curriculum unit on bread began with a bread-making session followed by sessions in which teachers investigated questions arising for them about such things as the biological aspects of yeast and the dangers of food additives. Readings of papers/books were sometimes set. Teachers also carried out action research in their own classrooms on gender differences in children's question asking and answering, use of equipment and choice of careers. During this program teachers kept diaries to record their own learnings and to reflect on the many questions, which surfaced and were discussed, related to their understanding of teaching, learning, science, technology, knowledge and classroom interaction.

This teaching approach, constructivist in its theoretical underpinnings, starts from the learners' understandings and questions about a topic and develops through their investigations to answer the questions. The learners formalise their understandings (and feelings) at the beginning and the end of the investigations, thereby focusing on their individual learning. The role of the tutor is manifold, changing from motivator to resource person, fellow investigator, challenger of ideas, diagnostician, guide, and researcher. Thus, the first semester workshops developed according to the needs of the participants, taking into account each teacher's differing experiences and understandings.

OUTCOMES OF THE INSERVICE AND PRESERVICE PROGRAM

The analysis of teacher responses to the inservice program (INS) indicates the success of the program in providing teachers with empowering learning experiences in science and technology education. Surveys, interviews, diary keeping and the quality of the curriculum units developed by the teachers have provided systematic data on the effectiveness of the program. The surveys asked teachers about their background in science, their experiences in teaching and learning science, and their understandings of science, technology, teaching, learning, knowledge and gender. A similar survey was used pre- and post- the one-semester preservice program (PRE), and preservice teachers also kept diaries. In the following, selection is made from both the quantitative and qualitative data from the inservice program and quantitative data from the preservice program.

<u>Achievement of the broad goals of the Project: changes in teachers' levels of interest, sense of competence, and perceptions of classroom happenings.</u>

* <u>Inservice Program</u> Analysis of survey responses (quantitative) indicates, as a consequence of participation in the program, a significant increase in the level of INS teachers' interest in science and technology, in teachers' perception of their background knowledge for teaching in both science and technology, and in teachers' sense of their own competence in teaching science and technology. This is strongly borne out in the qualitative data. There were also changes in teachers' perceptions of what is happening in their classrooms. As the year progressed girls were seen as more likely than before to be involved in science lessons, to ask questions, to investigate to find answers, and

to tinker or play around with equipment. Girls were seen initially by teachers as less likely than boys to be engaged in all of these activities.

* Preservice Program Analysis of preservice responses (quantitative) indicates a significant increase in the level of PRE teachers' interest in science but not in technology (initial levels of interest in each were the same); in PRE teachers' perception of their background knowledge for teaching in both science and technology; in the importance of teaching science, but not technology,for both boys and girls at early childhood, middle and upper primary levels (initial levels were approximately equal). There was no change in PRE teachers' perceptions of what is happening, in relation to both boys' and girls' activities, in their classrooms.

Confirmation and extension of initial findings : Inservice Program

The initial findings (Kirkwood, Bearlin & Hardy, 1989), obtained from open-ended evaluations at the conclusion of the first semester workshop program, have been confirmed and extended by analysis of the qualitative (and quantitative) data provided by the three surveys. Changes have occurred in INS teachers' concepts of science and technology, and in their concepts of teaching and learning. These changes have been facilitated by specific aspects of the workshops, and in turn have led teachers to make other changes, both within the classroom and more broadly in their personal-professional lives.

* Changes in teachers' concepts of science and technology Many overcame their fear/awe of science and technology, some speculated about the nature of scientific knowledge, some delved into areas previously not understood.

I feel very excited about the way I reached and responded to this particular course, especially since I was always frightened of the word science, let alone what was involved in science. (Janelle)

[I have learnt] that science is a way of making sense of the world. [I have learnt] that what we think are scientific facts are actually a consensus of what people at a particular time agree is the most probable reason for something happening, i.e. once people agreed that the world was flat, until enough people found evidence that led them to believe that it is actually round. (Wendy)

The toaster experiments opened my eyes in another way. In my diary I've written about my new "emerging awareness" of the relationship between science and technology. I'm not even aware why that relationship became apparent ... but I began to look at things differently. "Technology is not just machinery - it's changing things and the way they're used". (Pam)

* Changes in teachers' concepts of teaching and learning Some focussed on their own learning, or related this to children's learning or to their classroom teaching, others focussed on gender equity aspects.

I've learned an enormous number of things in a short time. I've learned a little bit of information about the actual content of what we did and that little bit is acting like a seed in my mind because I keep looking out everywhere for related information or incidents. I learned that one question can lead to an endless chain of questions, it's a self perpetuating process. I suppose its called curiosity. I only ever had this about people, relationships etc. but never about things. (Vivienne)

The teacher doesn't own the knowledge -- we have to allow our students to construct and take responsibility for this knowledge in making better sense of our world. (Norma)

However, the important learning recorded in my diary is not only related to my own learning, it is related to what I have been able to take back to my classroom. Teaching is being a resource person, setting the scene for learning, encouraging children to ask their own questions, setting up a supportive learning environment, valuing everyone's thoughts. (Judy)

More awareness of gender equity in the classroom across the curriculum. I'm conscious of my attitudes towards girls and boys all the time. (Marlene)

* <u>Changes in science education and across the curriculum</u>
Since I started the course, there have been changes in the attitude towards science at our school. This has occurred through displaying our experiments in the corridor near the library; and beginning a 'tinkers' club. This club started out with a 20% membership of boys. I was surprised but delighted to see so many girls. At the commencement of 3rd term, a science room is being set up. Whilst I still feel a little insecure about passing on my knowledge to colleagues, I am finding that they regard me as someone who can help them with their problems about Science teaching. (Rhonda)

I have actually applied this model to the other curriculum areas as far as possible. I continue to be amazed and delighted at the amount of knowledge children have about topics which I myself have little knowledge about! I have also found that the children respond very positively and enthusiastically to this style of teaching. (Eva)

* <u>Changes in personal power</u>
[I'm now] confident to tackle other electrical appliances e.g. the iron... [and] the washing machine -- which I did fix. (Barbara)

My private life has also changed - I am now more confident to try new things, like different courses at night, - "I can learn about anything I want to" - and not feel silly about it. (Janelle)

Thinking scientifically has also enabled me to help my daughter with her Year 9 Science and also with her maths. Now we look at something and say "What are we asked? What do we know? How can I use my information to solve my problem?" ... The best thing is that Mum is not dumb after all. (Rhonda)

<u>How were these changes facilitated?</u>
Participants specified valued aspects of the workshops: the context, atmosphere, teaching approach and the valuing of people's differing experiences, feelings and understandings.

* <u>The choice of topics</u>, firstly toasters and later bread , that were continuous with their experience and made science and technology accessible.

... by the choice of toasters (and later bread), familiar to women, the lecturer led the group from a comfortable kitchen background through an invisible barrier and lured us into what could have been seen as a possibly threatening, previously male-dominated area of "technology". (Liz)

* <u>The atmosphere of the workshops</u> The development of a non-threatening, supportive and positive atmosphere was important to all participants and was created for people in different ways. For some, it was through being involved in a totally female group (for the early childhood group) with a woman tutor:

I felt very comfortable about being amongst other early-childhood teachers, all of whom happened to be women, and being led by a woman I also felt a sense of acceptance and a sense of worth as a result of the atmosphere of our class. As a result, I was able to learn in a way best suited to me without worrying about other pressures. (Janelle)

For others, the self determination of their own learning path was important:

The freedom to ask and investigate my own questions has been the most positive aspect of the course. It has also given me the feeling of a certain power over science. Science is not a discipline to be in awe of but another way of learning. I feel that I can ask questions and use a large variety of resources (concrete, human and written) to investigate and therefore learn about those things around me. (Judy)

* <u>Accessible learning strategies</u>: the use of concept maps, diary-keeping, the hands-on approach, working in groups (sometimes with all women members), modelling the process.

You had a very ignorant teacher of "Science" when I arrived for our first session on 2.3.89. I wanted to do the unit yet I felt quite threatened by the unit - I felt I had been trained as a teacher but not trained in Science of any type really. Then you gave us the Concept Map to draw about toasters (after we had enjoyed tea and toast) and I thought I would, do this task at any rate. Then you asked us to pose questions about toasters. I could think of some that sounded reasonable and as the session progressed I didn't feel so frightened or so alone. (Marion)

Another successful aspect has been the group work. The diversity of each group's learning increased what the whole group learned. ...It has been less threatening to be in a group that has all women members. I know I wouldn't feel as free to speak in a group that I felt was critical or condescending and that is how I often feel in a group with men. It is better not to speak than risk not being heard. (Wendy)

* <u>The implicit valuing of women's experiences</u> and the explicit focussing on gender aspects of teaching and learning of science in classrooms was important to many.

The course has validated my own experience as a teacher and as a woman. The high profile given to the experience of women, the naming of problems which have prevented the equal distribution of education resources (and other) in so much of our lives, and the support given to explore these issues were very empowering. (Liz)

Nature, magnitude and timing of these changes in Inservice teachers

Analysis of the quantitative data indicates that the changes outlined above occurred, with very few exceptions, in the first semester. Changes occurred during the period of the workshop program in levels of teachers' interest and sense of competence in teaching science and technology and in perceptions of their background knowledge for teaching, and perceptions of classroom happenings.

During the second semester these changes were at least maintained; and in some instances, there was an additional move in the same direction as in the first semester. It was during this period that teachers were working on their curriculum units and had become part of the networks. We are planning to survey the 1989 inservice teachers later in 1990 to ascertain how lasting these effects of the inservice program have been.

Support Networks 1989

When the inservice workshop groups were consulted about the setting up of the networks which were planned to support the teachers' second semester curriculum development work, they chose to have four regional networks established. The early childhood workshop group decided to have an additional network for early childhood teachers which could overlap the regional networks. This decision emerged from a group that had developed strong bonds over the workshop sessions and recognised that early childhood teaching in science had particular emphases which should be supported in a network of its own. The project officer assisted in the setting up of the networks, with a teacher being identified as the coordinator for each group network. A newsletter was established which kept teachers in touch with meeting times and agendas, with what other teachers were experiencing in their teaching, and with ideas and resources. Meetings were held in each of the networks, approximately monthly. While attendance varied during the semester, evaluations showed that those who attended regularly found the sharing and support from other teachers helpful in developing and implementing curriculum units in their classrooms.

Through the networks the decision was made to mount a major exhibition of the inservice teachers' work at the University of Canberra to coincide with Australian Science in Schools Week. This exhibition not only helped to lift the profile of primary/early childhood science, but provided an opportunity for a wide range of people to view the quality of the work being done by the teachers.

Networking involved very heavy demands on the project officer's time: it was not simply a matter of assisting in network meetings. Visiting teachers in their schools, providing frequent advice on the telephone, developing the newsletter, and linking the networks to other individuals and institutions were some of the other activities.

The Multiplication Effect of the Inservice Program

We were surprised by the extent of the multiplication effect of the PECSTEP Inservice Course. Teachers have taken initiatives in science education that they would not have thought possible a few months previously: several are members of Department of Education Curriculum Framework Panels. Several have made presentations at local and national Science Teachers' Association meetings and conferences. Others are inservicing colleagues in their schools, and some are sharing their curriculum ideas through a local newsletter. Some are writing about their experiences in national journals; another has received a CRA grant to study science education resource centres around Australia.

Another, an early-childhood teacher (Jan Elliott), has been selected as a judge of a national science competition, the only woman and the only non-Ph D on the panel. She is shortly to visit England on a scholarship to share her work with science educators and teachers.

PECSTEP 1990

PECSTEP is continuing to develop during 1990, building on the experiences and research findings of the 1989 program. Among the most significant developments have been

* secondment of practising teachers An agreement between the Faculty of Education and the ACT Department of Education has resulted in two teachers who participated in the 1989 program being released from their schools to teach the inservice program with a University of Canberra lecturer (Tim Hardy) who also participated in the 1989 workshops;
* modification of the inservice workshops in the light of successful components of the 1989 preservice program;
* continuing work in science/technology education of the 1989 inservice group, some of whom are attempting to develop science curriculum and teaching approaches for the staffs of their schools or regions.

Forty-five teachers commenced the 1990 inservice program following the same general pattern of the workshops followed by curriculum work in schools with support from the system of networks. These are based on the same four regional networks established in 1989, and their continuing development is largely the responsibility of the two teachers working on the team. A similar diversity of approaches used in 1989 to researching development in the teachers is being employed this year. This continuing research endeavour has been regarded as important because of the contrast to the 1989 situation in the personnel who are teaching the 1990 course; two female primary teachers and a male lecturer. We will be able to explore what role the science background and gender of the tutors plays in the success of the program.

The workshops have again used an everyday technology -- this time irons -- as a way into exploring science and modelling an interactive approach to science and technology teaching. Irons have proved to be an even richer instrument for provoking questions and potential investigation areas which included heat, electricity, water, fabrics, history of ironing, design and manufacture. Irons have also provided an obvious opportunity to raise questions about their gendered usage. We have turned to the topic of fabrics (the equivalent of bread in the 1989 program) later in the workshop sessions to illustrate how readily an interactive approach can link areas of the science curriculum, in this instance, by leading from electricity and heat (of irons) into the chemistry and biological aspects of fibres.

Evaluation of the 1989 preservice program demonstrated the significance of some of its elements that had not been components of the inservice program. The most important was an activity that required teachers to interview a small number of children about their understandings of "living" and "non-living". We made use of the work done in this area by Osborne and Freyberg (1985). When teachers had reflected on their often surprising results and shared these with others, each teacher planned to teach a group of children about living/non-living things. Reporting in workshops of teachers' experiences demonstrated the effectiveness of this exercise in sensitising teachers to the need to question their assumptions about children's initial understandings and the effectiveness of much traditional teaching in science.

Other additions to the inservice program have included a survey by each teacher of the children in their class as to their interests in a number of topics in order to investigate the extent of gender differences in these interests. Toward the end of the program another activity which was explicitly concerned with gender inequities was the use of Lego Technics. The workshop activities demonstrated how Technics could be used as an effective tool in interactive teaching when carefully introduced in a gender-sensitive manner and related to a relevant social context; without such concern its usage can reinforce if not deepen girls' alienation from machines.

Recently we have come to recognise that the extensive and intensive interaction between the members of the tutoring team is a critical aspect of the program, and we have begun to research this. It is clear that mutual support and openness is crucial in an approach to inservice work which demands a good deal of sensitivity as we interact with teachers as they develop increased competence and confidence, not only in the classroom but in other areas of their life. We are also beginning to recognise that to teach the sort of program that we have developed in PECSTEP there is a need for personal development in the tutors that parallels that of the teachers in the program.

QUESTIONS ARISING

Interactive and Connected Teaching

How can we best account for the success of PECSTEP in achieving its goals? It has built on research in interactive science teaching, but is it perhaps better characterised as "connected teaching" as defined by Belenky, Clinchy, Goldberger and Tarule (1986) in their study of women's ways of knowing, as also by Martin (1985) and Noddings (1984). In this approach, which is deeply respectful of both knowledge and persons, the teacher does not focus on her own knowledge but on her students' knowledge, and the feelings associated with it, not a usual practice in science classrooms, as Belenky et al. suggest (p. 215). In this way women were enabled to come to see and understand scientific knowledge and knowing as something no longer separate and alien to them. Instead they saw it as related to and connected with their everyday lives, enabling them to make sense of their experience. Science became something over which they could have control, not something, which through its experts, had control over them: a demystifying and empowering experience. Their attitudes to science were changed by changing what science and science teaching and learning were perceived to be and experienced as being.

Gender-sensitivity

Gender-sensitivity on the part of the tutor/lecturer was essential in the construction of the learning experiences of the inservice program. Explicit treatment of gender issues was resisted by some teachers and highly valued by others. We believe that for lasting attitude change to occur there must be a change of consciousness on the part of the teacher which involves a changed understanding of the nature of scientific knowledge. What is not clear is whether this understanding must incorporate a gender perspective. Must women teachers be able to explain why their attitudes have changed, using a gender-sensitive theory of learning and teaching, if they are to be able to? We are also asking how essential is it for the tutor to be a woman? Can men also be effective connected, interactive teachers? Should we have women-only programs for inservice as well as preservice teachers?

Inservice and preservice differences

We have noted in the outcomes of the programs some interesting differences between the inservice and preservice teachers. For instance, inservice teachers expressed more interest in teaching both science and technology as a result of their program, while preservice teachers became more interested in science, but not in technology. As yet we do not fully understand this and other differences between the two groups.

The challenge is to make this approach as effective with preservice teachers, who are generally younger and less experienced, as with inservice teachers. The question is: what factors do we need to attend to with differing emphases in these two groups? One factor appears to be critical: the types of support systems needed by the practising teacher and by the preservice teacher, and currently we are giving close attention to this area.

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AUSTRALIAN STUDIES: A VEHICLE FOR SCIENTIFIC AND TECHNOLOGICAL LITERACY?

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ABSTRACT

In Victoria, schools are adopting or common certificate, the VCE (Victorian Certificate of Education) which encompasses two years of study (Years 11 and 12) and comprises 44 subject areas or Studies, each of one semester duration. Amongst the compulsory subjects is Australian Studies (Units 1 and 2) with its focus on Work in Australian society. This paper discusses concerns about the teaching of the compulsory subject Australian Studies in the new VCE. The purpose is to consider whether the science and technology component in the Australian Studies course can raise the students' level of scientific and technological literacy. The discussion is based on one semester's teaching experience of Year 11 Australian Studies and consequent reflections on practice.

INTRODUCTION

Eckersley (1988) argues that if the current trend towards a 'high tech' society continues, the future viability of Australia's economy will be closely linked with our achievements in science and technology, and that there is a need for increased support for research and development in these areas. It is recommended that the public understanding of science be promoted by increasing the level of scientific literacy in the community. A cultural change is required so that we have a culture of understanding and participation, regarding scientific issues. The current literature reveals that there are many interpretations of the meaning of the term "scientific literacy". The definition used in this paper is: People who exhibit scientific and technological literacy are active and effective citizens who understand and can deal with, scientific and technological developments relevant to their lives. They can use and communicate scientific information and have the interest to develop their science education throughout their adult years. Their knowledge and attitudes enable them to participate responsibly in debate concerning science and technology in society.

An important reason for attempting to develop scientific literacy in students is that in order to understand modern technology, citizens need to be scientifically literate. Citizens should be encouraged to be more reflective and concerned about what is going on and education has a role to play by providing students with the opportunity to consider relevant issues and to develop the knowledge, skills and attitudes to recognise and evaluate conflicting ideas. The author believes that for Australian citizens to be technologically literate they need to be scientifically literate, as well as having an understanding of the economic and political position of the country. Education can contribute towards this complex goal by providing curriculum materials specifically designed to encourage students to learn more about technology.

PROMOTING PUBLIC UNDERSTANDING OF SCIENCE

The public has the right to be involved in decision-making, just as citizens have the right to vote. It is unreasonable to expect people to make decisions if they lack basic knowledge and understanding of the issues involved. Brush (1987, p.75) suggests a role for education:

> The current revival of concern for the quality and effectiveness of education includes discussion of issues such as motivating students to learn subjects they regard as difficult, changing the public perception of scientists, encouraging informed participation in decisions about the uses of technology and conveying an appreciation of science as part of culture.

Recent wide-ranging surveys about Australian attitudes and values, reported by Eckersley (1987) indicate that there is public support for science and technology, but also concern that scientific and technological developments are changing life in unintended and unfavourable ways. Few of the people surveyed felt that they were well informed about science and technology, and they were gloomy about the future. Mathews (1989) opposes this view of technological determinism, which is the idea that technology is indeed an independent factor, and that changes in technology cause social changes. Weeramantry (1986, p.62) supports this view:

> The citizen who is thus subject to the power and influence of science and technology cannot much longer be kept out of the decision making process in relation to the direction which science should take. The public interest is an integral part of the input into the decision as to which research should go ahead.

Shortland (1988) suggests that scientists lack an overview of the impact and ramifications of their research and should not be the only decision-makers about scientific developments. He argues that the decision-making process should take on a wider perspective to include public participation. Genetic engineering and in vitro fertilisation (IVF) research are areas now under scrutiny by the human rights movement, feminists and religious groups. Many of those surveyed are interested in these issues but know very little about the scientific research involved. If the public do not understand the nature of the research generally - its philosophy, procedures, controls and its impact on society - nor the issues involved, then they will be unable to make informed judgements about what research should be carried out or given funding priority. Eckersley (1987) identifies the need to widen public debate on all aspects of science and technology and asserts that educators have the responsibility to design appropriate curricula for students to develop the knowledge, skills and attitudes essential for effective participation in debates. Courses should expose students to scientific and technological issues and encourage questioning and debate about the choices involved and directions to be taken in technology and science.

HOW CAN SCIENTIFIC AND TECHNOLOGICAL LITERACY BE ACHIEVED IN THE SECONDARY SCHOOL?

Miller (1983) was of the opinion that secondary schools are the most effective places to start to increase scientific literacy, and Cowlishaw (1987, p.87) defines the problem and proposes a "bridging class" for non-scientists or others scientifically illiterate:

> How can we overcome the feelings of fear and hostility that many people feel toward science and technology? People who suffer such feelings are not inclined to come on science courses. Those who could benefit most from scientific literacy courses are therefore least likely to take advantage of them.

In the context of these considerations the science and technology component of the compulsory VCE Australian Studies course (VCAB, 1989) may be a significant means of encouraging students to improve their understanding of science and technology and thereby allowing science to be more accessible to a greater number of students. In this way the important ideas of science and technology would be placed in a broader curriculum context.

The Ministerial Review of Post-Compulsory Schooling (Blackburn, 1985) recommended that the study of work in society should include the impact of present changes in technology and relate them to social history. Idealistically, students should, as a result of the study of the impact of modern technologies on society, be in a position to be active participants, willing to contribute to debate involving scientific and technological issues. Australian Studies is an inter-disciplinary subject which can include exploration of priority issues such as environmental studies, new information technologies, biomedical technology and the future of work.

Australian Studies if taught as the study design suggests, has the potential to provide for all students, a background to allow for more informed public discussion that appears so desirable. Australian Studies aims to enable all students, not just those who intend to continue to study the sciences, to be able to examine relevant scientific concepts and issues.

AUSTRALIAN STUDIES IN THE CURRICULUM

Australian Studies Units 1 and 2: Work in Australian Society contains four areas of study.

* Area of Study 1: Work: A Window on Australian Society.
* Area of Study 2: Australia's People and Patterns of Work.
* Area of Study 3: Australia: A "Fair and Reasonable" Community.
* Area of Study 4: Australia: A Technological Society.

The work requirements consist of Introductory Exercises, a Journal, Major Project, Folio Pieces and Presentation. It is not within the scope of this paper to give a detailed account of the VCE Australian Studies Study design, or the background behind its implementation. This paper will therefore only consider the propositions relevant to science and technology and suggest ways they might be dealt with in the school curriculum to attempt to increase the students' level of scientific literacy.

Those propositions relating to technology in the Study design are as follows:

1. Technological change has many significant implications for governments, employers and individuals.

2. Technological change has major effects on the structure of Australian industry.

3. The ways in which individuals, industry and government consider and implement technological innovation will significantly shape Australia's future.

The Study design requires an investigative approach and involves teachers from across the disciplines with varying perspectives. The different levels of teacher expertise in technology can be an advantage or disadvantage depending on the administrative and organisational response to the variations. In this aspect Australian Studies addresses the issue raised by Mathews (1988) who takes the view that the education system needs to "break down curriculum barriers and encourage cross-disciplinary courses". He argues that the changes occurring in Australia's economy and industry require flexible skill formation and technological literacy.

The obvious problem with this is that teachers may not feel confident in teaching certain areas. Area 4 particularly, with its emphasis on science and technology, is daunting for teachers who lack expertise in these areas, and could easily become the omitted element in Australian Studies. This highlights the need for a teacher with expertise in science to be involved in the planning of teaching strategies as well as in actively teaching the material. Team teaching is a recommended solution, and a possible way to increase scientific literacy would be for the science teacher in the team to design a five-six week unit focussing on science and technology in society. Classes could then be rotated through the teacher with interest and expertise in this field. A teacher with history background could similarly offer a section on technological change in its historical context and the history of Australian Science.

In Units 3 and 4: Australia A Changing Culture, the idea of making culture in the active sense; is perceived in a number of ways which are investigated. It is in Area of Study 4 Australia: A Productive Society, that technology needs to be considered. There is considerable scope in the propositions for increasing the level of scientific literacy of students. Stockley and Foster (1988, p.13) identify the components of the "productive culture" which the Hawke Government is trying to legitimise. They argue:

> Science and technology are the motive forces of the scenario. There is sufficient wit to realise that an increasing number mistrust the masters of nature, and so "scientific literacy" becomes an important part of the new cultural formation. Respect for, and increased funding to science and technology will become embedded in the public consciousness in the "productive culture".

TEACHING STRATEGIES

A Children's Science perspective, which takes into account the students' prior views, should be adopted in order for meaningful learning to occur. Students could be encouraged to generate questions which they would like answered. These questions would dictate the amount of scientific detail required for them to gain an understanding of the issue. In such a style the teacher needs to ascertain what the students already know about the technology and use their prior views as a starting point for the discussion, which leads to the students being active learners. Teachers need to use teaching methods which enable students to recognise and value their ideas, knowledge and experiences. Students are encouraged to reflect on their own learning. Appropriate teaching strategies could include concept mapping, creative writing, role play, game playing and group work in order to facilitate active participation of girls and boys in the learning process. The use of recent newspaper articles to document current events related to the research would be emphasised highlighting the relationship between science and society.

Gardner, Penna and Brass (1989) discuss the issue of improving teacher education and highlight the need to assist teachers to devise well conceived instructional materials and develop teaching methods aimed at enhancing complex skills. Some schools are moving towards the adoption of a constructivist view of learning. Gardner et al. (p.37) describe this view:

> Learning is regarded as a personal process in which learners construct meaning for themselves as a result of interactions with the world; students are encouraged to take responsibility for their own learning, to become independent learners and problem-solvers; learners are encouraged to link disparate knowledge through a curriculum containing areas of study which cross traditional boundaries (e.g. environmental education, health education, outdoor education); students and teachers negotiate some aspects of the curriculum.

Neville (1989, p.11) supports this approach and regards teaching as a process of facilitating learning:

> We learn very little by being told the answers to questions we have not asked. Learning originates in the actions of the learner, not those of the teacher.

Doonan (1987) regards <u>negotiation</u> between teacher and student as being appropriate for courses aiming for scientific literacy. She suggests that educating for scientific literacy has implications for the methods, processes and approaches for developing courses. Furthermore, Doonan (1987, p.101) supports the Children's Science view, and believes that classes should be arranged so that:

> students can <u>engage</u> with the issues <u>from where they are</u>. No one 'knows nothing' about science/technology, everyone has some relation with it.

Differing attributes of student groups to science and technology, for example: girls, boys, class, and ethnicity, will have implications for teaching strategies. In agreeing with Doonan that teaching methods should encourage a "critical, dynamic and usable understanding of science, technology and society", several questions arise:

* How can teachers design courses which aim for critical understanding of science but which are also pleasurable, stimulating and challenging?

* How can classes operate so that students are active in their own learning?

* What approaches can be used which aim to help individuals to develop a sense of empowerment so that people feel able to change things?

IMPLICATIONS FOR THE ROLE AND TEACHING OF THE AUSTRALIAN STUDIES COURSE.

The Australian Studies Study design provides the opportunity for increasing scientific and technological literacy, but there is a danger that the technological components may be overlooked unless staff who feel confident in this area are part of the Australian Studies teaching team. Some schools may limit the number of faculties represented in the team for administrative reasons or because many teachers themselves lack adequate knowledge and understanding of the technological issues. Therefore there is a need for teachers to attend in-service programs which focus on the Study design and include practical suggestions for implementing the ideas into the course. Cluster group meetings provide an avenue for discussion between teachers from different schools and is an effective means of sharing ideas and teaching strategies. In this way a supportive atmosphere is provided which encourages individual teachers to try out new ideas in the classroom. Arnold (1985, pp.16-17) supports the view that there is a need for significant changes in technology curricula and teaching methods, which in turn require a change in professional development:

> If teaching practice is to change, it will be necessary to employ a variety of professional development approaches. Short-term, one-off withdrawal courses can supply teachers with increased knowledge. However, such approaches have been shown to be a largely inefficient means of producing lasting change. Some longer-term school-based approaches to professional development are also needed so that teachers can be active participants in the process of change.

With the adoption of the new VCE Australian Studies course it will be necessary for research to be carried out in schools in order to gauge the effectiveness of its implementation. Evaluation by the teachers involved would be useful to identify difficulties and problems as they arise. Collaborative action research would be an appropriate way to encourage reflection on practice and should lead to an improvement in the teaching and learning of Australian Studies. The P.E.E.L approach and strategies as outlined by Baird and Mitchell (1986), could be an avenue for teachers to gain support and share concerns regarding the course content and work requirements.

Science and technology in schools often present an incomplete picture and this paper stresses the need for science and technology to be seen in "social context", with an emphasis on people-oriented activities and the human dimension of science and technology. One neglected aspect here is people's fear and worry regarding technological future(s). It is therefore important for course content to demystify science and technology.

Partly because of their cultural conditioning, girls find scientific and technological studies alienating, which deprives these areas of the talents of many young women. This is unfortunate when you consider that Australia's future economic success may depend on these areas. This paper recommends that in order to increase the number of people selecting careers in these fields the school curriculum needs to be broadened and science and technology presented with a human-oriented focus. An important point to note is that Australian Studies Units 1 and 2, which have input from several disciplines, with the theme of "work", could be useful to enable girls and boys to feel comfortable choosing science-oriented careers. The Study design has the potential to not only generate interest in science and technology, but to lead to active participation in these fields.

The importance of indirect teaching methods and student control of their own learning has been outlined. Teachers need to take on the role of facilitator, providing a relaxed classroom environment which encourages students to generate their own questions which they want to investigate. Students should be able to work in groups in which they share ideas and difficulties and design their own experiments in order to solve problems. Students need to be given time to reflect on their learning and participate in self-assessment of their progress.

Australian society as a whole can only benefit from improved scientific literacy for as Bernal (1966, pp. 308-309) has pointed out:

> Scientists also recognise their weaknesses, a lack of contact, not so much with the seats of power as with the people who can be the real beneficiaries of science. When that contact is renewed and improved we can hope to have a world where science ceases to be a threat to mankind and becomes a guarantee for a better future.

The philosophy behind the Australian Studies course and the Study design itself, provide considerable scope for increasing scientific literacy, and it is to be hoped that schools take advantage of this opportunity. If they do not society in the long run will be poorer for their want of trying.

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DEVELOPING A TAXONOMY OF SCIENCE CONCEPTS BASED ON A SCALE OF EMPIRICAL DISTANCE.

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ABSTRACT

The term 'concept' is used in different ways within educational literature and has at least two different, although related, referents in relation to science knowledge, namely, public knowledge and private understandings. A taxonomic structure for 'science concepts' (public knowledge) has been developed to provide a rationale for the choice of phenomena to be used in the investigation of students' 'concepts' and also to act as a frame of reference for generating insights about the data to be collected. Furthermore, it may be a useful heuristic to predict other science concepts likely to be highly problematic in school teaching situations and thus worthy of detailed research. The taxonomy, called a 'Scale of Empirical Distance' (SED), enables science concepts to be mapped according to their degree of closeness to concrete realities. The scale shows a recognition of the empirical basis of science concepts and the role of human senses in the perception of the material world even though "absolute objectivity of observation is not a possible ideal of science" as Harre (1972) has noted. The scale uses two binary variables, namely, 'visual' and 'tactile', to generate four categories of science concepts ranging on a continuum from concrete to abstract. Some concepts related to 'matter' will be classified and discussed.

INTRODUCTION

The treatment of knowledge as an aggregation of concepts has received considerable attention from teachers, educationists and psychologists, particularly in the last twenty years (Ausubel, 1968; Gagne, 1977; Johnson-Laird & Wason, 1977; Novak, 1977; Scholnick, 1983; Osborne & Freyberg, 1985; White, 1988). All three groups have been attracted by the problems and issues related to the nature of concepts, personal meaning of particular concepts, the identification of key concepts, hierarchies of difficulty, sequencing possibilities and implications for both learning and teaching.

The Oxford Primary Science Project (Redman et al., 1967) which set out to enquire into the formation of scientific concepts in children 5-13 years of age and to develop a science curriculum for children in British primary schools, brought to light the variety of views of different professionals as to what concepts should be developed in a school science curriculum. The Project sought the ideas of scientists, lecturers and researchers in universities and industry on what concepts were important to an understanding of science. Primary school teachers were also invited to describe the nature of the science work they did with children and to state the science concepts they thought children might have formed as a result of their work. In practice, teachers showed a preference for topics such as magnets, air and water, floating bodies and nature study but appeared to be uncertain or unaware of the scientific concepts they wanted children to develop. Educators on the project team sought then to identify those all-embracing ideas which ve meaning across the whole field of science. They reasoned that, because "children sometimes think in larger categories first and then think in terms of particular examples inside the group, there was thought to be a real arguement for identifying the important global concepts of science and attempting to find out how the children form these- or if they can form them at the primary school age." (Redman et al., 1967, p 5)

The deliberations of invited scientists resulted in the listing of four major concepts, namely, Energy, Structure, Chance and Life, each embracing a set of up to a dozen sub-ordinate key ideas, also called concepts, such as 'uncertainty and probability', 'disorder and randomness', and 'pattern' embraced by 'Chance'. The research team summarized their view of science and its implications for teaching by stating, in a later publication, that "where science was formally a collection of branches of knowledge, often mutually exclusive, it is now seen as the interplay of relatively few concepts." (Redman et al., 1969, p2)

DIFFERING VIEWS OF 'CONCEPT'

Despite the appearance of some clear common ground, the Oxford Project illustrates that the word 'concept' is often used quite differently by teachers, educators, psychologists and scientists. For the immediate purposes of this paper some of the different descriptions of the nature of concepts both between and within such groups will be mentioned briefly.

Firstly, distinctions have been made between different types of concepts in studies from both psychological and educational perspectives. Commonly such distinctions have been dichotomous in nature as is the 'ostensive concept - relational concept' distinction referred to by Preece (1978) as being fundamental and traceable, historically, at least as far back as Augustine. Ostensive concepts are those which can be pointed to and thus are directly related to tangible objects. The combination of pointing and the use of words establishes the concept. Relational concepts are those which are defined in terms of other concepts, ultimately ostensive ones. Gagne (1977), Cantu and Herron (1978) and Pines and Leith (1981) use a similar categorization with different labels, namely, concrete and abstract.

Of basic concern to psychologists is the question of how people store, retrieve and use knowledge and their view of concepts reflects this. Gleitmann et al. (1983) refer to concepts in two ways in relation to their representation in the brain, namely as mental categories represented by definitions and those represented by prototypes. A mental category may be defined by a formal statement of necessary and sufficient criteria. This is the classical or definitional theory of concepts which contrasts with the second view based on family resemblance or prototypicality theory as described by Rosch (1977). In the classical view of concept a judgment as to whether an instance is or is not an exemplar of a particular concept is clear cut, since it depends on whether it meets or does not meet all the definitional citeria, whereas in the prototypical view there is a gradient of membership of a category represented by a prototype, some exemplars of the concept being more exemplary than others, that is, closer to the prototype. For example, whilst emus and pelicans appear to exhibit classical definitional features of birds by possessing feathers, wings and a capacity to lay eggs, they are less 'birdy' than sparrows or hawks which are probably more prototypical of birds for most people.

White (1988) describes concepts in terms of his defined 'elements' of memory. An assemblage of one or more of seven types of element constitutes the knowledge a person possesses of any particular concept. He has named the elements as 'strings', 'propositions', 'images', 'episodes', 'intellectual skills', 'motor skills' and 'cognitive strategies'. Thus, a concept is a set of related elements of memory associated with a word or phrase as its label. As such it can be limited or extensive according to the number, type and nature of the elements present in an individual's repertoire. It is something which is personal and private in its totality but capable of being shared, in part, by others as well as being open to extension without limit by the association of more elements.

Pines (1985) develops his view of concept from a notion of 'elements' of cognition which are mental, symbolic representations of objects and events of the world the most fundamental of which are human sensations which become organized into perceptions. These elements are variously interrelated and it is the quality and quantity of these relationships which give rise to the meaning people attach to their experiences. He then goes on to define concepts to be "... complex summaries of numerous such relations that can be expressed as propositions." (p. 102). It does appear that Pines takes the view that a concept is the substantive, articulatable or publicly accessible distillation of a person's private world of meaning about some regularity. Concepts so viewed sit somewhere between personal knowledge structure and the organized systems of public knowledge accepted by the communities of particular disciplines or interests. Gilbert and Watts (1983) have recognized the ambiguity arising from the interchangeable use of the term concept between these two referents, personal and public knowledge.

Whereas psychologists generally appear to focus on aspects of cognitive functioning in describing the notion of concept, some science educators tend to focus on the organized components of public knowledge about which there is current agreement. Although West et al. (1985) take as their point of departure in research the words and statements from syllabuses, examinations and study materials together with what is communicated orally by teachers, they take 'concepts' to be private understandings and 'concept labels' to be the words linked in the propositions of public knowledge.

From the perspective of a classroom teacher, there exists a public knowledge structure which the practitioner intends to teach and it is to each of the related entities of that structure which the term concept is commonly applied. For example, 'solid', 'liquid' and 'gas' are such concepts in science which have their exemplars and definition statements and which are linked with and by concepts such as 'melt', 'evaporate', 'condense', 'sublime' and numerous others in publicly accepted interrelationships which describe certain phenomena in the physical world.

A DEFINITION OF CONCEPT LABELS

The above review of the use of the term 'concept', although purposely limited, is sufficient to demonstrate the currency of alternative usages of this concept label. Thus, in order to avoid ambiguity, it is proposed to use the term 'science concepts' to refer to components of public knowledge of the physical world about which there is a consensus within a community of thinkers from time to time. Any 'science concept' would be the distilled summary or set of propositions and examples derived from those common aspects of private understandings of the members of the scientific community. It represents the multiple intersection of ideas and understandings about some aspect of the world and would be referred to by the same concept label used to represent the private understandings. The term 'concept ' will be used to refer to components of private knowledge. Any 'concept' comprises a set of related elements of memory associated with a word which labels it for thought and communication. Whereas science concepts are recorded, explicated and discussed in books and their modern equivalents and are available for perusal at will, concepts remain personal and relatively inaccessible to others.

A CLASSIFICATION OF SCIENCE CONCEPTS

The research reported here developed from an intention to expose, in part, primary school students' concepts of selected phenomena and to identify any implications for the teaching of the science concepts used to describe and explain those phenomena. Given the considerable evidence as to the apparent ineffectiveness of much secondary school teaching of science concepts it seemed appropriate to develop a taxonomic structure for thinking about science concepts that might illuminate possible causes of, and solutions to, some of these practical difficulties experienced by teachers. A taxonomy would provide a rationale for the choice of phenomena to be investigated and a frame of reference for generating insights as the data are collected. It may also serve as a heuristic to predict, as White (1987) has suggested, those science concepts which could be highly problematic from the point of view of teaching and thus worthy of detailed study. In this connection it may provide a rationale for the selection of appropriate content for school science curricula. Furthermore it might lead to explanations of any patterns which may appear in the range of students' concepts about the phenomena selected for study.

One dimension by which school subject content is already classified by practising teachers is that of 'concreteness'. 'Concrete', and its antithesis 'abstract', are notions which are part of the professional vocabulary of teachers and are used to categorize, in a binary way, some of the different aspects of what they aim to teach. It is assumed that these terms have sufficient currency in educational discourse for them to be used in devising a taxonomy of science concepts which is useful to both researchers and teachers.

Whereas 'concrete' and 'abstract' are terms commonly used in a dichotomous way, they are proposed here as the end points of a continuum with an intervening scale of relative concreteness to be called the 'Scale of Empirical Distance' (SED). This name draws attention to chosen essential components of concreteness as they relate to the practice of science as well as the potential use of the scale to map science concepts. These aspects will become apparent in the following description of the scale.

The extent to which any phenomenon is accessible to human experience through the visual or tactile senses will govern the closeness to concreteness of the science concept used to refer to that phenomenon. Science concepts which relate directly to phenomena which are both visual and tactile are taken to be 'concrete' and would be located at one end of the continuum. A relatively small distance from concrete are those science concepts of phenomena which are visual but non-tactile, and further out are those science concepts which are non-visual but tactile. At the greatest empirical distance are those science concepts refering to phenomena which are neither visual nor tactile but are abstract notions of invented things or processes, which may or may not exist, and are accessible to experience only through their second order effects.

THE EMPIRICAL BASIS OF THE SED.

Science is fundamentally and initially concerned with human perceptions of the material world and thus has an essential empirical component. It seeks to describe and explain in rational terms the phenomena of objects and events as they appear, but also, science goes beyond their immediate sensing and manipulation. The perception of phenomena is mediated through one or more of the five senses: visual, tactile, auditory, olfactory and gustatory. Sensory data are transferred from the sense organs to the brain and by some interpretative process, involving the recall of past experience; we become aware of the world about us and proceed to form a range of concepts and explanations which constitute the meaning for us of our experience. Thus, empirical data are essential to the activity of scientists whether preceding or following the generation of scientific concepts and propositions. A taxonomy which recognizes the empirical relations of science concepts is thus likely to be useful.

It is appropriate to explain the choice of the two binary criteria as the elements of the scale when the sources of empirical data are the five senses. Vision is undoubtedly the sense providing the richest source of information. Its degree of acuity has normally developed at a young age to permit perceptions about size, shape, colour, texture, relative position and motion of objects in the vicinity of an observer, even at great distance, through the medium of electromagnetic radiation. It is conceivable that auditory sense could be developed by individuals to a greater degree of acuity than is normally the case but it could never provide the richness and range of perceptions possible with vision. The senses of taste and smell, although the means for important perceptions about some aspects of phenomena, are limited both by their nature and by the general lack of linguistic infra-structure to communicate the narrow range of perceptions derived from their normal functioning.

The sense of touch has been chosen as the second criterion to structure the scale since it is not only a means for perceiving size, shape, texture, relative position, motion, temperature, malleability and strength of objects and materials, but also central to the curious habit of human beings to handle objects. Furthermore, the senses of hearing, taste and smell are reducible to the tactile sense more broadly conceived. For example, vibrating air particles impinge upon the specialized 'skin' constituting the ear drum whilst adjacent sensory devices in the inner ear transduce the kinetic energy of these small pieces of matter into a perceptible form . Even more equivalent to normal tactile sense are the senses of taste and smell in which chemical particles of matter are brought into direct contact with skin receptors which mediate the process of perception. Hence, in using the term 'tactile' in the scale a broader coverage of sensations is actually implied.

TABLE 1
SCALE OF EMPIRICAL DISTANCE (SED)

CLOSE (concrete)	1.Visual + Tactile	solid liquid	element compound mixture
	2.Visual / Non-tactile	gas (?)	Earth Sun Moon
SED			
	3.Tactile/ Non-visual	gas (?)	heat mass momentum
FAR OUT (abstract)	4.Non-visual + Non-tactile		atom molecule ion

PLACING SCIENCE CONCEPTS ON THE SED.

Investigations of children's concepts in the two science conceptual areas of 'matter and its forms' and the 'Earth, Sun, Moon system' have been reported elsewhere (Jones, 1984; Jones, Lynch & Reesink, 1987, 1989) and a third topic, 'air and related phenomena' is presently a focus of attention. These topic areas were chosen because each one, overall, appeared to involve different sorts of science concepts. Those in the first study deal with phenomena which are generally accessible through visual and tactile sensing for some aspects of their range of meanings. The other two topics use science concepts dealing with phenomena which are progressively less accessible, empirically, even for the simplest meaning of each of the science concepts involved. In setting out the Scale it is important to note that a science concept may have a range of meaning, that is, propositions can vary from simple, particular and descriptive to complex and general. Simple meanings would include examples of objects and events and more complex meanings would include operational definitions of the properties and behaviour of those objects and events. Thus, Table 1, which sets out the SED on a vertical axis, shows science concept labels plotted according to their most particular and most empirically verifiable meanings. Some examples will help to illustrate these aspects.

The science concept 'solid', for example, has a wide semantic range which is conveyed in the set of propositions listed in Table 2. The type of statement, whether more particular or more general, is shown at the side of the table. General (operational) is a type of statement involving an operational definition and General (class) is a type referring to a class of phenomena. The starred proposition is the one open to the most empirical verification and governs the placement of the science concept on the SED.

TABLE 2

A RANGE OF MEANINGS FOR SCIENCE CONCEPTS
SOLID, MIXTURE AND GAS.

Solid	
* 'ice is a solid'	Particular
'a solid has a fixed shape'	General 1 (property)
'solid describes a form of matter' (solidness)	General 2 (class)
Mixture	
*'cordial is a mixture'	Particular
'a mixture can be separated by physical means into its components'	General 1(property operationally defined)
'a mixture contains more than one type of element or compound or more than one state'	General 2 (composition)
Gas	
*'carbon dioxide is a gas'	Particular
'some gases smell'	General 1 (property)
'moving gas feels like wind'	
'air is a gas mixture'	General 2
'most gases are colourless and invisible'	

Solid is plotted at the 'Close' end of the scale because it has one or more variants of meaning which are empirically verifiable by both visual and tactile means. For the same reasons 'mixture' is similarly categorised. Some propositions using this label are also shown in Table 2. However it is not implied that any unknown sample of a mixture can be perceived to be a mixture immediately, but that it is possible to obtain direct empirical evidence as to the nature of the sample. In contrast, 'atom' and 'molecule' are science concepts which have no directly perceptible instances and thus no meanings associated with visual or tactile phenomena. They are plotted at the most 'Far Out' end of the scale.

'Gas' is a science concept which seems somewhat less empirically verifiable than the other states of matter. Most gases, including all common ones, are colourless, transparent and invisible yet they are open to tactile sensing via skin or nose. A range meaning for 'gas' is shown in Table 2 to support its mid-scale placement. Although a very few gases are coloured they are not part of common experience, hence 'gas' appears with a query in the visual category. Gas is a problematic concept.

Herron et al. (1977) have discussed some difficulties associated with the analysis of selected science concepts in terms of critical and variable attributes. In relation to those which name properties of objects, as does 'mass', they claim that it is not possible to give an example of the science concept 'mass'. They argue that one can show an object that has mass but this is qualitatively different from showing a 'chair' which is a class of objects. However, it is argued here that mass is qualitatively similar to 'chair' and 'solid' but is at a greater empirical distance from concrete. 'Mass', as a measure of inertia, is open to tactile sensation such as when one attempts to move stationary objects of different mass horizontally, in a situation with low friction. It is proposed to place 'mass' at distance three on the SED.

IMPLICATIONS FOR TEACHING AND LEARNING

All the science concepts about matter at Level 1 on the SED can be explored and discussed at the highly empirical level yet it is common for textbook writers and teachers to quickly abandon this level and proceed to argue and explain in terms of atom, molecule and ion. This may explain why some students fail to understand: they are more sensitive to the lack of sufficient empirical basis. 'Atom', 'molecule' and 'ion', are non-visual and non-tactile ideas, and although they are commonly introduced using visual and tactile simulation (atomic model kits etc.) yet, as the semantic level is raised, the arguments become very sophisticated.

The position of 'gas' on the SED in relation to solid and liquid is worth noting. Although chlorine and iodine gases in concentrated form are visible they are quite uncommon in this form, and generally outside normal experience. This, along with the limited tactile properties of gas probably helps to explain why it has always been a relatively difficult idea in students' learning.

There is a strong case for having students spend more time exploring the visual and tactile aspects of phenomena so as to build up an extensive 'fund of experience' at the macroscopic level in order to provide a substantial base for other levels of meaning which appeal to ideas at the microscopic level and beyond. For any science concept 'x', what 'x' can do or be is usually easier to think about because these are associated with a more concrete level of meaning compared to thinking about what 'x' is. The magnitude of the jump from empirical considerations to theoretical explanations is often quite large and perhaps we continue to underestimate the need for considerable empirical experience over a longer time and a broader range of examples in order to develop science concepts.

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"EXPERT" AND "NOVICE" SUBJECTS' APPROACHES TO GENETIC PROBLEM SOLVING IN A COMPUTER-BASED SETTING

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ABSTRACT

A small group of subjects differing in levels of expertise in genetics undertook a problem-solving task in a computer-based setting. Transcripts of 'think-aloud' protocols were obtained. Data revealed contrasts between expert and novice subjects in their approaches to the problem, and differences both in inferred understanding of genetic concepts and procedural knowledge. Experts carried out prior planning by identifying suitable strategies; they displayed well developed content knowledge, and appropriate use of procedures in which sequences of procedures were grouped into single productions. In contrast, novices showed poor planning, used a 'try-it-and-see' approach to selection of crosses, and confused some basic concepts. Problem tasks of the type identified in this study complement other learning experiences, and have the potential to assist learners to enhance their understanding of genetic concepts.

INTRODUCTION

Exposure to problem solving has been identified as an essential part of the experience of students in their studies in science. It has long been recognized that the essence of problem solving is captured less in the answer attained as in the procedures followed in reaching that answer or solution. Problem-solving strategies used by subjects from varying backgrounds have been examined in several domains, including mechanics (Chi, Feltovich, & Glaser, 1981; Champagne, Gunstone & Klopfer, 1982), chemistry (Camacho & Good, 1989), and genetics (Stewart, 1983; Smith & Good, 1984; Hackling & Lawrence, 1988). Many of these studies have focussed on differences in performance of novices and experts, or of successful and unsuccessful subjects. The basis for research of this type has in many cases been the development of models of appropriate performance that can inform classroom instruction.

In several studies, pencil-and-paper problem tasks have been used. In other studies, a computer-based setting has been used to explore concepts held and strategies used by subjects engaged in problem-solving tasks (Slack & Stewart, 1990; Kinnear & Martin, 1989; Rivers & Vockell, 1987). The potential value of a computer-based setting in which subjects can engage in dynamic interaction with a computer simulation was identified by Krajeik, Simmons, and Lunetta (1988) as providing a valuable research strategy for studying of problem solving. As well, a computer setting allows problem solvers to interact with a simulation as part of solving open-ended problems which require not only data analysis, but also data generation, and, in some cases, model construction and manipulation.
This paper reports on part of a larger study investigating, at a case study level, approaches to problem solving of subjects separated on a 'novice/expert' dichotomy.

In this study, the concept of independent assortment of genes was the focus of study. This study sought to contribute to the following questions:

* How is knowledge used by experts and novices during problem solving?
* What approaches are used by novices and experts in problem solving?
* What representations are used by novices and experts during problem solving?

MATERIALS AND METHODS

Subjects

A total of 10 volunteer subjects, all familiar with microcomputer use, participated in this part of the study. Five subjects were broadly classified as 'novices'. These 'novice' subjects (N1-N5) were graduate students in a Science Education program, with their prior formal studies in genetics being the completion of a first-year College Biology course that included genetics. Five other subjects were broadly classified as 'experts'. This group was heterogeneous, and included three University professors from Genetics Departments, and who were currently teaching genetics (E1-E3), one professor from a Science Education Department who had some time previously taught genetics at high school level (E4), and one postgraduate student who had completed a major study in genetics at College level and was currently enrolled in a doctoral program in genetics (E5).

The computer program

The program used in this study was a simulation of transmission genetics, KANGASAURUS (Kinnear, 1989). This program has two distinct modes of operation. Operation in the first mode provides a context in which a genetic model is constructed covertly by the computer, and the user has access to parents and offspring at the level of phenotypes only; this 'covert-model' mode requires users to identify genetic models consistent with outcomes generated by these models. Operation in the second mode provides a context in which the construction of a genetic model is overt, with variables being explicitly set by users. In this 'overt-model' mode, users have access to both phenotypic and genotypic data, and can observe the operational outcomes of a genetic model. Through these two modes of operation, the program can be used in problem-solving tasks that cover a range of problem types. For this study, the program was used in the 'overt-model' mode.

In the overt-model mode, users can assign values to variables within the ranges identified: number of autosomes (1, 2, or 3 pairs); scale bar governing size of chromosomes (5 - 25 map units); sex chromosome system (XX/XY or ZW/ZZ, or XX/XO); number of genes (1 or 2); number of alleles for each gene (2 or 3); relationship between phenotypic action of alleles (complete or partial dominance); function of gene: selected from 13 identified traits, for example, body colour); allelic symbols (letter chosen); gene locus (position on any chromosome chosen by moving an arrow across screen display; crossing over, in case of linked genes (include or exclude); lethality (include or exclude); maternal and paternal genotypes (any permissible genotype), and if heterozygous for linked genes, cis or trans arrangement.

The tasks

The first task was a ranking task in which subjects were asked to rank a list of concepts typically found in courses on transmission genetics, in terms of their own perception of their difficulty. The 'easiest to understand' concept(s) was (were) identified by the number 1, and higher numbers were used to denote increased perceived difficulty. The printed list presented to subjects comprised the following concepts: *segregation of alleles, sex linkage, probability, dihybrid cross, independent assortment, dominance, gene interaction, autosome, meiosis, locus, crossing over, genotype, monohybrid cross, Punnett square.*

The second task required subjects to respond to the following: '*Use lines to represent homologous chromosomes and use letters to represent alleles of a gene. Draw a diagram that shows the spatial arrangement of the genotype of an organism that is heterozygous for two genes that assort independently.*'

Prior to undertaking the computer-based task, each subject had a short supervised session to ensure familiarity with the operation of the program. Subjects were then presented with a card stating: *A fellow student says that s/he is a bit confused about what is meant by the term 'independent assortment'. Set up a genetic system and carry out a cross that would demonstrate this to your friend.*

Subjects were asked to 'think aloud', and verbal protocols were taped as part of a collection of data that involved the simultaneous video recording of subjects and of the computer screens that they were viewing. The three sets of data, one verbal and two visual, were incorporated into a single record as described in Simmons and Kinnear (1990). For this paper, data were drawn from the transcripts prepared from the verbal protocols.

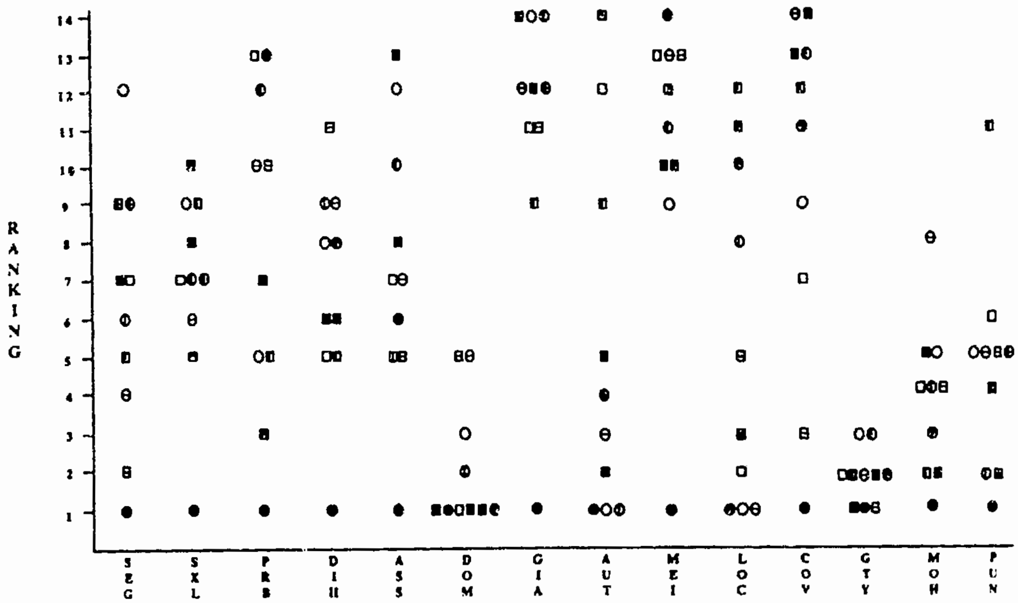
RESULTS AND DISCUSSION

Concept ranking

The ranking of the concepts in terms of each subject's judgement of perceived difficulty yielded the results shown in Fig. 1 All subjects except E5 ranked the concepts differentially, with some subjects assigning several concepts as having the same perceived difficulty.

Because rankings are ordinal measures, unit differences between values do not convey an equal progression in the level of perceived difficulty, and no significance can be attached to the numeric values. However, average rankings were calculated in so far as they provide an indication of relative positioning of concepts. Average values for each group are shown below the concepts listed in Figure 1. In the case of the expert group, subject E5 is excluded for this purpose.

The concepts ranked as the 'easiest' by the novices were genotype (GTY), and *dominance* (DOM); for the experts, the 'easiest' concepts were identified as *autosome* (AUT) and *genotype*. The concepts ranked by both groups among the 'hardest' included *gene interaction* (GIA) and *meiosis* (MEI). These are both complex processes that embed a number of subsidiary concepts, and have been identified as among those topics that are regarded as difficult to learn and difficult to teach (Finley *et al.*, 1982; Johnstone & Mahmound, 1980). Similarity of ranking does not imply that the subjects in each group hold the same understanding of the concepts. The narrow distribution of the ranking of concepts such as *genotype* and *meiosis* contrasts the wider spread in the rankings given to concepts such as *locus* (LOC), *crossing over* (COV), and *segregation of alleles* (SEG). The width of distribution may reflect variability in representations held by the subjects, with a wider spread indicating a greater heterogeneity of mental representations held.



N	6	7.8	7.6	6.6	7.6	1.8	11	8.4	12	6.6	9.8	1.6	3.4	5.6
E	7.8	7.3	10	8.5	8.8	2.8	13	2.3	12	5	12	2.5	5	4.3

Subject identification: N1:■, N2:□, N3:◫, N4:⊟, N5:⊞, E1:○, E2:Θ, E3:Φ, E4:⊕, E5:●

Fig. 1 Ranking of concepts in terms of subjects' perceived difficulty

Broad agreement exists between both groups regarding their rankings of most concepts, with the exception of *autosome*. The expert group ranked this as easiest with a mean ranking of 2.3. The mean ranking given by the novice group was higher (8.4), indicating that they perceived most concepts as easier than autosome. It is suggested that experts, having an integrated view of genes and chromosomes, recognize autosomes as a class of chromosome, and so as genetic 'objects'. Given a commonly-reported failure of genetics students to interpret the behaviour of genes and alleles in terms of the behaviour of the chromosomes on which they are located (Tolman, 1982; Stewart, 1983), it is suggested that the concepts of genes and chromosomes are poorly linked in novices, that their understanding of genetics is based on a consideration of genes without essential reference to chromosomes and that accordingly the concept of autosome is less familiar.

Views of independent assortment

Figure 2 shows that only two novices (N2 and N4) produced valid diagrammatic representations of independently assorting genes. Subject N1 correctly assigned a heterozygous genotype (AaBb), but placed the alleles of the two genes on one double-stranded chromosome; further, the alleles of each gene were incorrectly placed at non-homologous loci. Subject N3 correctly drew two pairs of chromosomes but failed to

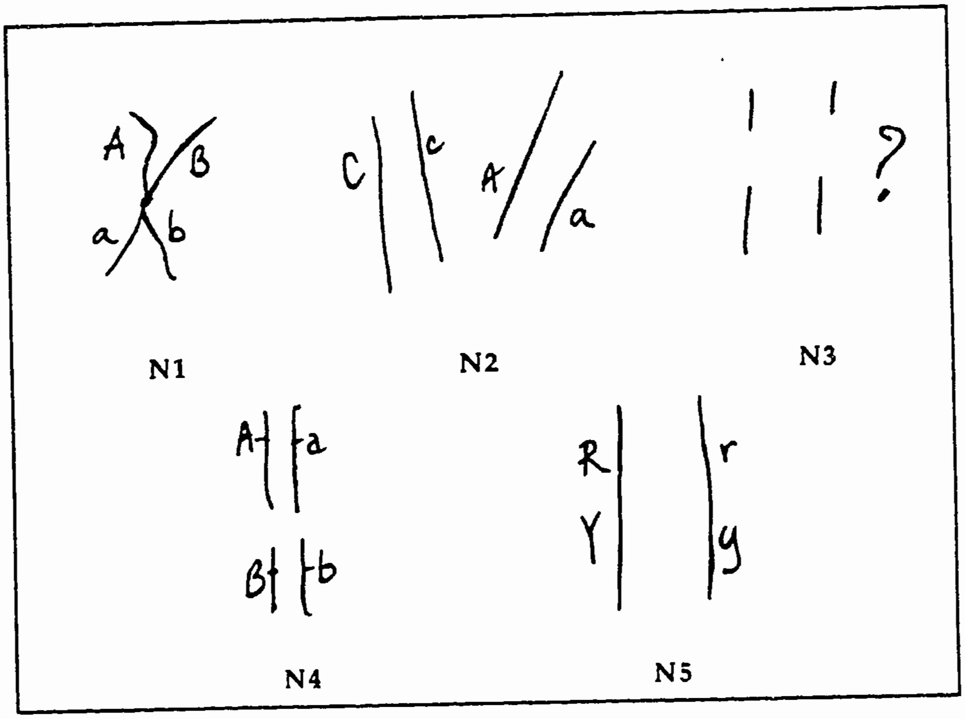


Fig. 2 Pictorial representations of independent assortment by "novices"

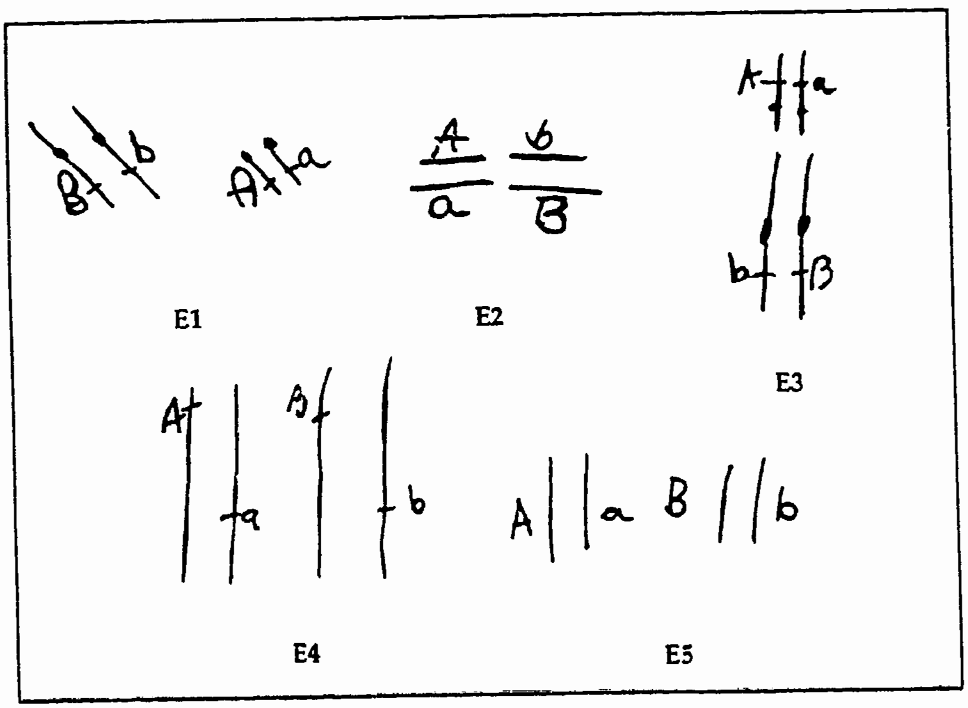


Fig. 3 Pictorial representations of independent assortment by "experts"

identify any alleles. Subject N5 correctly assigned a heterozygous genotype, marked appropriate positions for the alleles of one gene, but did not locate the alleles of different genes on non-homologous chromosomes. While alleles of two genes located on the same chromosome can assort independently if separated by a distance of greater than about 40 map units, it is assumed that subject N5 did not have this conditional representation in mind. All expert subjects, apart from subject E4, produced valid representations (Figure 3).

Because the number of genes was specified as two, this drawing task did not test subjects' understanding of the minimum number of genes involved in independent assortment. The computer-based task revealed that some subjects identified a single gene only as the essence of demonstration of independent assortment to a third party.

The computer-based task required subjects to set up a genetic model with relevant variables included at appropriate values, to choose appropriate parental genotypes, and to interpret the results of the cross in terms of independently assorting genes. Extracts from subjects' verbatim transcripts relating to the setting up of a genetic model are given below in italics. The inclusion of the mark - - - - denotes that part of the transcript has been omitted. The mark ... (LP) denotes a pause in excess of 3 seconds, while insertion of ... denotes a pause of less than 3 seconds. Explanatory comments placed in [square brackets] and underlining for emphases have been added by the experimenters.

Differences between the approaches of novices and experts to this problem were revealed by the transcripts.

1. Novices showed little evidence of planning before using the program and most began model construction without any explicit identification of a strategy. Two novice subjects redescribed the problem and identified a strategy before starting to set up their genetic models.

   Subject N1: '*OK ... independent assortment ...what you want to work with is a gene that has at least two alleles on it that are going to assort independently of each other ... Hmm ... I'm just going to chose one pair of autosomes ... - - - - Choose the number of genes ... (LP) Just one.*'
   Subject N5: '*... OK the best thing with independent assortment is to start with a monohybrid cross ... on a gene that has one pair of autosomes ... - - - - OK we want to work with one gene pair because it's easiest to work with independent assortment. They will be represented by two alleles which is just ... uh... the two genes that are represented in a trait.*'

   However, both subject N1 and N5 identified an incorrect strategy, namely the use of a single-gene (monohybrid) cross.

   In contrast, experts showed evidence of planning as part of the redescription of the problem before program use was commenced.
   Subject E1 immediately after reading the task '*... (LP) So we need a dihybrid cross ... (LP) we need two genes ... we need two nonhomologous pairs of chromosomes and we put one gene on each pair of chromosomes ... (LP) and*

ideally the alleles of the gene ... they ought to be a diallelic gene and the alleles should be dominant and recessive to make it the simplest situation ... (LP) and I guess I would start off in the usual way ... the way we always do in lectures ...'

2. Novices showed absence of any reference to the goal of the problem task during the execution of the task, and in some cases appeared to lose sight of their goal.
Subject N3: *'I feel like I'm going in circles.'*
Subject N4: *'OK what I wanted to do didn't work out because I forgot about dominance.'*
Only one novice subject (N2) made any reference to the 'friend' in the problem task: *'Just keep it easy ... this person may not be able to understand it very well.'*

In contrast, experts repeatedly referred to the problem goal during the execution of the task, including reference to keeping the model as simple as possible:
Subject E2: *'Let's pick complete dominance just for simplicity sake. Do I want to have lethality? No that would be too complicated for teaching my friend about independent assortment. - - - - OK I'm glad we've got this card to remind me of what we're doing.'*
Subject E5 after completing the set up of the model: *'Let's remember what independent assortment is all about.'*

3. Novices showed lack of purpose in choice of parental genotypes, used a 'try-it-and-see' strategy for crosses, and did not predict outcomes.
Subject N3: *'So let's see what happens.'*
Subject N4: *'I'm going to do enough crossing here that when I look at the summary I have ... what the ratios are going to be will show up fairly well.' - - - - 'I'm not sure that I don't have extraneous material here ... We'll see how it works.'*
Subject N1: *'I'm not sure what I'm doing is going to show independent assortment ... 'cause I know what the general concept is but I'm not sure of the actual mechanisms of it in terms of separation of the alleles ... So I'm just going to pick some parents and see what happens ... see if it makes sense to me after it gets done.'*

In contrast, experts set up crosses purposefully and made predictions about expected outcomes of crosses.
Subject E1: *'We should find some kangasauruses with tails and wide stripes.--*
Subject E5: *'We're going to have stumpy tailed and monofinned. Basically what we want to see is a 3 to 1 ratio in both characteristics after a series of crosses.'*
Subject E2: *'So I would expect one out of four offspring to be ... double recessive.'*

4. Novices showed poor closure of the problem with little, if any, interpretation of the cross.

Subject N4's conclusion: '*OK I have blue ... Tailed blue tailed orange and no tail blue and no tail orange ... so that there should be independent assortment then and that means those two genes assort independent of one another because of ... I should have seen the reproduction of all four.*'
Subject N5: '*Well I'm satisfied with the result of the cross ... uhm it is kind of hard explaining it ...*'

In contrast, the experts tended to showed decisive closure with interpretation of their cross results in terms of chromosomal separation during meiosis and in terms of probability of occurrence of expected classes of offspring.

5. Novices showed defective content knowledge reflected in confusion regarding terminology, and poorly-defined concepts. One subject consistently used the term *gene* instead of *chromosome*. As a result, this subject often referred to genes and alleles as 'things' or 'it' or 'them':
Subject N3: '*We want <u>them</u> on separate <u>genes</u>. Stick <u>it</u> on the <u>gene</u> number two so the genes are not linked.*' [Deciding on location of a gene]- - - - '*So what I'm deciding is would you be able to tell if <u>they</u> are on a separate gene if I have her completely dominant*' - - - [Deciding on maternal genotype] ' ... *so by putting <u>things</u> on separate <u>genes</u> and by having one recessive ... homozygous recessive ... and having the heterozygous one would show ... that would show some aspect of dominance but it would also cause some recessive traits to come out ...*'
Subject N5 incorrectly identified mitosis as the chromosomal process concerned with independent assortment.
Subjects N1 and N5 confounded the process of assortment (which relates to genes) with that of segregation (which involves alleles).

In contrast, the content knowledge of experts was sound and their procedural knowledge was organized into sequences that were generally readily and appropriately invoked.

One expert subject who was not currently involved in teaching genetics initially represented the problem in terms of a single gene, and began to set up up a genetic model accordingly. However, during his model building, he said: '*My concept of independent assortment is that it is a random phenomenon whether you get one gene or another and ... and actually it doesn't ... ah now that I'm thinking about it ... one ah ... gene ... let's see ... chromosome will independently assort ... and ah ... oh now yeah I'm not sure it really does - - - - So ... I guess we have to go back to the system and use a two-gene system with a gene on each chromosome to show that they are independent of each other.*' In this case, the expert was initially 'rusty' on terminology. The process of problem solving shifted inert knowledge to knowledge that was brought into active use in the problem task.

The results reported with this problem-solving task are consistent with the findings reported by other researchers (Smith, 1988; Slack & Stewart, 1990). The problem task used in this study, namely one in which a genetic process was to be demonstrated in a computer-based setting to a hypothetical third party, has not previously been reported. The results of this study indicate that a setting, in which solvers are empowered to build and, where appropriate, revise models, and then use models, has the potential to identify misconceptions and to assist students to construct meanings for genetic labels that encompass several concepts. Stewart and Hafner (1990) have argued for studies of model-revising performance as well as model-using. For experts, problem tasks of the type described in this paper would not be expected to enhance their understanding since the content and procedural knowledge base of experts is highly developed and integrated. However, for genetics students, who are exemplified by novice subjects, exposure to this type of problem task has the potential to contribute to the development of knowledge and facilitate learning.

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THE CONSTRUCTIVIST PARADOX: TEACHERS' KNOWLEDGE AND CONSTRUCTIVIST SCIENCE TEACHING

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ABSTRACT

Advocates of constructivist science recommend that school science begins with children's own constructions of reality. This notion of the way in which students' knowledge of science grows is closely paralleled by recent research on teachers' knowledge. This paper draws on case study evidence of teachers' work to show how two experienced teachers' attempts to develop alternative ways of teaching science involved reframing their previous patterns of understanding and practice. Two alternative interpretations of the case study evidence are offered. One interpretation, which focuses on identifying gaps in the teachers' knowledge of science teaching, leads to the constructivist paradox. The second interpretation explores the constructivist parallel, an approach which treats the process of teachers' knowledge growth with the same respect as constructivists treat students' learning of science. This approach, the authors argue, is not only more epistemologically consistent but also opens up the possibilities of helping teachers lead students towards a constructivist school science.

INTRODUCTION

Constructivist science is emerging as the new orthodoxy in science education. For some, constructivist science may seem to be one more program of change, the next in a long line that began with the curriculum reforms of the 1960s and includes Project Physics, Chem Study, Web of Life, Nuffield, ASEP and the science, technology and society movement. For others, constructivist science is a fundamental point of departure, requiring science educators to accept a new epistemology of science (von Glasersfeld, 1987; Cleminson, 1990; Tobin, Kahle & Fraser, 1990).

Constructivist science builds on the observation that scientific knowledge is constructed by men and women. Whereas positivists might see knowledge of the universe as a giant jigsaw puzzle, and the task of scientists as finding the lost pieces, constructivists allow the possibility that there are many different jigsaw patterns by which we can represent our knowledge of the universe. Working together, scientists share their jigsaws, agree which gaps are worthy of inquiry, and what counts as compelling evidence that they have found a missing piece.

There is widespread intellectual support for these ideas. Post-positivist philosophers in general (e.g. Schutz, 1973; Ricoeur, 1974; Gadamer, 1975; Foucault, 1976) and philosophers of science in particular (e.g. Polanyi 1962; Lakatos, 1970; Popper, 1972; Feyerabend, 1975) have argued that knowledge is constructed within communities of like-minded people, rather than discovered and guaranteed by the certainty of an objective experimental method. The practice of science is not the linear, rational process which scientists often presume, nor which is described in school science text books (Garfinkel et al., 1981; Knorr-Centina, 1982; Matthews, 1990). What we call scientific knowledge is no more than intersubjective agreement among a group of scientists. Such agreements about scientific reality depend on the paradigm within which they are constructed, and tend to live and die with particular groups of scientists working within a paradigm (Kuhn, 1970). At the extreme, the idea that all knowledge is socially constructed has been taken to mean that science has no greater authority than astrology, animism or mysticism. The more moderate view argued here is that "science can acquire valid and useful knowledge that is nevertheless a product of human thought, subject to change in the light of new evidence and reasoning" (Brush, 1989, p. 64).

In parallel with these ideas, science educators have argued that traditional school science, with its positivist assumptions about knowledge, should be replaced by a new constructivist approach. Building on the psychological theories of Piaget (1929), Kelly (1955) and Vygotsky (1962), constructivists have proposed that school science should begin with children's own constructions of reality (Osborne & Wittrock, 1985; Pines & West, 1986). Teachers should encourage students to make their own ideas explicit, present students with events which challenge these ideas, encourage the generation of alternative interpretive models and provide opportunities for students to use new ideas in a range of situations (Driver & Bell, 1986). In short, science teachers should resist "the scientific preference for imposing truths on the world, rather than just letting the world speak in its own messy way" (Matthews, 1990, p. 12).

For many teachers, reared on positivist assumptions about science, the idea that scientific knowledge is a matter of intersubjective agreement among scientists rather than transcendental and permanent truths discovered about the universe is very disturbing. A constructivist notion of science also conflicts with the predominant, content-centred, chalk, talk and lab. book pedagogy of science teaching. More than this, it conflicts with the ideas about science which have dominated teachers' own academic training and the ideas about science which have dominated popular thought for many years. As Gunstone and Northfield (Notes 1 & 2) have pointed out, constructivist school science requires fundamental changes in many teachers' concepts of teaching and learning.

Prompted by this gap between what teachers know and what constructivists encourage them to do, this paper brings together some ideas about science with some ideas about teachers' knowledge, and attempts to open up for discussion some parallels and paradoxes.

TEACHERS' KNOWLEDGE

Like scientific knowledge, theoretical accounts of teachers' understanding of their work are constructed within communities of like-minded people. Two such constructions of the nature of teachers' knowledge are in terms of horizons and images. These metaphors have been used by the authors as the basis for understanding the nature of teachers' work in two separate studies of teaching (Louden, in press; Wallace, 1989).

The first view is a that teachers' knowledge is framed by horizons of understanding (Louden, in press). Viewed from this perspective, teaching is a struggle to discover and maintain a settled practice, a set of routines and patterns of action which resolve the problems posed by particular subjects and groups of children. These patterns, content and resolutions to familiar classroom problems, are shaped by each teacher's biography and professional experience. The meaning of these patterns of action only becomes clear when it is set in the context of a teacher's personal and professional history, hopes and dreams for teaching, and working environment. A teacher's response to new problems is shaped by these historically sedimented predispositions to action which form a horizon of understanding. Such horizons are not static, but are constantly in the process of formation. Confronted by new problems and challenges, a teacher struggles to resolve them in ways that are consistent with the understanding he or she brings to the problem at hand. This process, in turn, leads to the construction of new horizons of understanding about teaching.

Another view of teachers' knowledge is in terms of image (Clandinin, 1985; Wallace, 1989). An image of teaching is a kind of knowledge, embodied in the person and connected to the individual's past and present. It reaches into the past, gathering up experiential threads meaningfully connected to the present. Image is like a glue that melds together a person's diverse experiences, both personal and professional. Because no two persons have the same experience, an image is individual and unique. Images connect the teacher with content and pedagogy, providing an explanation for the saying, "You are what you teach." The power of these images is that they serve to summarise or encapsulate teachers' predispositions to action, and consequently shape the direction and possibility of teachers' growth and change.

These two constructions are part of a family of thinking about teachers' knowledge, a family within which there is substantial intersubjective agreement about the nature of the knowledge teachers have and use (Elbaz, 1983; Clandinin 1985; Hunt, 1987; Butt & Raymond, 1987; Connelly & Clandinin, 1988). The construction which such people share emphasises that teachers' knowledge is tacit, biographical and experiential.

The epistemological parallels between post-positivist science and these notions of teachers' knowledge are striking. The history and philosophy of science suggests that the process of science is not as linear and rational as has been proposed in accounts of the scientific method, and that what counts as scientific truth depends on constructions of reality shared among groups of scientists. Similarly, constructivist science uses children's own constructions of reality as the essential starting point for scientific learning. Research on teachers' knowledge shares the conclusion that knowledge is socially constructed. Furthermore, this research directs attention to the personal and experiential base of teachers' knowledge and the role of previous patterns of practice in shaping the growth of knowledge. The next section of this paper tells two stories about learning to teach science in order to further explore these epistemological parallels.

MAKING MEANING OF SCIENCE

The stories which follow have been chosen to illustrate the process of learning followed by teachers as they deal with new situations. They form part of two longer studies of teachers and their work carried out by the authors in Canadian elementary schools (Louden, in press; Wallace, 1989).

Bill: The English Teacher

The first story in this section concerns a teacher and a researcher working together. As part of the collaborative quid pro quo, the researcher -- one of the authors of this paper -- offered to take the Grade 7 and 8 science lessons which had been allocated to the teacher. Neither the teacher, Johanna, nor the researcher had taught science before, although they were both experienced teachers. Little outside help was available, so the researcher, Bill, decided that the best option was to follow a detailed set of lesson notes provided by the school board.

Following these notes, Bill taught a series of conventional lessons on a familiar topic of school science: "Solutions and Mixtures". Although Johanna was grateful that Bill was relieving her of the unwanted burden of teaching science, she could not believe that what the students were being taught would be useful to them and she pressured him into changing his approach. As a compromise. Bill set an assignment on a different syllabus topic and employed a method of teaching which suited Johanna's preference for self-paced activities based on topics of interest to students. In the lessons that followed the teachers were off centre-stage, there was plenty of time for one-to-one discussions with students, those who were interested in the topic made some progress on the assignment, and the teachers' meagre knowledge of what and how to teach science was not tested.

However, as the date for the completion of the assignment drew closer, Bill became increasingly nervous that the students had not been directly taught the skills of the scientific method which were essential to successful completion of the assignment. His response was to use some of the remaining time to return to teaching the content and skills required to complete the assignment.

For the next session, Bill decided to conduct a lesson on writing up an experiment, again using the school board topic on solutions and mixtures. As the Grade 8 class began filing into the room, it occurred to Bill that the experiment could be done in the format of a television game show, a format he had practised as a teacher of English. He reminded the class that one of the questions in their science assignment asked them to conduct an experiment, and explained that Johanna and he had thought that they might like some help in planning and describing their experiments. In the lesson which followed, Bill employed the game show format to teach his science lesson. By setting up experiments on stools in the centre of the room and using student assistants to conduct the experiments while acting as game show hostesses, Bill was able to teach a lesson and entertain the class. The lesson turned out to be full of animation and enthusiasm. The "hostesses" played up to the audience and responded well to Bill's instructions and suggestions. The audience followed every bit of the theatre in the centre of the room and made notes as Bill dictated them.

Bill finished the lesson by carefully describing the observations he was looking for, soliciting comments from the two student assistants about their own observations. Finally, he dictated a brief conclusion on the characteristics of a solution. The class ended with a brief round of applause for Bill's assistants. As one of the assistants was returning to his desk he said, "That's the closest I've ever been to Pat Sajak" (Note 3).

Despite this vote of approval and Bill's enjoyment in teaching the lesson, he judged it to be a limited success. The goal and content were science, but the pedagogy was clearly English.

Malcolm: The Craft Teacher

The second story concerns the involvement of Malcolm, an experienced Grade 4/5 elementary teacher, in a school board sponsored program designed to increase the amount of science taught in elementary schools and to promote an active, cooperative approach to teaching science. This approach promoted a problem-solving orientation to science where students could select problems and design solutions in a socially cooperative setting. Students were to be encouraged to be creative and to explore and share non-standard solutions to science-related problems with their classmates.

The program was well funded and well supported by the school board. Along with other staff members, Malcolm attended a series of central inservice sessions where curriculum materials and teaching strategies were introduced. Collegial support groups were established in Malcolm's school, and the participating teachers were supported by visits from the science consultant. In Malcolm's school, the teachers were given school time to discuss pedagogical issues with their peers and to observe other classes in action.

Malcolm's standard practice was to divide the teaching day into two halves. The first half of the day was spent doing mathematics and English. For this activity, Malcolm taught in manner which was familiar to him. Usually Malcolm would formally present material at the commencement of a lesson and then check students' understanding by asking a few questions. Desks were arranged in rows, the class worked quietly and diligently on their tasks and interaction between the children was minimal. The second half of the day, Malcolm liked to use for a practical activity. In the main, this activity was centred on a particular craft: collage, pottery, quilting, copper beating and so on. Malcolm was particularly proud of his craft work. There was often evidence of his students' work displayed around the school and he would invariably show photographs of the work of previous classes to visitors. Malcolm's enjoyment of teaching craft stemmed from his sense of himself as a very practical person. He had discovered through experience that craft was a very good way of engaging students of different ability levels.

For a craft lesson, Malcolm would occasionally move the furniture in the room to create a group setting, but more often than not he retained the formal setting. Regardless of the arrangement, Malcolm had very definite rules about classroom interaction and variations from the assigned task. It was not unusual to see a class of children all working away quietly on the same craft activity. Malcolm found it very difficult to allow more interaction and was most comfortable when students were all busy on a similar task. He struggled with this because he was aware of the debate surrounding the social learning of children in classrooms. He experimented with ways of allowing more interaction and variation but each time reverted to the more formal approach.

When it came to being involved in the new science program, Malcolm was not fazed by the idea. In previous years, he had the responsibility of being science coordinator in the school. He talked quite confidently and openly about his science program and volunteered to become involved in the new active learning program. Susan was Malcolm's collegial partner in the new science program. In contrast to Malcolm, Susan organised her classroom around active learning centres for most of the day. Malcolm's contact with Susan consisted of a number of low-key discussions about content and pedagogy and some visits to Susan's class. This contact did cause Malcolm to question some of his teaching methods and to do a little experimenting with new ways of working students in groups. He did try grouping students in mixed ability levels for one science lesson on the science topic "Structures." For the bulk of the topic, however, Malcolm used much the same technique as he employed during his craft lessons. In a lesson on building bridges, for example, Malcolm handed out pins and straws and explained to the students that they should build a structure spanning a gap, by joining the straws together with pins. The children set to work on their individual structures as if they were doing a craft activity. The end result was a room full of sculptured straw bridges. The concluding discussion, conducted by Malcolm, referred to problems such as construction, load bearing and maximum span. These were all relevant questions in the context of the activity as it was conducted. Although they contained some more science, they were not much different from the kind of standard question about technique which might have been asked at the end of a craft lesson.

The message from Malcolm's work is that in spite of considerable external and collegial support, his science background and his struggle with himself about what constituted good teaching, his science lessons took the form with which he felt most comfortable. Like Bill's drift towards English, Malcolm's drift was towards craft.

DISCUSSION

Two alternative readings of these stories may be offered: one which exposes an epistemological paradox between constructivist science teaching and learning, and another which builds on the parallel between students', teachers' and scientists' ways of knowing.

The Constructivist Paradox

One reading would begin by drawing attention to the gaps in these teachers' knowledge of teaching. Although Malcolm had been a willing participant in the school board's cooperative learning programme, his lesson offered the children few opportunities for collaboration, and the only discussion time was the brief whole-class question and answer session at the end of the lesson. Similarly, judged either by the standards of the school science syllabus or Johanna's goal of self-paced learning of topics of interest, Bill's lesson was not very successful. The students may have enjoyed the experience but, as the applause at the end of the lesson and his student's comment about Pat Sajak showed, students' attention was focused on the game show theatre, not on the experimental method Bill set out to teach.

To follow this line of argument, and suggest that these teachers failed because of gaps in their knowledge, would be to join a broad stream of research commentary on teachers and teaching. Perhaps like "Peter" (Tobin, Kahle & Fraser, 1990) or like "Mrs W" (Cohen, 1990), Bill and Malcolm may have lacked the content knowledge required to teach structures or the experimental method. Or, perhaps like "Sandra" (Tobin, Kahle & Fraser, 1990) they lacked the pedagogical content knowledge (Shulman, 1987) to manage teaching this content. With greater content knowledge they may have been able to "teach for understanding", as Cohen's Mrs W intended; with more pedagogical content knowledge they may have managed more "higher-level cognitive learning" (Tobin, Kahle & Fraser, 1990).

From a constructivist point of view, these teachers would certainly be judged to have much to learn. Malcolm's silent structures lesson prevented students from making their own ideas explicit or generating alternative interpretive models. Similarly, Bill presented the experimental method as if it were linear and rational, and his stage-management of students' observations prevented them from reconstructing their own understanding of scientific activity.

Notwithstanding the accuracy of such critiques, this line of argument leads to what may be called the constructivist paradox. This paradox concerns the meaning ascribed to the current state of teachers' and students' knowledge. When students don't understand, teachers are enjoined to begin with the knowledge students already have, to help them make these ideas explicit, and to provide opportunities for this knowledge to be elaborated and changed. When teachers don't teach for understanding or for higher level cognitive knowledge, however, they are seen as having the wrong knowledge. Students are expected to need to reform their knowledge; teachers are at fault because their knowledge is incorrect.

The Constructivist Parallel

An alternative reading of Bill's and Malcolm's stories would build on the parallel between constructivist science teaching and teachers' knowledge (Gunstone & Northfield, 1986). For the same epistemological reasons that learning constructivist science is "a process of knowledge generation in which prior knowledge is elaborated and changed on the basis of fresh meanings negotiated with peers and the teacher" (Tobin, Kahle and Fraser, 1990, p.7), learning to teach science ought to be a process of gradual reformation and elaboration of teachers' established knowledge and patterns of teaching.

Viewed in these terms, Bill's efforts to come to grips with teaching science are less likely to be seen in terms of success or failure. He began with what he knew, he attempted to incorporate his own view of proper school science, he deferred to Johanna's view of teaching, and finally he offered the lesson described above because of his sense of responsibility to the students to teach the syllabus. All of these efforts were shaped by his horizons of understanding of teaching and the practical patterns of action which embodied this knowledge. In attempting to find an adequate compromise he used an old and familiar pattern drawn from his experience as an English teacher and turned a potentially boring dictation and demonstration science lesson into piece of theatre.

Malcolm, the experienced, well supported, well informed elementary science teacher was involved in a program inconsistent with his image of teaching. Faced with interactive notions of science teaching which challenged his assumptions about classroom management, he reverted to a well established craft teaching pattern. This pattern was consistent with his own image of himself as "a practical person." It was consistent with the view of teaching and learning he shares with many teachers, that students' attention to learning should not be distracted by social conversation. In craft, he had developed some very successful patterns of teaching which were consistent with his own image of teaching. His participation in the science program led him to teach some new science activities, but these were taught from within his own historically sedimented predisposition to action. For him to have done differently would have contradicted his biographically embedded knowledge of teaching. This knowledge is capable of change but, like students' knowledge of science, new ways of knowing can only emerge from reconstruction of old ways of knowing and teaching.

These stories suggest that teachers' constructions of their work have a powerful influence on their capacity to change. New knowledge emerges from existing horizons of understanding and images of teaching. In both cases, new problems are solved by building on old ways of teaching. Both teachers recycled old patterns of teaching which they knew would interest students, would not cause problems of classroom control, and which were well polished solutions to quite different classroom problems. For each of these teachers, these patterns embody the personal, experiential, traditional knowledge which they carry forward to each new practical classroom problem. For science educators, these stories contain an important lesson. Those who advocate that science teachers adopt a new epistemology must avoid the constructivist paradox and build on the possibilities offered by the parallel between constructivist science and the construction of teachers' knowledge.

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Note 3 At this time, Pat Sajak was the host of the "Wheel of Fortune" game show popular in North America.

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DIAGRAM INFORMATION AND ITS ORGANISATION IN MEMORY: EXPLORING THE ROLE OF SKILL AND EXPERIENCE.

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ABSTRACT

Two contrasting methods of investigation were used to characterise the basis upon which the mental representation of a scientific diagram was organised in individuals having different levels of experience and skill in the interpretation of this type of diagram. Each of these methods is described and several important methodological issues are discussed. In the first method (the Card Sort method), subjects performed a three-stage grouping of diagram elements in a card sorting task that produced an hierarchical ordering of the information constituting the diagram. In the second method (the Copy-Recall method), subjects copied then produced drawn recall of a given diagram. Measurements of the sequence in which diagram elements were produced and the time intervals between each production were used to infer the underlying cognitive structuring involved in the mental representation of the diagram information. Questions are raised concerning the way resulting data can be analysed and interpreted most effectively.

INTRODUCTION

This article concerns qualitative aspects of the processing of information contained in scientific diagrams. It arises from the general finding that high and low knowledge individuals differ in the way they process domain-specific information. The focus is upon methods of investigation used to help characterise and account for differences in diagram processing. The approaches described explored possible differences in the way individuals with high and low knowledge of a scientific domain mentally represent diagram information characteristic of that domain. Two different methods of investigating the mental representation of scientific diagrams are described and their features discussed.

In a classroom of beginning science students, the teacher and the students typically represent two extremes of background knowledge in the subject matter to be taught. Research in problem solving and learning across a variety of subject areas indicates that individuals with a high level of background knowledge in a particular domain typically process information in that domain quite differently from those who have a low level of background knowledge (Chi, Glaser & Farr, 1988). In the context of a science classroom, this suggests that sometimes the teacher and the students may differ substantially in the way they process instructional materials used in a lesson. This difference is not simply a matter of the amount that can be processed or understood in some fashion by these high and low knowledge individuals (although clearly this will differ). It also concerns qualitative aspects of how the information is processed, such as the significance accorded to the individual components of that information and how these components are seen as being interrelated (Bransford, Vye, Adams & Perfetto, 1989). If 'high knowledge' teachers and 'low knowledge' students process a given section of a particular lesson in ways that are qualitatively different, they may come to quite different sorts of understandings of the subject matter presented as a result.

Experience and Diagram Processing

In a comparison of year 8 high school students and students who had completed the final year of a university science degree, Lowe (1987) found that the group with the lower level of background knowledge in science tended to approach diagrams illustrating a scientific concept in a somewhat superficial manner. A feature of this approach was a failure to take account of some of the critical relationships among the components of the diagram. In contrast, those with much higher levels of scientific background knowledge appeared actively to seek out these relationships within the diagram and to use them as a basis for constructing scientific meaning for the diagram as a whole. Why did these two groups differ so fundamentally in their approaches? The possibility that differences in background knowledge concerning scientific diagrams were responsible rather than other more generalised factors is the topic of the research that forms the basis for this article. It is clearly undesirable for students of science, especially those in introductory courses, to employ a superficial approach to diagrams. Such an approach is unlikely to contribute to the students' development of new scientific understandings that the diagrams are intended to promote. Before the possible role of background knowledge in the effectiveness of diagram processing can be determined, methods for exploring the origins of differences between individuals with high and low background knowledge in their handling of scientific diagrams are needed.

Because qualitative as well as quantitative aspects of a person's background knowledge are probable influences on the way information is processed, it is important to go beyond the content of a knowledge representation and consider the structure of that representation. The content and structure of an individual's stored knowledge about a particular subject area together constitute that person's mental representation of the subject. If this knowledge constitutes a person's broad and on-going representation of the knowledge domain concerned, it will be described here as that individual's resident mental representation of the domain. A resident mental representation can be considered as the product of the various encounters the person has had with material in that domain. It may contain both abstract semantic knowledge distilled from a range of these individual encounters as well as quite specific episodic knowledge retained from some particular encounters. The description 'resident' distinguishes this type of mental representation from more specific, and typically shorter-term, representations that we build up in our minds as a result of processing a particular set of information from the content domain. This latter type of knowledge will be described as a constructed mental representation and is considered to be developed when the particular set of domain information that the person must deal with is unfamiliar. The notion of a constructed mental representation is in general agreement with the view that learning is a constructive or generative process in which new meanings are built by the individual learner, rather than being acquired from others by a process of transfer (Osborne & Wittrock, 1983,1985). For the purposes of this article, it will be assumed that the building of a useful constructed mental representation for a particular diagram will be strongly constrained by the nature of an individual's resident mental representation of such diagrams.

Mental Representation of Diagrams

Within a particular subject domain, the knowledge differences between high and low knowledge individuals can be thought of in terms of differences in their resident mental representations of that domain. For example, a student who is just beginning his or her studies in the domain of school chemistry would normally have little background knowledge in chemistry and so would be expected to have a poorly developed resident mental representation of that domain. In contrast, an experienced chemistry teacher's resident mental representation of the domain would be expected to be well-developed.

Part of the teacher's resident mental representation of school chemistry would deal with diagrams which are typical of that subject area. This part could represent knowledge about matters such as (a) the sorts of information that diagrams typical of this subject area contain, (b) the particular ways these diagrams depict this information, and (c) how diagram information can be organised in the mind to facilitate cognitive operations involving these diagrams. An example will clarify this last aspect. It may be that there are forms of mental organisation, such as hierarchical chunking, that a teacher imposes upon a diagram which allow the information it contains to be processed more effectively. White (1988) has given a hypothetical illustration of how such an organisation might be applied to a diagram of gas generation apparatus. He contrasts a teacher's hypothetical organisation with the sort of organisation that a student might employ and suggests how the teacher's organisation may be more facilitative of the cognitive processes typically required during learning. As far as chemical diagrams are concerned, it seems unlikely that beginning students of science would have a particularly well-developed resident mental representation because of their lack of background in the subject domain. Although the above discussion is focused upon chemical diagrams, this particular type of diagram was used only for the purpose of illustrating what probably applies to scientific diagrams in general.

Even in the early stages of their courses, beginning students of science are required to work with diagrams and be able to reproduce them in a manner that is scientifically accurate. Cognitive processes such as searching mental data structures, recognising relevant information and making inferences in order to generate new information are likely to be influenced by qualitative aspects of mental representation (Larkin & Simon, 1987). However, the building of coherent and scientifically appropriate constructed mental representations of diagrams by beginning science students may be hampered by their lack of suitable resident mental representations. For this reason, it is important to characterise empirically the types of mental representations of scientific diagrams possessed by those with high and low levels of domain-specific knowledge. Identification of the representational attributes of high knowledge individuals that allow them to handle diagrammatic information effectively may suggest teaching strategies that would help lower knowledge students develop more useful resident mental representations for this type of material.

INVESTIGATING MENTAL REPRESENTATION OF DIAGRAMS

The investigation of the way diagrams are mentally represented raises a number of general methodological issues that stem from the special characteristics of these materials. The nature of some of these issues and the ways they were addressed in the methods developed for the current research programme will be discussed before describing the methods themselves.

The first isssue arises because diagrams are often a combination of graphic material and text (captions and labels). It clearly is important to consider how each of these constituents is mentally represented in its own right as well as considering the mental representation that forms when they are in combination. (However, this is not meant to imply that there is necessarily a clear distinction between these two forms of information in the mind.) The two methods described here were developed to focus upon graphic constituents only. For this reason, the type of diagram chosen for investigation (a weather map diagram) was one that could stand alone without the need for textual adjuncts. However, a focus on the graphic constituents of scientific diagrams raises the problem of how to tap the mental representation of that type of information in a manner which, as far as possible, acknowledges its intrinsic visual nature. Most ways of investigating science learning rely heavily on written or spoken text as a means of presenting information and collecting data about the way that information is processed. In the case of diagrams, it clearly is inappropriate to collect data solely in textual form if we wish to avoid distortions and modifications that inevitably occur when an attempt is made to transform visual information into the written or spoken word. For this reason, the methods to be described required subjects to produce more appropriate forms of output, either by physically manipulating given diagrammatic material or by producing their own drawings. Although verbal data were collected in one of the methods, the other was based solely upon non-verbal performance.

One of the methods developed involved subjects producing their own drawings of a given diagram which raises a second issue. This is the question of the extent to which the results obtained reflect the processing involved in the person's cognitive operations with their mental representation or simply reflect processing involving the practicalities of performing a drawing task. In other words, to what extent would the results obtained be an artifact of the method used rather than a reflection of an individual's mental representation? Considering the particular diagrams and subjects to which this method was applied, this is not a trivial question. Subjects in one group were professional meteorologists while those in the other were non-meteorologists (teacher education students). Meteorologists do a great deal of drawing of weather maps in their daily forecasting activities. As a consequence those in the meteorologist subject group would presumably have developed a quite high level of skill in producing figurally accurate renditions of the graphic elements that comprise weather maps. In contrast, the non-meteorologists would be unlikely to have had similarly relevant drawing experience and hence may be at a disadvantage as far as their capacity to render weather map information accurately was concerned. For this reason, it was considered important to include an additional drawing task as part of this method to control for drawing skill differences. This control task involved subjects copying a stylised illustration of a lakeside scene that had been specially constructed to parallel closely the types of lines and shapes found in a weather map.

The final issue to be discussed here concerns how the results obtained should be interpreted. The matters investigated by the methods to be described are subtle and the process of making inferences from the findings fraught with difficulties, many of which are due to the absence of precedents for this type of investigation. As a result, it is even more important than usual to be explicit about the assumptions that are made in the process of interpreting the data. In general, it will be assumed that the way a subject's output is organised during performance of a task reflects the way their mental representation of the task content is structured. By this assumption, subjects' performance during the task gives an indication of the cognitive operations they are performing to complete the task. In addition, these operations are in turn constrained by the type of mental representation they possess of the material being processed. One of the methods to be described used a spatial organisation task to probe mental structure while the other focused upon the temporal organisation of activity during task performance. Comparison of the results of these two quite different approaches may suggest features that characterise an underlying mental representation rather than characteristics of the methods themselves.

THE METHODS

Card Sort Method

The first method was developed as a modification and extension of the card sorting task described by Chi, Feltovich and Glaser (1981). It required subjects to sort a series of 34 cards (12.5 cm X 7.5 cm), each of which displayed the same weather map diagram. This map was adapted from a legitimate Australian weather map and consisted of an outline of Australia together with all the meteorological markings from the original map (with the exception of the numerical information). This set of meteorological markings was characterised as consisting of 34 individual graphic elements that belonged to 9 distinct figural categories. The only difference between the cards used in this procedure was that each one had a different graphic element highlighted. The task consisted of three successive stages that will be described as the primary sort, the subdivision sort and the combination sort respectively. In the primary sort, the 34 cards were spread out in front of the subject who was asked to sort them so as to form groups in which the highlighted markings on the cards belonged together in some way. Subjects were told that they could use as many or as few groups as they considered necessary and were asked to sort the cards according to what immediately occurred to them as the most natural groupings. It was made clear to the subjects that it was their personal reaction which was required and that there were no 'right' or 'wrong' answers. Once the subject was satisfied with the groupings, s/he was asked to explain the reasoning underlying the choice of groupings. To add additional focus to this explanatory process, the subject was asked to reflect upon what held the elements in each group together and what distinguished each group from the other groups formed. In addition, the subject was asked to supply a brief descriptive title for each group that would identify each group clearly. The grouping reason explanations and group titles were recorded by the experimenter and the suitability of these records checked with the subject.

In the subdivision sort, the subject was asked to subdivide, where possible, any of the primary sort groups into smaller groups (with the constraint that new groups should be formed only if there was a clear and natural basis for the subdivision). After formation of these subgroups, the subject's explanations for grouping and descriptive titles were recorded as before. In the combination sort, the original groups produced by the subject in the primary sort were re-established. The subject was then asked to combine any of the groups s/he wished so as to form a smaller number of more inclusive groups. Once again, explanations for grouping and descriptive titles were recorded.

Groupings produced by the subjects during the three sorting stages were used to determine the frequency with which each element was associated with each of the other 33 elements that together made up the complete set of markings on the map. Separate cluster analyses (complete linkage) were performed for the meteorologist subject group and for the non-meteorologist group. In addition, a qualitative analysis of the grouping reason explanations and group titles was made to characterise the nature of (a) associations involving elements within groups and (b) relationships between the groups themselves.

Copy-Recall Method

This method required subjects to draw a copy of a weather map, then, on a blank outline map, produce a drawing of what they could recall of the meteorological markings on the previously copied map. The weather map used in this procedure was the same adapted map as used in the card sorting method described above. In addition, the lakeside scene display described earlier was employed as a control for drawing skill and as the basis for a task that intervened between map copying and recall to prevent recall from short term memory.

The displays used for the copying tasks (scene and map) were presented to each subject by rear projection of a 35 mm slide (Figure 1).

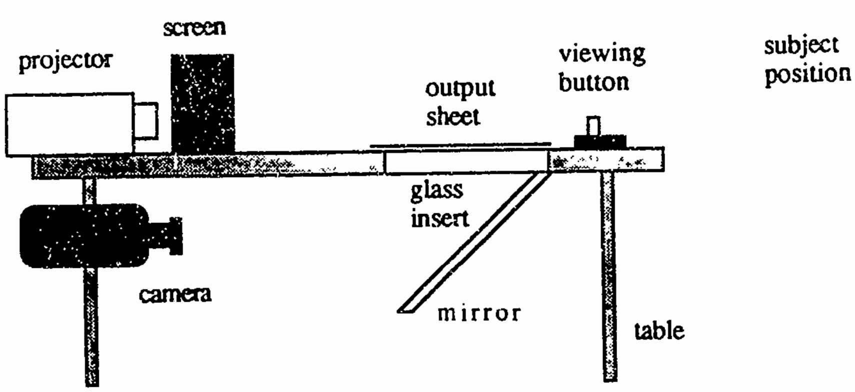

Fig. 1 Apparatus for copy-recall task

In performing the task, subjects made a series of viewings of the display on the screen and after each viewing, drew as much as they could of what they had seen onto an appropriate output sheet. This A4-sized sheet was blank except for a lake outline in the case of the scene task, or an Australian map outline in the case of the map task. The subject continued this alternate viewing and drawing process until satisfied that the copy of the display was complete.

The order of the tasks was as follows. First, subjects copied the lakeside scene from the display screen using the procedure described above. Next they copied the weather map diagram in the same way. Following this task, they were shown their drawing of the scene and asked to describe it as fully as they were able, pointing out what they were talking about as they gave their description. When satisfied with their description, they were given a blank map outline sheet and asked to produce drawn recall of as much as they could of the weather map they had copied previously. Their drawn recall behaviour during this task was also videotaped.

Two main types of data analysis were used, one that dealt with the subjects' processing activities as they drew the displays and the other that dealt with the products of these activities (the copies of the scene and map, and the drawn recall of the map). For the process results, cluster analysis was performed based upon the display viewing times. Further analyses dealt with the sequence in which graphic elements were drawn. Analysis of the product results evaluated the completeness and accuracy of both copied displays and the drawn recall produced for the map.

DISCUSSION

The results obtained from these two approaches gave rather different perspectives on what may distinguish the resident mental representations of professional meteorologists from those of non-meteorologists. However, the results appeared to complement one another sufficiently for these approaches to both be considered useful ways of characterising mental representation of weather map diagram information. Although the findings of these investigations are of interest in themselves, the focus of this paper is upon the techniques used to generate these findings. Because of the lack of research in diagram processing and the unique characteristics of diagrams, few established tools are available to those who wish to study this neglected area in depth. Consequently it is important to develop and refine techniques that could be used to investigate possible influences on diagram processing. These techniques need to be sufficiently general to be applicable to a range of diagram types and sufficiently powerful to be able to deal with the more intractable aspects of diagrams as objects of study. The final section of this article will discuss some of the problems that arose with these two methods and the analysis of the data they generated.

The first problem impinges upon both the design of experimental materials and the approach to analysis. It concerns the difficulty of appropriately defining what constitutes an 'object' for the purposes of the investigation. This was a problem for the materials design in the card sorting task and for analysis in the copy-recall task. In other investigations of pictorial material (for example, Mandler & Johnson, 1976), realistic drawings of everyday objects are generally used with the experimenters assuming that there is no difficulty in distinguishing between objects and their parts. However, in weather maps and many other types of diagrams, the unusual nature or depiction of the subject matter means that a novice in the area may use quite different criteria for defining what constitutes an object from someone who is familiar with the field. In the present investigations, there was a problem in identifing each distinctive marking on the page without at the same time implying that a distinctive marking was necessarily a discrete object in terms of the subject matter depicted. This is an issue that concerns the difference between a graphic entity and a conceptual entity. In some cases, such as with isobars and alphabetical symbols, the approach taken was to treat an isolated graphic stroke or set of physically connected strokes as a single entity. In others, such as with fronts, geometrically distinct markings were treated as individual entities, despite the fact that they were physically connected. These decisions were based upon a consideration of the way such features were drawn by meteorologists and non-meteorologists in pilot studies. From these studies, 34 graphic elements that were drawn in such a way that they appeared to be treated as discrete items by the majority of subjects from both groups were selected as the units of analysis.

The second problem is related to the first and concerns the relations between the objects making up the display rather than the objects themselves. When graphic output is the only product of an experimental technique, there is a limitation on the information that can be obtained about the semantic relations which bind graphic elements in a display together. There is no doubt that information about the use of particular spatial relations in a diagrammatic display is intrinsically important. However, important relations also exist for which there are no obvious spatial clues. Proximity and physical similarity are compelling general influences on our tendency to conceive of relations between two or more objects. If two graphic elements on a weather map possess very different physical characteristics, are quite distant from each other on the map and are separated by many other features, it is intuitively reasonable to consider them as being unrelated, or at best only weakly related. In contrast, in the absence of information to the contrary, elements that are physically similar and adjacent are likely to be seen as strongly related. However, under some circumstances each of these interpretations could be quite erroneous and unnecessarily restricted. Physically dissimilar, spatially separated elements can be very strongly related in some cases, while physically similar elements that are adjacent can sometimes be only weakly related. Although the spatial relations produced when a person draws a weather map may give some guide to the way he or she structures the information mentally, it must be remembered that physical distance is not equivalent to mental distance. Hence, supplementary methods are needed to probe the semantic relations between graphic elements and this seems to require verbal output by the individual concerned that can clarify the graphic output.

The final problem to be discussed here is practical rather than theoretical in nature and involves the analysis of drawn output. Whether the focus is upon the drawing process itself or upon the final product of that process, methods of comparing the set of marks produced and the way they are drawn are necessary. The analysis of results from the copy-recall method described above was both limited in its scope and extremely time consuming. In order to compare the maps drawn with the original and with each other, some means of quantifying attributes of individual markings and their disposition within the area bounded by the map border was required. The bulk of the measurements of the characteristics of the 34 graphic elements selected as the units of analysis were based upon the construction of an enclosing rectangle around each element. The 'position' of the element was taken as the centre of this rectangle, while the element's 'area' and 'proportions' were determined from the length of the rectangle's sides. Other measures used included the location of places where arch shapes occurred within elements and where the elements intersected the map outline or border. Although these latter two measures were relatively direct characterisations of the properties concerned, the other measures involved some approximation in order to operationalise them with the resources available. In addition, it became evident from later parts of the research that a variety of additional more complex measures that could span a number of different elements would provide useful further information.

CONCLUSION

Considering the widespread use of diagrams in science education, the comparative lack of research into influences upon diagram processing is a matter of concern. However, an important requirement for effective research in this area is a set of methods and analysis techniques that are theoretically robust and yet neither unmanageable nor too restricted in an operational sense. Although the methods and analysis techniques described in this article provide a basis for further research into influences on diagram processing, the problems discussed show that they would benefit from extension and further refinement. In particular, less labour intensive approaches to investigation that coud easily be used on a larger scale are required, together with a wider range of measures of diagram characteristics that can readily be applied and analysed with a minimal sacrifice in precision.

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RESEARCH INTO THE ENVIRONMENT OF SCIENCE LABORATORY CLASSES IN AUSTRALIAN SCHOOLS

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ABSTRACT

Existing instruments for assessing student or teacher perceptions of characteristics of actual or preferred classroom psychosocial environment are unsuitable for one of the most important settings in science teaching, namely, the science laboratory class. Consequently, the Science Laboratory Environment Inventory (SLEI), was designed to assess student or teacher perceptions of seven scales: Teacher Supportiveness, Student Cohesiveness, Open-Endedness, Integration, Organization, Rule Clarity and Material Environment. An important feature of the design of the study was that the new instrument was field tested simultaneously in six countries: Australia, USA, Canada, England, Nigeria and Israel. This paper is based on a sample of 4643 students in 225 individual laboratory classes, together with the teachers of most of these classes. Preliminary analyses were used to shed light on various important research questions including the differences between Actual and Preferred environments, gender differences in perceptions of Actual and Preferred environment, the relationship between the science laboratory environment and attitude towards science laboratory work, differences between school and university laboratory classes, differences between teachers' and students' perceptions of the same laboratory classes, and differences between laboratory classes in different science subjects (Physics, Chemistry, Biology).

BACKGROUND

This paper describes several research applications of a new instrument for assessing perceptions of psychosocial environment in science laboratory classrooms. This work is distinctive in that it extends classroom environment research traditions in non-laboratory settings (Fraser, 1986, 1989; Fraser & Walberg, in press) to science laboratory classes, and because the instrument was field tested, validated and applied simultaneously in six countries.

The initial development of the Science Laboratory Environment Inventory (SLEI) is described by Giddings and Fraser (1990). The first version contained eight scales: Teacher Supportiveness, Involvement, Student Cohesiveness, Open-Endedness, Integration, Organization, Rule Clarity and Material Environment. Items passed through several successive revisions based on reactions solicited from colleagues with expertise in questionnaire construction and science teaching at the secondary and higher education levels.

The unrefined version of the SLEI contained 72 items altogether. After the field testing and item analyses described later in this paper, a refined version was formed (Table 1) containing 52 items and seven scales (with Involvement omitted). This meant that not all scales in this version of the instrument contained the same number of items. The number of items per scale is indicated under each scale name. Each item is responded to on a five-point scale with the alternatives of Almost Never, Seldom, Sometimes, Often and Very Often. The scoring direction is reversed for approximately half of the items.

TABLE 1
DESCRIPTIVE INFORMATION FOR EACH SCALE IN THE SCIENCE LABORATORY ENVIRONMENT INVENTORY (SLEI)

Scale Name	Description	Sample Item
Teacher Supportiveness (9 items)	Extent to which the teacher/ instructor is helpful and shows concern for all students.	The teacher is concerned about students' safety during laboratory sessions. (+)
Student Cohesiveness (8 items)	Extent to which students know help, and are supportive of one another.	Students in this laboratory class get along well as a group. (-)
Open-Endedness (6 items)	Extent to which the laboratory activities emphasize an open-ended, divergent, approach to experimentation.	We know the results that we are supposed to get before we commence a laboratory activity. (-).
Integration (8 items)	Extent to which the laboratory activities are integrated with non-laboratory and theory classes.	We use the theory from our regular science class sessions during laboratory activities. (+)
Organization (7 items)	Extent to which the laboratory activities are clearly defined and well organized.	There is confusion during laboratory classes. (-)
Rule Clarity (7 items)	Extent to which behaviour in the laboratory is guided by formal rules.	There is a recognized way of doing things safely in laboratory. (+)
Material Environment (7 items)	Extent to which the laboratory equipment and materials are adequate.	The laboratory is too crowded when we are doing experiments. (-)

Items designated (+) are scored 1, 2, 3, 4 and 5, respectively for the responses Almost Never, Seldom, Sometimes, Often, and Very Often. Items designated (-) are scored in the reverse manner.

VALIDATION OF THE SLEI

Data were subjected to item analysis in order to identify items whose removal would enhance each scale's internal consistency and discriminant validity. Scale internal consistency was improved by removing items with low item-remainder correlations (i.e. correlations between a certain item and the rest of the scale excluding that item), and discriminant validity was improved by removing any item whose correlation with its a priori assigned scale was lower than its correlation with any of the other seven scales in the SLEI. Item analyses were conducted separately for each of the four subsamples of upper secondary school students (students in their final two years of secondary education) described in Table 2 (Australia, USA, Israel and Canada) and the four subsamples of university students (students in their first two years of tertiary education) described in the same table (USA, Israel, Canada and England). An important step in the validation process was that an item was retained only if it displayed satisfactory statistical characteristics for each of these eight individual subsamples.

TABLE 2
DESCRIPTION OF THE SAMPLE

Schools/Universities	Country	Sample Size Students	Classes	Sites
Schools	Australia	1875	111	14
	USA	885	45	3
	Israel	359	15	10
	Canada	282	12	9
		3401	183	36
Universities	USA	719	20	2
	Israel	104	3	2
	Canada	323	11	1
	England	96	8	1
		1242	42	6
Total		4643	225	42

Table 3 shows the internal consistencies (alpha coefficients) data for the refined version of the SLEI, for the total sample of schools and for the total sample of universities. Data are reported separately for the Actual and Preferred forms. The pooling of the data across the countries, although strictly speaking conditional on each country's data having similar reliabilities, correlations and beta coefficients, is presented to reflect an overall view of the instrument. This table shows that the alpha coefficients for the total sample of school students ranged from 0.69 to 0.82 for Actual form and from 0.60 to 0.80 for the Preferred form. For the total sample of university students, the values for the refined version ranged from 0.64 to 0.91 for the Actual form and from 0.60 to

0.83 for the Preferred form. Comparable values were obtained for the Australian subsample. These data suggest that the refined version of each SLEI scale has acceptable internal consistency, especially for scales containing a relatively small number of items, in both its Actual and Preferred forms.

TABLE 3
INTERNAL CONSISTENCY (CRONBACH RELIABILITY COEFFICIENT) AND DISCRIMINANT VALIDITY (MEAN CORRELATION WITH OTHER SCALES) FOR ACTUAL AND PREFERRED FORMS

Scale	Form	Alpha Reliability School	Alpha Reliability Univ	Mean Correlation School	Mean Correlation Univ
Teacher Supportiveness	Actual	0.82	0.83	0.48	0.33
	Preferred	0.80	0.77	0.55	0.40
Student Cohesiveness	Actual	0.78	0.79	0.39	0.25
	Preferred	0.72	0.72	0.51	0.44
Open-Endedness	Actual	0.69	0.64	0.06	0.13
	Preferred	0.60	0.60	0.15	0.10
Integration	Actual	0.82	0.91	0.44	0.24
	Preferred	0.80	0.83	0.48	0.41
Organization	Actual	0.78	0.77	0.49	0.38
	Preferred	0.76	0.75	0.57	0.43
Rule Clarity	Actual	0.74	0.76	0.40	0.21
	Preferred	0.69	0.67	0.41	0.32
Material Environment	Actual	0.74	0.73	0.44	0.35
	Preferred	0.72	0.67	0.55	0.41
Sample Size		3401	1242	3401	1242

Data about discriminant validity were generated using the mean correlation of a scale with the other scales as a convenient index for the same samples. Table 3 also shows that the total sample of school students yielded values for the discriminant validity index ranging from 0.06 to 0.49 for Actual form and from 0.15 to 0.57 for the Preferred form. For the total sample of university students, the values obtained for the refined version ranged from 0.13 to 0.38 for the Actual form and from 0.10 to 0.44 for the Preferred form. Similar values emerged for the Australian subsample. Although only arbitrary criteria exist, these values can be regarded as small enough to suggest that each SLEI scale has adequate discriminant validity for use in its Actual and Preferred Forms. It appears the SLEI measures distinct, although somewhat overlapping, aspects of classroom environment.

Preliminary analyses have been conducted within countries and for combined samples for various applications of the refined 52-item version of the SLEI. The findings from these analyses should be considered tentative at this stage until the data have been re-analysed using more sophisticated multivariate statistical techniques with a larger sample which includes the data currently still being collected.

Associations between Student Attitudes and Classroom Environment
In past classroom environment research, it has been common to investigate associations between student outcomes and the nature of the classroom environment (Fraser & Fisher, 1982). Consequently, in addition to completing the Actual and Preferred versions of the SLEI, each student in the sample completed a simple "enjoyable - not enjoyable" eight-item Likert-type scale entitled "Attitude to Science Laboratory Work". Table 4 shows the results of the simple and multiple correlation analyses used in exploring the degree of association between student attitudes and their perceptions on the Actual form of the refined version of each SLEI scale for the total sample

TABLE 4
SIMPLE AND MULTIPLE CORRELATION ANALYSIS OF ASSOCIATIONS BETWEEN ATTITUDE TO LABORATORY WORK AND SLEI SCALES FOR SCHOOL STUDENTS

Scale	Total Sample		Australia	
	r	ß	r	ß
Teacher Supportiveness	0.59**	0.14**	0.38**	0.06
Student Cohesiveness	0.52**	0.10**	0.32**	0.08**
Open-Endedness	- 0.31**	- 0.10**	0.04	- 0.03
Integration	0.59**	0.19**	0.39**	0.15**
Organization	0.59**	0.25**	0.42**	0.23**
Rule Clarity	0.47**	0.01	0.30**	0.03
Material Environment	0.52**	0.02	0.32**	0.02
Multiple Correlation	0.66**		0.47**	
Sample Size	3401		1875	

* $p<0.05$, ** $p<0.01$

of school students and the sample of Australian school students. The information reported includes for each sample the multiple correlation between attitude scores and the set of seven environment scales, the simple correlation (r) between attitude scores and each SLEI scale and the standardized regression coefficient (beta) for each SLEI scale. The magnitude and statistical significance of the regression coefficient provide measures of the association between attitudes and a particular SLEI dimension when scores on the other six SLEI scales are held constant.

Table 4 shows that the multiple correlation between attitudes and the set of environment dimensions was 0.66 for the total school sample and 0.47 for the Australian sample. Overall, the classroom environment dimensions in the SLEI were related positively with student attitudes (the only exception being that Open-Endedness was related negatively to attitudes for some subsamples). In particular, better student attitudes to laboratory work were found in classes which were higher in Teacher Supportiveness, Student Cohesiveness, Integration and Organization.

Gender Differences

Profiles of boys' and girls' mean scale scores were plotted separately for the Actual and Preferred forms of the 52-item refined version of the SLEI for the total sample of 3401 students at the upper secondary school level (Fig. 1). This graph shows the well-established pattern in which scores on the Preferred form were more favourable than those on the Actual form for both girls and boys, and for both school students and university students (Fraser, 1982, 1986).

Girls appeared to prefer a more favourable classroom environment than the one preferred by boys on most SLEI dimensions (Fig. 1). However these differences were not large. Similarly, a comparison of boys' and girls' average perceptions of actual classroom environment reveals a consistent pattern of relatively small differences. Generally girls perceived their classroom environments more favourably than did boys. The largest differences occurred for the Teacher Supportiveness scale: males were less positive about this aspect compared to their female counterparts. As this scale relates to classroom communication, it may be the case that females are less concerned with problems in this area than their male peers because of differences in maturity.

Differences between Various Science Subjects

Fig. 2 depicts, for the total sample of 1242 university students for both the Actual and Preferred forms of the refined version of each SLEI scale, the subscale means for the three subjects of Biology, Chemistry and Physics. The profiles for the three different subjects are surprisingly similar, although there are some interesting differences on two scales: Organization and Rule Clarity. These preliminary results suggest that, for university students, Organization was perceived to to be higher in Biology classes than in Chemistry or Physics classes, and that Rule Clarity was considered highest in Chemistry classes and lowest in Physics classes, with Biology classes in between these two extremes.

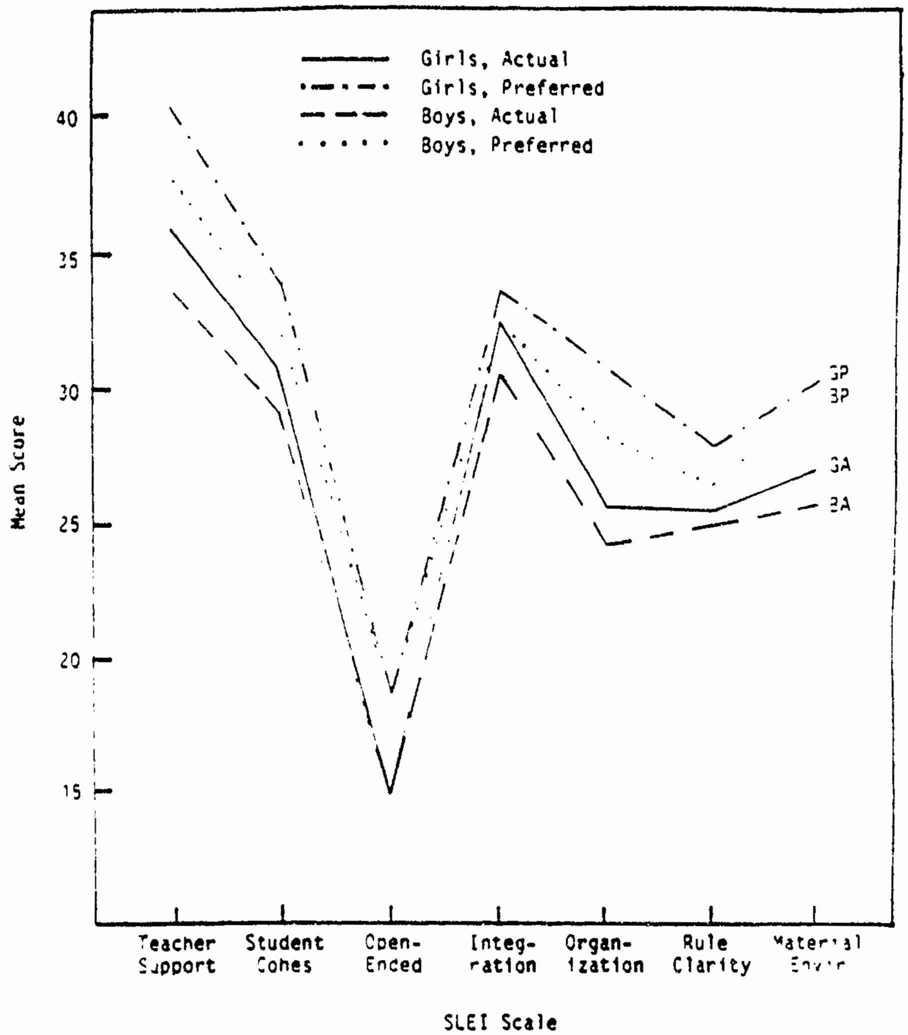

Fig. 1 Gender differences in Actual and preferred perceptions on the SLEI for School Students.

Differences between Countries

The mean actual environment profiles for the refined version of the SLEI were plotted for four different countries (Australia, USA, Israel, Canada) involved in the school sample (Fig. 3). Although overall there was considerable similarity in the profiles evident in the different countries, some noteworthy differences emerged for particular scales. For example, for the university sample, it appeared that the Canadian and British science laboratory classes were characterized by greater Integration and less Rule Clarity than either American or Israeli classes.

Differences between Students' and Teachers' Perceptions

Past research (e.g., Fraser, 1982, 1986) indicates that teachers typically hold more favourable perceptions of the environment of their classes than do their students in the same classrooms. In order to allow investigation of whether these differences between teachers and their students existed for science laboratory classes, the teachers of most

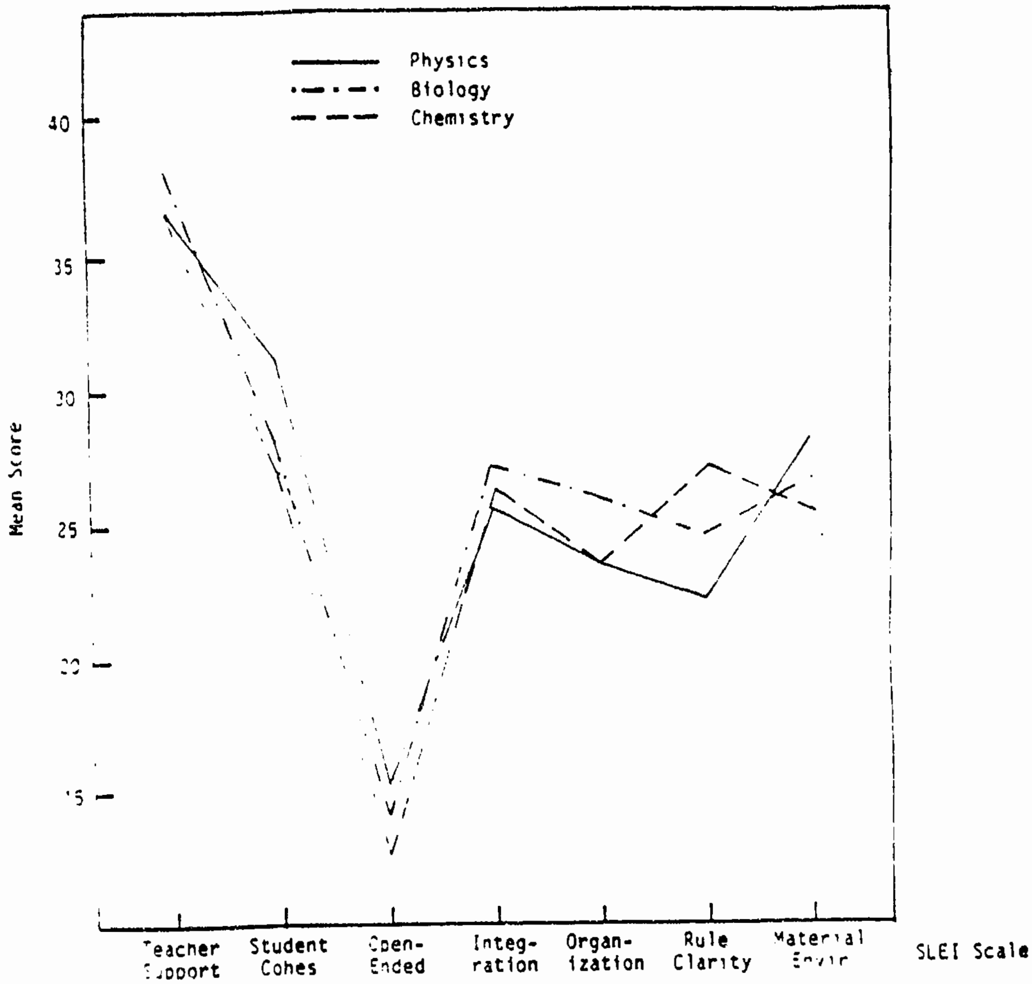

Fig. 2 Differences between science subjects for actual form of SLEI for university students.

laboratory classes for which students had provided responses also completed the SLEI in relation to the same classes. A comparison was made of student and teacher means for the Actual form of each scale for each of the four subsamples of school students and each of the four subsamples of university students. Results clearly replicated past research findings in that teachers' perceptions were more favourable than their students' perceptions on most SLEI dimensions for most of the eight subsamples. One interesting exception was the Open-Endedness scale: students and teachers held comparable perceptions for some subsamples.

CONCLUSION

This paper describes data related to the Science Laboratory Environment Inventory designed to assess seven dimensions of the Actual and Preferred environment of science laboratory classes at the upper secondary school and higher education levels. Noteworthy features of the SLEI include its specific relevance to science laboratory classes and its salience to science teachers and students. Comprehensive validation

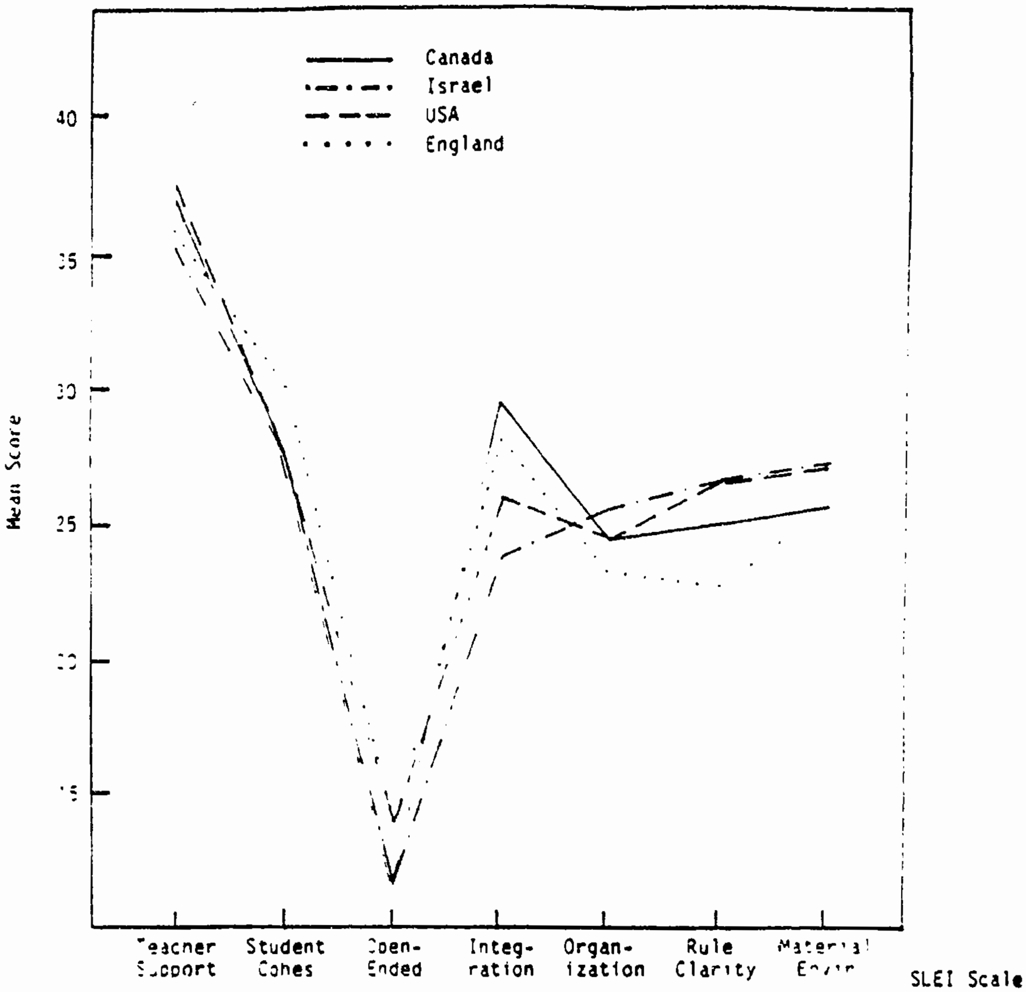

Fig. 3 Differences between countries for actual form of SLEI for university students.

information tentatively attests to the internal consistency, reliability and discriminant validity of the Actual and Preferred forms of the SLEI for use in either senior high school or university classrooms in several different countries. Research with the SLEI replicated considerable prior research in that associations were found between the nature of the science classroom environment and student attitudes (Fraser, 1986); students generally preferred an environment that was more favourable than the one they perceived was actually present; and teachers perceived the science laboratory classroom environment more favourably than did their students in the same classrooms (Fisher & Fraser, 1983).

It is hoped that science teachers and other researchers will make use of the SLEI to pursue several research and practical applications analogous to those completed successfully in prior work in non-laboratory classrooms. These include curriculum evaluation studies, person-environment fit research into whether students achieve better in their preferred environment, teachers' initiatives to improve the environment of their own classes, and investigations of the impact of the nature of science laboratory classroom environments on a range of student outcomes.

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DEVELOPMENT OF STUDENT INQUIRY SKILLS IN A COMPUTERISED CLASSROOM ENVIRONMENT

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ABSTRACT

This paper discusses a study in progress which involves the use of a computerised research science database (Birds of the Antarctica) and specially designed curriculum materials. The purpose of the study is to investigate the extent to which students' inquiry skills can be facilitated by the materials. Much attention is given in the programme to developing both students' inquiry skills and their subject-matter knowledge. Year 11 and 12 students' knowledge and skills development are interpreted as they interact with the computerised database and the curriculum materials. Preliminary findings about students' abilities and perceptions are discussed and, in particular, constraints to the development of inquiry skills and construction of understanding are explored.

INTRODUCTION

Teaching science as inquiry (Schwab, 1963) has evolved during the past quarter of a century. This approach arose from a fundamental need in science education to teach science as an active process involving inquiry and knowledge, rather than relying on exposition of content alone. Science inquiry has been defined in operational terms as a set of specific processes or skills which are used by scientists in their work. These processes include planning experiments, collecting information, organising and interpreting information and drawing conclusions (Fuhrman, Lunetta, Novick & Tamir, 1978).

A significant departure from the notion of inquiry suggested by Schwab (1963) and Fuhrman et al. (1978) was expressed by Kuslan and Stone (1969) who emphasised that inquiry learning is "why" centred, and not a prescribed set of skills for solving scientific investigations. They referred to effective science teaching which integrates the notions of science as information and science as the search for understanding. In their approach to inquiry learning, the answers are not known in advance, and questions such as "How do you know...?" are characteristic of the inquiry style. This approach focuses on the learners constructing their own understandings, and on the social interactions taking place in the classroom. In a personal sense the learner is actively engaged in constructing meaning by bringing his or her prior knowledge and development to bear on new situations (Driver & Oldham, 1986; Driver, Note 1). In the social sense, construction of meaning takes place when students negotiate their understanding by engaging in class discussion, exchanging ideas (Prawat, 1989) or interacting with the computer software in order to explore and develop further ideas (Oliver & Okey, 1986; Nachmias & Linn, 1987; River & Vockell, 1987).

In this study a computerised database on the ecology of the birds of Antarctica was used to help students develop inquiry skills. The Birds of Antarctica database enables students to retrieve information, use and develop their inquiry skills by interpreting information, suggest hypotheses to explain data, generate questions or hypotheses to extend the investigation, and design appropriate information retrieval techniques to answer each question or challenge each hypothesis. The focus of the research involves students' development of inquiry skills as they are engaged in scientific investigation through the use of a computerised database.

METHOD

The research study involved seven Applied Computing classes in four schools in metropolitan Perth; six classes are in Year 11 and one in Year 12, with about 130 students altogether. Each student responded to a pretest and a posttest instrument, the Inquiry Skills Test, designed for the study, to assess students' inquiry skills on three scales: Interpreting, Analysing, and Application (Zohar & Tamir, 1986).

In the program, students interacted individually with the database and the specially designed curriculum materials for approximately 20 hours. The materials consist of a booklet which guides the students in using the database and retrieving information. The booklet's main purpose is to encourage the learner to generate questions and design appropriate investigations by using all the different functions of the database. In addition, students and teachers are engaged in class discussions to enable students to negotiate their understandings arising from using the program and their prior knowledge, and to verbalise their own ideas.

In order to investigate how students develop inquiry skills, the study employed an interpretive research methodology (Erickson, 1986) using the following data sources:

* field notes of classroom observations;
* audiotape recordings of classroom discussions;
* audiotape recordings of individual students 'thinking aloud' as they interact with computers and curriculum materials;
* intensive semi-structured interviews with students and teachers; and
* student entries in a student booklet designed for the study.

By means of triangulation of these data, the study seeks some understanding of the learning processes, rather than provides a basis for prediction and control over the learning situation (Cziko, 1989), involved in inquiry learning using a database.

Two Year 11 classes started the programme; all had experienced computing in the classroom but they had no prior experience of database work. By contrast, students in the Year 12 class had prior experience with computing and databases. The concept of a database and how to manipulate it were familiar to most of the Year 12 students.

The results of the Inquiry Skills Test, administered as a pre-test, served also as a guide in selecting six students for case study analysis of their individual construction of inquiry skills. These students agreed to work with a tape recorder and to 'think aloud' while interacting with the programme (Ericsson & Simon, 1984). A range of students, with high and low scores on the pretest, were chosen.

I followed and observed every session in Year 11 and Year 12, wrote field notes about the processes in the class, audiotaped class discussion and interacted with the selected students. Because of differences in students' prior knowledge and experiences, the intensity of the learning process in the Year 12 class was a completely different experience compared to that which occurred in the other two classes observed concurrently. Initially, I did not think to focus on the development of Inquiry Skills in Year 12, but for reasons described later I found that the students in this class volunteered the largest amount of information and were very explicit about their thinking processes. In this class, the most interesting and fruitful discussions occurred, and the students seemed to be very excited and motivated by the programme. As one student said at the beginning of the programme after he had experienced a single period with the programme: "It's very well done (the programme), one of the best that the school has. You can obtain a lot of information, you can produce records that have relevant information that you can hold to it" (interview with Tom 25.5.90).

DEVELOPMENT OF INQUIRY SKILLS

This section discusses the qualitative data in relation to students' development of inquiry skills. The discussion focusses on opportunities that students encounter which constrain and enhance the development of inquiry skills. Analysis of the data shows that students need to a) learn the database language and b) visually understand the database in order to c) construct hypotheses and test their viability, and d) construct questions through creative thinking. Each of these needs is discussed in relation to the research question of how students develop their inquiry skills while engaged in the computerised database programme.

Overcoming Obstacles: Need to Learn The Database Language

From the start of the first lesson, most Year 12 students interacted with the database and didn't hesitate to try the different functions in order to retrieve information. Some demonstrated a good understanding of how to work with the database, as they followed the curriculum material (students' booklet) very closely and at their own pace, while the teacher, at this stage, was observing students interacting with the computers. While experiencing the Help Screen (see Fig. 1) and working with the first sets of Tests (investigations), students seemed to understand the framework and structure of the database. In particular, they developed their abilities to translate questions into the appropriate codes and, therefore, were able to use the language of the database. The Help Screen provided students with explanations of how to use the database language and the different functions of the database. In that first session all students experienced some of the different functions of the database, such as writing a test and retrieving information.

The first obstacle that the students had to overcome was using the codes of the database in order to conduct a Test. The use of the language of the database required students to use certain codes. For example, when students were asked "How many observations were made when the sea was covered with ice?", they had to use the Help Screen to find the codes for "ice" (ic) and for the description "covered with ice" which corresponded with the value of 5. Then they were able to conduct the test using the coded statement "ic = 5".

Some students, generally from Year 11, had difficulty understanding the questions even before they had to transfer them to the language of the database. The constraint that these students encountered was in understanding the questions presented to them in the student booklet. On one occasion a student could not relate the question in the booklet "How often was the air temperature -5° C?" to the statement "Number of Observations" that appeared on the screen (field notes p. 32). These students attained low scores on the Inquiry Skills Test.

They had great difficulty in translating the questions in the student's booklet to the codes and values of the database. They also saw the process as "another language", and considered as difficult the writing of the test in a certain way so that the information could be retrieved by the computer.

One student (Lynn, Year 11) had problems retrieving information for a very basic investigation, and needed teacher prompting for each step.
Student: What does it mean 'How many birds were feeding when observed?'

The teacher directed the student to use the Help Screen, which contains all the information that is needed to operate the database.

Student: What key shall I press?
Teacher: It says on the screen.

The student hesitated then with the help of the researcher continued.
Researcher: What is the code for feeding?

Student: Doesn't say it.
Researcher: Read what is on the screen. What is the code and value for birds feeding?
Student: Oh, it's bb = 1. What shall I do with it now?
Researcher: Go back to the test screen and write the test.
Student: And what shall I write down?
Researcher: Write the Test (investigation) using the codes and value that you found (field notes 1.6.90).

Although Lynn had prior experience working with computers, she hesitated at each stage of retrieving the information. She had problems translating the questions to codes and values, and needed reinforcement for each movement she was doing. She did not get to the first level of mastering the manipulation of the database, although she received individual attention from the teacher and researcher. The basic stages of practical skills needed in order to manipulate the database were not clear to her.

Most students who participated in the study immediately went to the Help Screen and found the relevant codes and values in order to run a Test. In the early stages they were using the Help Screen by trial-and-error. From the initial state of using the Help Screen in the trial-and-error mode, most Year 11 and Year 12 students advanced to a more accurate and specific mode of use in order to retrieve the information. However, the students who scored low on the Inquiry Skills Test used the Help Screen less frequently and preferred to use the Appendix, although it gives only part of the information. The use of the Appendix required less interaction and less manipulation of the keyboard, which may explain why the lower achieving students preferred to use the Appendix. One of the obvious reasons for that was lack of experience with the computerised database. At this point the students needed more practical examples and more 'hands on' experience to understand the concept of using the Help Screen and the 'language' of the database. Although these Year 11 students used the Help Screen in a trial-and-error mode, they did not advance to constructing an understanding about how the Help Screen was structured.

For the Year 12 students, problems which arose in relation to understanding the database language generally were resolved by negotiation between the students. For example, a conflict occurred when a student gave an interpretation to a question which was different from the interpretations of the other students in the class. The student translated the description of wind in the question into a code (WS = 10) although it already was stated in code form. He argued whether it was necessary to transfer the question to this code. The second student insisted that "unless the units of the variable are mentioned (which they weren't in this case), it should be changed to code" (field notes p. 41). Here, this student applied the rules of the database even though he didn't have to make the shift to the code. He said "But I thought it means 10 knots, wouldn't you use code 3 rather than code 10?" (as stated in the question). This problem then became a class discussion among students. Students argued for and against consistent use of the codes. The discussion took place mainly between two students (Tom and Carl, field notes p. 41) while all other students listened. Finally, the two students reached a consensus which satisfied Tom who initially had posed the problem. This type of discussion dealt with clarifying issues in relation to basic practical skills, that is, how to design an investigation in order to retrieve information.

As demonstrated above acquiring practical skills enables students to effectively communicate with the software by using the database language, design an investigation using the correct codes and operators, and retrieve the relevant information.

Overcoming Obstacles: Need to Visually Understand the Database

During the first few sessions, most students in Year 12 were able to construct their understandings of the structure of the database, by visualising the structure (see Fig.1)

Only after students visualised the database could they easily leave the Main Screen (see Figure 1) and use the other options required to obtain the information. In an interview with a Year 12 student the researcher asked how he solved a particular problem. Anthony explained: "I pictured where the Help Screen is, and how to get to it and only then I was able to work effectively with the data."

This visual understanding of the database increased the interaction between student and computer. Students easily shifted from Test Screen (see Fig. 1) to Help Screen, and back to Test Screen and Observational Screen. Most Year 12 students seemed to prefer to use the Help Screen rather than the Appendix in the booklet and expressed enjoyment about their ability to control the data while using the Help Screen. These basic manipulations of the database, and use of different extensions of the database, were reinforced by the teacher in Year 12 who prompted student interactions with the database by posing questions.

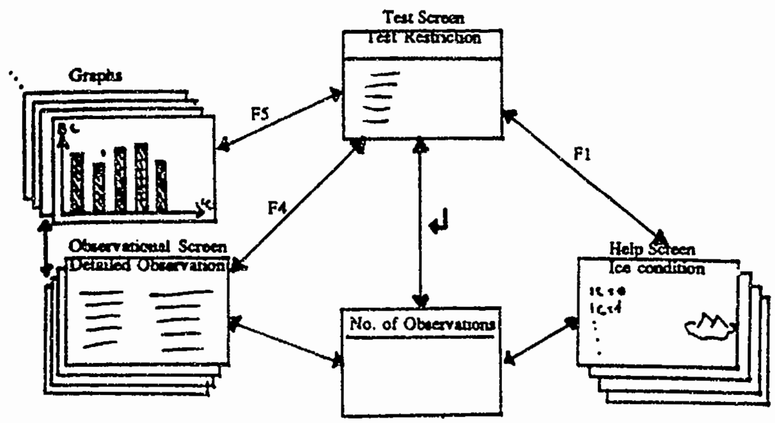

Fig. 1: Structure of the database

However most of the Year 11 students found it difficult to visualise the structure of the database. They perceived the software as an abstract concept and could not move from one screen to another because of their inability to conceptualise the organisation of the database. The movement from one screen to another required a global understanding of the structure of the database which they could not acquire and, therefore, they could not adopt the practical skills which were elementary to the higher ability students.

To help with the visualisation the teacher of the Year 11 group referred the students to a 'card catalogue' which he borrowed from the school library. He used a physical visual analogy to demonstrate the structure of the database to the students. In an interview the teacher explained "I like to get students to think about a card file system where they can see concrete cards with all the information written on it. ... It is only when you approach these students in physical terms that they have a good chance of understanding and applying concrete ideas to the software which is quite abstract" (teacher interview 1.6.90).

Subsequent to this teacher demonstration, many of the Year 11 students constructed their understanding of the database and were able to overcome some of the practical skill problems they were experiencing. However, one of the reasons which prevented students from manipulating the database was that the class was required to progress together in a lock-step approach: students followed the teacher without having enough opportunity to experience the database by themselves. So, some of the Year 11 students could not construct an individual understanding of the structure of the database.

Visual understanding of the structure of the database would appear to be a prerequisite which enables students in Year 11 and Year 12 to manipulate the database and acquire practical skills.

Constructing Hypotheses and Testing for Viability

In the early stages of dealing with the curriculum materials and the software, the Year 11 students were asked to find different birds' behaviour from the data and, then, to infer with reasons why most of the birds that were observed by the scientists were sitting on the ice. Some of the students suggested that the birds might be Penguins. One Year 11 student used his prior knowledge :"Penguins like to sit on ice, so it must be a Penguin". He didn't go beyond guessing, and didn't support his hypothesis by running another 'test' or checking the data. As the teacher mentioned, "the student didn't try to back his statement with any logical argument" (teacher interview 1.6.90).

However, when students did give reasons or explanations for behaviour or phenomena, they usually did not go beyond the level of guessing, and did not support their argument with supportive evidence from the database. The fact that students were not fully manipulating the database prevented them from individually exploring and designing more information retrieval. The other explanations that the teacher gave were: "I haven't found any of the students in either Year 11 classes who have the ability after they made a statement to back that statement with any form of logical argument or logical problem solving procedure or testing their statements..." In the answer they said: "They are Penguins... so why bother? They are not interested in the process" (teacher interview 8.6.90).

From this incident, it is clear that most of the Year 11 students stayed at the "guessing" level and did not look to support their hypotheses by conducting more investigations and extending their use of the database. At this stage of the study, students' explanations and use of general knowledge to support their explanation was very limited.

In Year 12, where students already had gained the practical skills for dealing with the database, there was more discussion overall, and the discussion about the number of observations for certain birds' behaviour gained more momentum. Students' used their general knowledge to interpret that birds sitting on ice are Penguins, but they were not satisfied with their hypothesis. They used their procedural knowledge and tried to give support to their initial hypothesis by designing a new investigation to find more information about the birds which exhibit the behaviour "sitting on ice". Firstly, they identified the 'bird species' and found that it was a Penguin, and not another species, by running another investigation through the database.

In another incident, the class discussion focused on the issue of whether it is always necessary to support or disprove a hypothesis by running more investigations on the database. To answer the question: "What is your hypothesis about the preferred living conditions of (a) Emperor Penguin and (b) Wandering Albatross (student booklet p. 22), the class was divided in their ideas. One student answered the question by simply stating his hypothesis, whereas another student (Carl) replied:

"How can you say that? Did you check for other weather conditions?" The first student (Anthony) :"I just did what the question required, not more." Tom: "You have to do more Tests to find the answer." (field notes 18.6.90)

Clearly in this case, the Year 12 class was divided into two groups. The group that did only the first step of formulating a hypothesis according to previous information (and this is one step above the initial step of guessing, discussed above). They argued that they should stick closely to the booklet and the instructions. It seems that they couldn't see the need to further support their hypotheses. Most of these students obtained low or average scores on the Test of Inquiry Skills.

The other group reached a higher level of understanding of a scientific investigation. After making a hypothesis, they automatically engaged in designing more and different investigations to support their hypothesis. This group argued that "You can't hypothesise without running a test and finding justification from the database." (field notes 18.6.90) This group consisted of students who obtained high or average scores on the Inquiry Skills Test.

Some of the students developed higher level skills by designing further data retrieval to support their hypotheses; further, they were able to construct hypotheses to explain the data that were recorded by scientists.

Constructing Questions Through Creative Thinking

When the students were asked to generate new questions and design investigations accordingly, most Year 11 students limited themselves to the examples that were given to them in the student booklet, and did not proceed beyond the narrow level of this set of examples. Their understanding of the opportunities existing in the database was limited to what is "on the screen" and they did not demonstrate creative thinking to use the database "to its limit".

On the other hand, a small group of students, most of whom were in Year 12, came up with interesting questions and exhibited creative thinking. These students developed the practical skills and managed to manipulate the database without any problem. The questions were not confined to the content of the database, but extended to other related areas which the students inferred from the database.

For example, one of the students formulated the question: "Which bird is the most tame of all the 26 species?" This student designed a few investigations to answer his question. He ran the tests for all bird species which demonstrate the behaviour of 'sitting on the ship' or 'in the hand', or 'accompanying ship', or 'following its wake'. Based on the data that he received, the student wrote some assertions about that species being the most tame (field notes 15.6.90).

When the teacher asked: "What new information about the environment have you acquired so far?", a student replied by describing a Test that he designed to find the migration period of some of the species. "I tried to work out when migration periods for certain birds were. I chose several days during the time of the voyage and found out when different birds are at their maximum number" (field notes 8.6.90). The student exhibited creative thinking from his area of interest and designed the investigation accordingly.

From the observations made to date, students generated questions and developed creative thinking in their investigations only when they could easily manipulate the database.

CONCLUSION

The learning programme, Birds of Antarctica, and the associated developed curriculum materials, have been developed to help students construct their higher-level thinking skills. The discussion in this paper deals specifically with the database language, visual understanding of the database, students' construction of hypotheses and tests for viability, and their construction of questions through creative thinking.

Attempts to report on the development of inquiry skills have led to the emergence of two significant groups of skills. One is related to manipulating the database and retrieving information, which was mainly demonstrated in Year 11, and the other relates specifically to higher-level skills, such as constructing questions or hypotheses, and was demonstrated in Year 12.

The interactions described in this report suggests that students can develop inquiry skills only after they acquire practical skills. The data obtained from classroom observations and interviews with students and teachers, revealed that students who had acquired a reasonable proficiency with the practical skills developed inquiry skills more readily than the students who were not so proficient. Those students who had developed some of the practical skills and could easily manipulate the database used it more effectively to develop inquiry skills.

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HISTORY, PHILOSOPHY AND SCIENCE TEACHING: CURRENT BRITISH, AMERICAN AND AUSTRALIAN DEVELOPMENTS

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ABSTRACT

The history and philosophy of science components of the new British National Curriculum, and the American Association for the Advancement of Science Project 2061 curriculum guidelines are described. Some curriculum background is given to these developments; and a contemporary international project concerned with the utilization of the history and philosophy of science in science teaching and teacher education is also described. Finally the recent Discipline Review of the Training of Science and Mathematics Teachers in Australia is examined and criticised for its lack of recommendations about the need for appropriate history and philosophy of science courses to be included in science teacher education programmes.

INTRODUCTION

Science education has largely been conducted independently of explicit reference to the history and philosophy of science. There have of course been some exceptions to this history of separate development. Some philosophers and historians of science, such as Nunn, Schwab, Robinson, Conant, Holton, Scheffler and Martin have engaged with science educators and their curricula and pedagogical problems. Among curricula, the Harvard-based Project Physics course, developed in the mid-1960s, is a fine example of what collaboration between scientists, historians, philosophers, and science educators can produce when the resources and determination are present (Holton 1967, 1978).

However these scholarly interventions and curricula developments have been exceptions to the general rule. The recent history of the relations between HPS and science education has been aptly summarised in the title of a 1985 paper: 'Science Education and Philosophy of Science: Twenty-five Years of Mutually Exclusive Development' (Duschl 1985).

Pleasingly this long tradition of intellectual apartheid seems now about to end.

The two outstanding contemporary examples of the convergence between HPS and science education are the new British National Curriculum, and the American AAAS Project 2061 curriculum. The history and philosophy of science is prominent in both of these reform proposals. Beyond these there have been curricular developments in Denmark, The Netherlands, and Italy that have also been constructed on historical principles, and that attempt to introduce some elementary philosophical considerations into school science courses (Bevilacqua & Kennedy 1983, Thomsen 1986, Blondel & Brouzeng 1988, Nielsen & Thomsen 1990).

Concurrent with these curricular innovations, there is underway a large international project on 'History, Philosophy, and Science Teaching' that is an ambitious cross-disciplinary, and cross-national project. This project involves about 500 scholars in 25 different countries. It has thus far produced six special issues of scholarly journals on the topic of 'HPS and Science Teaching' (Note 1). These contain a great deal about the rationale for bringing a HPS dimension into school science classes, and particularly for including it in teacher training programmes. The journals also contain many case studies showing how HPS has been utilized in biology, chemistry, and physics lessons. In addition an extensive bibliography of writings on HPS and Science Teaching has been produced (Note 2).

EARLIER CURRICULA

The major science curricula reforms of the early 1960's proceeded largely without the participation of either historians or philosophers of science (many of them proceeded without school teachers, one might add). There were two notable exceptions, one the previously mentioned Harvard Project Physics Course , the other being versions of the American Biological Science Curriculum Study (BSCS).

The Harvard Project Physics course, which at its peak accounted for about 15% of high school physics students in the US, has been the most widely used school curriculum based upon historical principles and which exhibited an explicit concern for the cultural and philosophical dimension of science. Its success in retaining students, involving women in science courses, developing positive attitudes to science, developing critical reasoning skills, and raising scores on attainment tests, has provided evidence for the inclusion of HPS in contemporary curriculum developments. This evidence is reviewed in Aikenhead (1974), Brush (1989), Russell (1981), Holton (1978), and in the symposium on Project Physics. (Holton et al., 1967)

The lessons from the failures of Project Physics are also instructive, in particular the consequences of the failure to prepare teachers adequately in HPS so that they could cope with the curriculum in the open-ended and critical manner expected. The curriculum was launched without adequate pre-service or in-service training provisions for teachers.

The BSCS course was informed by the ideas of the biologist-philosopher-educationalist J.J.Schwab who promoted the pedagogical creed of 'science as enquiry'. Schwab (1963) wrote the Teachers' Handbook for the BSCS curriculum, and in it he advocated the historical approach, saying that 'the essence of teaching of science as enquiry would be to show some of the conclusions of science in the framework of the way they arise and are tested. ... [it] would also include a fair treatment of the doubts and incompleteness of science' (p. 41). History is also advocated because it 'concerns man and events rather than conceptions in themselves. There is a human side to enquiry' (p. 42).

In Britain as long ago as 1917 the British Association for the Advancement of Science had urged an historical approach to school science teaching, saying that: the history of science was a solvent that dissolved the artificial barriers between literary studies and science that the school timetable sets up (BAAS 1917, 140).

Hogg in 1938 said of the historical approach to chemistry teaching that:

The historic development is a logical approach. The slow progress of the early centuries was owing to a lack of knowledge, to poor technique and to unmethodical attack. But these are precisely the difficulties of the beginner in chemistry. There is a bond of sympathy between the beginner and the pioneer (Hogg 1938, vii).

Over the past few decades there have been numerous reports of the British Association for Science Education that have again urged a more historical, humanistic, contextual approach to science teaching (Sherratt 1982, Newton 1988, Jenkins 1990). The stumbling block has always been the historical and philosophical inadequacy of teachers. Manuel, in urging the inclusion of HPS in courses of teacher training, said:

This more philosophical background which is being advocated for teachers would, it is believed, enable them to handle their science teaching in a more informed and versatile manner and to be in a more effective position to help their pupils build up the coherent picture of science - appropriate to age and ability - which is so often lacking (Manuel 1981, p 771).

THE BRITISH NATIONAL CURRICULUM

These decades of agitation bore fruit when the first ever national school science curriculum was introduced in Britain in 1989. It is divided into seventeen attainment targets or fields of study. The seventeenth attainment target is called 'The Nature of Science.' The NCC in the beginning of its report deems it important to draw attention to this field. It says that: This is concerned with the nature of science, its history and the nature of scientific evidence. Council recognises that this aspect has not enjoyed a traditional place in science education in schools. ... Since this target may be relatively unfamiliar to teachers, several examples have been given for each level to illustrate the area of study (NCC 1988, 21).

The Committee elaborates its intentions when it introduces the field within the body of the Report. It says of this attainment target 17, (the HPS field), that: pupils should develop their knowledge and understanding of the ways in which scientific ideas change through time and how the nature of these ideas and the uses to which they are put are affected by the social, moral, spiritual and cultural contexts in which they are developed (NCC 1988, 113).

Concerning the programme of study for 11-14 year-olds, it says that they should through their own investigations, case studies, and investigation of the life of a famous scientist and/or the development of an important idea in science, be given the opportunity to:

* study the ideas and theories used in other times to explain natural phenomena;
* relate such ideas and theories to present scientific and technological understanding and knowledge;
* compare such ideas and theories with their own emerging understanding and relate them to available evidence.

For 14-16 year-olds, the Committee recommends that pupils continue the course of study outlined above, but they should also:

* distinguish between claims and arguments based on scientific data and evidence and those which are not;
* consider how the development of a particular scientific idea or theory relates to its historical and cultural, including the spiritual and moral, context;
* study examples of scientific controversies and the ways in which scientific ideas have changed (NCC 1988, 113).

Beyond providing a programme of study, the NCC Report also itemises expected attainments in competence levels 4-10 for this HPS field. It is worth relating some of these statements of attainments in full. The report says pupils should:

* at Level 4, be able to describe the story of some scientific advance, for example , in the context of medicine, agriculture, industry, or engineering, describing the new ideas and investigation or invention and the life and times of the principal scientist involved.

* at Level 7, be able to give an historical account of a change in accepted theory or explanation and demonstrate an understanding of its effects on people's lives - physically, socially, spiritually, morally. For example, understanding the ecological balance and the greater concern for our environment; the observations of the motion of Jupiter's moons and Galileo's dispute with the Church.

* at Level 10, be able to demonstrate an understanding of the differences in scientific opinion on some topic, either from the past or the present, drawn from studying the relevant literature. For example, plate techonics and the wrinkling of a shrinking Earth OR living things reproduce their own kind and spontaneous generation of species. (NCC 1988, 114-115)

The NCC says of these levels of attainment that they are 'pitched both to be realistic and challenging across the whole ability range' (NCC 1988, 117). There is no doubt that they are challenging; how realistic they are will in large part depend upon the ability and competence of teachers.

The problem of having science teachers trained in HPS is recognised in the preamble of the NCC Report. In bold type it states that: Council recommends that it should provide additional non-statutory guidance on the teaching of the attainment target The Nature of Science (NCC 1988, 21).

THE 2061 REPORT

In 1985 the American Association for the Advancement of Science established an extensive national study to recommend an overhaul of school science. This study was called Project 2061 (as it was initiated during the visit of Halley's Comet, and it was recognised that children then starting school and seeing the comet would be seeing it again in 2061). In 1989, after four years of deliberation and consultation, the project published its recommendations in a report titled Science for All Americans (AAAS 1989).

Science for All Americans contains 12 chapters giving the recommendations of the National Council On Science and Technology Education. Chapter One is on 'The Nature of Science', chapter Ten is on 'Historical Perspectives'. In both of these chapters historians and philosophers will find much which is familiar, and encouraging for those who have long advocated the inclusion of HPS into school curricula. In the first chapter there are discussions of objectivity, the mutability of science, the demarcation dispute, evidence and theory, method as logic and imagination, explanation and prediction, ethics, social policy, and the social organisation of science. The intention is that these themes be developed in science courses, and that pupils completing school science know something of them.

In introducing chapter Ten on 'Historical Perspectives' the report says that there are two principal reasons for including some knowledge of history among the recommendations. One reason is that generalizations about how the scientific enterprise operates would be empty without concrete examples. Consider for example, the proposition that new ideas are limited by the context in which they are conceived; are often rejected by the scientific establishment; sometimes spring from unexpected findings; and usually grow slowly, through contributions from many different investigators. Without historical examples, these generalisations would be no more than slogans, however well they might be remembered.

This is a serious point for teacher training courses in HPS to consider. Too often HPS courses neglect the actual history of science, so that students have to learn the debates between positivists, Popper, Kuhn, Lakatos, Feyerabend etc. all of whom support their account of scientific method with recourse to historical examples, but students are left taking their historical examples on faith. What should be a course that enhances critical thinking, becomes a catechism lesson.

The report goes on to say that:

> A second reason is that some episodes in the history of the scientific endeavour are of surpassing significance to our cultural heritage. Such episodes certainly include Galileo's role in changing our perception of our place in the universe; Newton's demonstration that the same laws apply to motion in the heavens and on earth; Darwin's long observations of the variety and relatedness of life forms that led to his postulating a mechanism for how they came about; Lyell's careful documentation of the unbelievable age of the earth; and Pasteur's identification of infectious disease with tiny organisms that could be seen only with a microscope. These stories stand among the milestones of the development of all thought in Western civilization.

These comments remind us, sadly, that the history of science has fallen between stools. Arguably the greatest achievement of western civilization, and that which has undoubtedly been responsible in large part for the shape of western history is usually not dealt with in school (or university) history departments because it is too technical or difficult; and it is not dealt with in science departments because it is supposedly too irrelevant.

HPS AND SCIENCE TEACHER TRAINING IN AUSTALIA

In Australia there are no HPS-related curriculum developments in science comparable to those of the British National Curriculum, or the American Project 2061 suggestions. However, a more humanistic, contextual, historical science teaching is not entirely dependent upon curriculum topics; it can be achieved with almost any curriculum if teachers can see the benefit of it, and are prepared to engage students with historical, and broadly cultural, questions. The names Darwin, Galileo, Newton, Boyle, Mendel, Mach, Einstein are going to figure in most school science courses. The concepts of law, evidence, scientific method, causation, objectivity, falsification, experiment, explanation, are also going to appear in any science course.

It is thus legitimate even in non-historical curriculum for teachers to elaborate upon, and engage students in discussion of the lives, achievements, and times of these individuals; and also to elaborate upon the meaning of central scientific concepts encountered in texts and lessons. But to do this requires some familiarity and competence in HPS.

Fortunately we now have good evidence on the extent to which Australian science-teacher-training programmes provides (or more accurately does not provide) this familiarity and competence. The evidence can be found in the 1989 Federal Government's Department of Employment, Education and Training report on the Discipline Review of Teacher Education in Mathematics and Science (DEET 1989, this will henceforth be referred to as the Review).

The Review is in three volumes, extending over some 1100 pages. It is concerned both with what is happening in the 52 institutions where science teacher training is conducted, and also with what should happen in such programmes. It is normative as well as descriptive. In its own words:

> Chapters 3 and 4 set out the Panel's views of expected features of courses which would lead to quality teacher education in mathematics and science. These views draw on consideration of the literature and reports related to mathematics and science education, advice from commissioned papers, submissions received, information collected during the Review, and observations made on visits. (vol. I, p.15)

Its recommendations cover the categories of science studies, education studies, curriculum studies, and practice teaching.

Volume II, the descriptive part of the Review, details the courses and staffing in 52 universities and colleges. An initial reading reveals that there is only one institution in all of Australia where would-be science teachers do any course on the history and philosophy of science: the University of New South Wales. There may be other institutions that include such material in method or theory courses but they are not listed separately, or they are not of such moment as to deserve comment. I understand that one such a course operates at the Tasmanian State Institute of Technology in Launceston, and another at Adelaide University. It is reasonable to conclude that HPS plays no part in the preparation of the 2,853 trainee secondary science/mathematics teachers in Australia (1,683 in concurrent courses, and 1,170 in end-on courses), or the 19,000 primary teaching trainees.

The lack of HPS in courses is reflected in the Review's study on students' Confidence in Broad Aspects of Content Knowledge. Its item on 'Knowledge of Historical Development' is last among 8 items (Vol. II, p. 49). In its study on student Confidence in Content Areas, the 'Nature of Science' item is rated in the middle of 10 items (Vol.

II, p. 50). Whether this confidence rating would be maintained if students were asked to comment upon a few of the items in Attainment Target 17 of the British National Curriculum is an interesting question. It is noteworthy that these results for science students are replicated for mathematics students: for graduate students, their confidence about the 'Nature of Maths and Its History' almost falls off the graph (Vol. II, p. 45).

In Vol. I Chapter 2 the Review deals with 'Australian Society and Schooling' and gives a largely utilitarian, social-relevance justification for the study of science, saying that 'science and technology have a major role in the future development and prosperity of Australia' (Vol. I, p. 9); that Australia needs an increasing number of scientists; and that the understanding by Australians of public health and conservation issues requires a more scientifically literate population and other such claims.

Vol. I Chapter 5 deals with the normative issues, the recommendations for improving 'The Education of Science Teachers'. The panel states that it has 'been able to put together a description of what would be science teacher education of high quality' (Vol. I, p 36). It is noteworthy that the history and philosophy of science does not figure explicitly in its recommendations for an ideal programme, not in its Science Studies, nor Education Studies, nor Curriculum Studies, nor Practicum categories.

A member of the Review Panel, Professor Peter Fensham, has said that the panel took a conservative view on its recommendations: it recommended only courses of action that were already in place in a variety of Australian institutions: 'if it is not already being done in Australia then it is likely to be impractical, or not worth doing' (ASERA conference July 1990).

Among other things, what this stance overlooks, is that HPS training does occur in Australian, and other, science teacher education programmes, but it is implicit training or indoctrination: students absorb a scientific epistemology and view of the history and philosophy of their subject by osmosis. As there is ample evidence available on how the epistemology of teachers affects their approach to classroom lessons and the structuring of programmes and the conduct of assessment (Gallagher, 1990), these implicit views ought to be made explicit, and opened up for scrutiny.

The question of philosophical training is raised in its Science Studies recommendations where 'The Nature of Science' is given separate mention. Science Studies should 'assist students to gain a sense of the nature of a science as a means of describing, investigating, explaining, and reporting about particular aspects of natural phenomena'. It recommends that this goal be achieved by allowing trainee teachers to conduct some experimental investigation, by requiring them to access scientific literature, and finally by 'a mandatory unit in second year that involves communication skills' (Vol. I, p. 46). These recommendations clearly fall well short of any prescribed course in the history and philosophy of science.

In its recommendations about Curriculum Studies, the panel says that 'The new directions of curriculum materials for science in relation to both technology and society (the Science, Technology and Society movement) is now an obvious dimension to include in curriculum studies' (Vol. I, p. 53). The new directions that the panel might have in mind could be the British SISCON and SATIS materials, and the Dutch PLON materials. But if, without argument, these are an obvious thing to include, then why not the history and philosophy of science?

A nice, clear, normative view of a quality science teacher is given in the opening pages of a 1929 science text. There a successful science teacher is described as one who:

> knows his own subject ... is widely read in other branches of science ... knows how to teach ... is able to express himself lucidly ... is skilful in manipulation ... is resourceful both at the demonstration table and in the laboratory ... is a logician ... is something of a philosopher ... is so far an historian that he can sit down with a crowd of boys and talk to them about the personal equations, the lives, and the work of such geniuses as Galileo, Newton, Faraday and Darwin (Westaway, 1929, p. 3, quoted in Sherratt, 1983, p. 418).

This is the ideal that the British and American curriculum developments require of science teachers. The Australian Review only approximates this ideal.

There are of course problems posed by the dramatic drop in entry requirements for science teacher programmes in Australian universities. In NSW, some courses have an HSC aggregate mark of 260 for admission, when the commerce, medicine and law mark is 410. The Westaway ideal presupposes a teacher who has command of the discipline; this is increasingly difficult to achieve as the quality of student intake declines.

The major question yet to be addressed in the U.S.A. and the U.K. is how to teach HPS to prospective science teachers. The question is unfortunately not as urgent in Australia, but it ought to be thought about. To require students to complete a course in the Philosophy Department is far from ideal: this is seen as yet another burden on their backs, and is usually far removed from anything they see as immediately relevant. The course needs to be tailored to the future teaching demands of the science teacher. I have described one such course in Matthews (1990c). If their science courses - undergraduate physics, biology etc. - have been taught in an historical and philosophical manner than that is perhaps the best way to introduce the subject in preservice training. Unfortunately this is rarely the case.

CONCLUSION

My argument is that for good reasons there have been major developments in British and American school science in which the history and philosophy of science, or better the historical and philosophical aspects of science subject matter, have been included in the curricula. If the STS material, or outlook, is now an 'obvious dimension' to include in curriculum studies for Australian trainee science teachers, why not the history and philosophy of science?

There is little doubt that science teachers who know something of the history and philosophy of their subject can enliven their classroom presentations, and bring more coherence to the structure of their programmes. All research shows how important the teacher is to the outcome of science instruction. If teachers know something of the rich history of their subject, and have an enthusiasm for the many philosophical questions that Galileo, Newton, Darwin, Einstein and the others saw at the heart of science, then the quality of teaching and learning must be improved.

A separate argument, that will not be developed, is that a competent grasp of the STS materials and the Gender Issues that the Review is rightly concerned with, requires some knowledge of the history of science, and this in turn some knowledge of the philosophy of science. So on both counts the inclusion of an appropriate course in the history and philosophy of science seems as if it should have been part of the recommendations of the Review for 'science teacher education of high quality'.

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Note 1. These have been Synthese, 80, (1) (1989), Educational Philosophy and Theory 20 (2),(1988), Interchange 20 (2), (1989), Studies in Philosophy and Education 10 (1), (1990), Science Education 74, (5), 1990) and The International Journal of Science Education 21 (4), (1990).

Note 2. An extensive bibliography of writings on HPS and Science Teaching can be found in Synthese, 80 (1), (1989); and in Interchange, 20 (2), (1989)

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FOCUS FOLKLORE : REFLECTIONS OF FOCUS TEACHERS ON THE SCI-TEC IN-SERVICE PROJECT

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ABSTRACT

In June 1988, the SA Minister of Education announced the allocation of $650,000 to boost science and technology in State primary schools. Subsequent allocations have raised funding for Phase 1 and 2 of this 'SCI-TEC Project' to over $1m. This level of funding for science and technology in primary schools is unprecedented in Australia.

During 1989 the Independent Schools Board sponsored a pilot project along similar lines and in 1990 the Disadvantaged Schools Program of the Catholic Education Office followed suit. Although different structures have been provided, an interactive approach to in-service has been the underpinning for all three projects.

This paper examines what has happened in each of these projects so far, and reviews the strategies used to:

* develop interactive models of in-service education.

* involve teachers as effective change agents in their schools

* enhance t. e impact of focus teachers working in neighbouring schools

* record the insights of all participants in the projects

* maintain accountable procedures when using a model of in-service which rejects a 'top-down' approach.

BACKGROUND

In 1986/87, the Education Department of South Australia conducted a major review of primary education in the state (the Primary Education Review or P.E.R.), which revealed concern by teachers about the quality and quantity of science experiences of South Australian children during their primary years of schooling, Years R (Reception) to 7. The needs identified by the P.E.R. were in the resource area (both equipment and curriculum materials) and in the level of expertise and confidence felt by teachers in primary schools in the state (Education Department of South Australia, 1988).

On 8 June 1988 the Minister of Education allocated $500,000 for additional resources, including curriculum materials, for science/technology at the Primary level and a further $150,000 for teacher in-service. Subsequent allocation brought the total commitment of funds to $1.4 million.

The South Australian College of Advanced Education and the Education Department of South Australia prepared an in-service program for teachers in the designated "focus" schools in the state. A 0.5 time Project Co-ordinator (Yvonne Zeegers) and two 0.5 time Project Officers (Peter Russo and Brian Marshall) were appointed from the Education Department for the duration of Phase 1. Only the Project Co-ordinator position has continued for Phase 2 and 3. The impact of this decision on the management and monitoring of a state-wide project has been significant.

In 1989 the authors were approached by the Independent Schools Board of South Australia to mount a similar project for eighteen Independent Schools. In March 1990 an approach was made to the authors by the Disadvantaged Schools Project of the Catholic Education office in South Australia to organize and conduct a whole school in-service program in three of their schools.

DEVELOPMENT OF THE IN-SERVICE MODEL.

From the outset, the Sci-Tec Project was based on the premise that each of the teachers selected to participate as a focus teacher already possessed a wealth of knowledge, skills and attitudes which were compatible with the aims of the project. The first task of the project was therefore to enable these focus teachers to share this expertise with all other participants. The second task was to blend this expertise with the expertise of the other year 5-7 teachers in the focus schools, and ultimately other participating schools.

Discussion with the Project Officers produced several approaches deemed likely to achieve this:

* modelling and maintaining a collegial approach throughout the activity-based program in Phase One.

* facilitating interactions between focus teachers during activity sessions and in informal 'social' discussions.

* openly valuing the ideas of all participants, particularly their views of what science and technology are in the context of the primary school.

* seeking a <u>school</u> commitment via the principal of each focus school to match the personal commitment of the participants, and the financial and ideological commitment to this model of the Education Department.

* locating in the focus schools most of the time devoted to the project.

* encouraging participants to reflect critically on their beliefs about science and technology, and on the processes by which they had come to these beliefs.

* using a "hands-on", child-centered approach in which children investigate problems which <u>they</u> find relevant.

* having two focus teachers from each school so that there would be immediate in-school support when they began providing in-service for their colleagues. (This was not possible for smaller schools, but is still considered a basic principle).

* ensuring a gender balance similar to that of the mix of year teachers across the state, by requiring at least one of the focus teachers nominated from each school to be a woman.

* involving all participants in the planning of the activities and the establishment of support networks.

Further in-service strategies were developed to meet specific geographical, environmental and pedagogical needs of particular schools, but all were kept compatible with those listed above.

Theoretical underpinnings.

As may be seen from this list, we have been strongly influenced by the work of critical social theorists such as Jurgen Habermas, Henri Giroux and Stephen Kemmis (e.g. Carr & Kemmis, 1986), and also by the work of the Learning in Science Project (L.I.S.P.) based at the University of Waikato in New Zealand (Osborne & Freyberg, 1985), and the Project for Enhancing Effective Learning) (P.E.E.L.) based at Monash University (Baird & Mitchell, 1986).

One of the major problems we faced, reflected in the findings of the Primary Education Review was the lack of confidence primary teachers had in their ability to teach science and technology. Most felt that they *lacked the expertise to teach in these areas* (Education Department of South Australia, 1988). Earlier introductions of an interactive approach to science by science advisers, and two key teachers in science in 1988 had precipitated some anxiety in many of the teachers, and so it was decided not to introduce all elements of interactive learning to classroom science in the early stages.

Evaluating R-7 science at the classroom level (Education Department of South Australia, 1985) suggests that teachers operating in a transmission/demonstration mode, should feel free to follow the path of science education over the past twenty years via process, discovery/enquiry and problem solving modes towards an interactive approach, (albeit at a greatly increased pace), and that each small step should be recognized and valued. We decided that we would model an interactive approach as the teachers followed this path.

Exactly what this "interactive model of in-service" would be was less than clearly articulated at the time. In fact, this articulation has developed as the project team has "interacted" variously with the three in-service projects, and as we have seen the focus teachers provide in-service to other teachers during Phases 1 and 2 of the Sci-Tec Project. However, the parallels with the teaching model advocated by Biddulph and Osborne (1984) and modified by Faire and Cosgrove (1986) are fairly clear.

Faire and Cosgrove	Sci-Tec In-service
Teachers and children negotiate a topic and find background information.	Focus Schools and Teachers negotiate their in-service involvement in the project.
Children's before views are shared and discussed	Teachers' before views are shared and discussed
Exploratory activities involve the children in the topic and focus their thinking on specific aspects	Exploratory activities in science/technology immerse teachers in this topic. Group discussion focuses their thinking.
Questions which the children find interesting/puzzling and they wish to investigate are collected. The meanings of these questions are clarified.	Questions which the teachers perceive will address their needs are collected. How they perceive that their needs may be met is clarified.
Activities designed to investigate these questions. Children formulate an action plan for the investigations and then carry it out.	Teachers develop a program of activities to meet their needs. Shared responsibility in the execution of this program.
Children's after views are displayed, compared with each other and earlier views.	Teachers' after views are collected via posters, role plays, journals and reports.
Reflection on what has been learned, what still needs to be sorted out, and what new and interesting problems have arisen.	Reflection on agreed ideas, what is still uncertain, and what new strategies need to be explored to meet new needs.

At every stage of the procedure, decisions are made collaboratively. The process of decision making is refined and based more and more authentically on democratic participation. The extent of the commitment of all participants to the process is an excellent indicator of their acceptance of shared responsibility for what is learned as well as how it is learned.

Advantages of this approach

Studies showing that teachers have misconceptions about science and technology (e.g. Summers & Palacio, 1989), and our own observations, indicate that teachers hold a wide range of views about the meaning of terms such as "hands-on science", "problem solving", "recording outcomes of investigations", and even "developing a science program". As the LISP team found, such misconceptions have far-reaching implications for further learning if not challenged.

An interactive approach to in-service takes all such views into account, i.e. it enables all views to be shared, challenged and reflected upon. All teachers are encouraged to reflect not only on their personal knowledge, skills, techniques, resources and needs, but also on where these ideas have come from.

It should be noted that while some teachers believe their knowledge about key science concepts is "adequate", many have deep fears about this. The approach we have taken is to assume that feeding them "more of the same" content-based science would be a waste of time. We have therefore always introduced key concepts, principles and laws in the context of the activities they are doing or planning. *What have you learned from this*? has been a focal question for discussion and reporting throughout each activity. Most have been surprised how much they do know, and all have expressed greater confidence about being able to understand the main ideas set out in the Teacher's Notes in the resources they are using, or in references. Nonetheless this remains a concern.

Activity-based learning.

The in-service sessions were activity-based, but the activity did not stand alone, as it also provided a vehicle for teachers to address some of the in-service education needs which they had expressed when planning the program for the day. No activity was ever used without these "hidden purposes" being spelled out, along with reasons for choosing the activity, and the original source from which it came. Whenever possible there was also discussion about other curriculum implications such as developing of a sequence of activities in the vertical and/or horizontal curriculum, and how the "ideas of the day" could best be introduced to other teachers.

In maintaining an interactive learning environment, we kept in mind the guidelines of the LISP team:

> Children can begin to take responsibility for their own learning, but this requires an atmosphere where both teacher and pupils genuinely care about and respect each other's ideas, ... (Biddulph & Osborne, p 9).

Focus teachers have frequently commented favorably on the caring environment permeating the Sci-Tec Project. This is due in large measure to the approach taken by Yvonne Zeegers as Project Co-ordinator.

CHARACTERISTICS OF EACH PROJECT

While the model has some of the features of the trainer of trainers model, it differs in a number of respects. The "trainers" operated from a non-deficit model and did not see their role as providing "the answers that the focus teachers lacked". Uppermost in the minds of these "trainers" was the need to develop the focus teachers' ability to analyze the various in-service activities and see their potential for the classroom and for future in-service. Each activity was perceived as a model for reflecting on classroom practice rather than a particular "trick" to be replicated with a class. This philosophy is a fundamental tenet of all three projects.

If anything, the two non-government schools projects have been more committed to an interactive model of in-service than the state school project. This has probably come about as experience and confidence have grown.

State schools project.

The project was planned to operate over three years. In 1988-89 focus teachers developed science and technology programs in their own classrooms and began to offer in-service activities to Year 5 to 7 teachers in their own schools.

During 1989-90 each focus school encouraged two key teachers from up to five neighboring schools to share their expertise in science and technology teaching, and to identify their needs. The focus teachers continued to support these key teachers who in turn worked with their Year 5 to 7 colleagues to plan and implement science and technology activities appropriate to their classrooms.

In Term 2 1989, six disadvantaged schools became focus schools. As these six schools were then almost twelve months out of phase with the original 24 focus schools, this initially caused some difficulties but by July 1990 they had been blended into the total project.

1990-91 will follow a similar path. Each school takes on a new group of up to five schools, continues its own professional development, and acts as an on-going support centre for the 1989 schools. Local support networks, including all Sci-Tec schools in each District, will be established. This means that more than half of all primary schools in South Australia will be taking part in the project.

A detailed description of the SACAE/S.A. Education Department Sci-Tec Project can be found in a paper presented at the Sixth ICASE-Asian Symposium held in Brunei Darussalam (Note 1).

The Independent Schools Board Sci-Tech Project

While this project is similar to the Sci-Tec Project, it differed in two fundamental ways:

* The teachers would be drawn from the whole primary range and would in-service the whole school staff and not just teachers teaching in the same range.

* Funding was provided by individual schools and the follow-up funding would vary widely. (The biggest expense in all projects was buying in relief teachers to release focus teachers for in-service activities.)

The Catholic Education Office Disadvantaged Schools Sci-Tech Project

This project proved markedly different from the state project and the ISB Project in the following ways.

* The in-service program was delivered to whole school staffs from three different Catholic schools. Therefore there was no concept of a focus teacher in the CEO Sci-Tech Project.

* The schools had very limited funds with which to purchase curriculum materials and equipment to follow up ideas developed during the in-service phase.

* The teachers attending were not volunteers in the sense that the teachers in the two other projects were, and were not necessarily interested in teaching science in their respective schools. Thus teacher librarians, ESL specialists and the like were involved.

Common characteristics.

Each project began with an intensive in-service program and regular meetings of the teachers were held to maintain the momentum of the projects. Each school in turn hosted the meeting and was responsible for the agenda. This in itself was valuable as it enabled the teachers to gain a perspective of the different situations in each school. It also improved communication between them as they contacted "host" schools with suggestions for each agenda.

Each meeting began with an activity/resource sharing session, and was followed by a sharing session about the progress of the project in each school. As problems or issues of mutual interest arose, they were discussed at length, with various strategies being aired to help provide solutions to the problems. These were the times when the mutual support network, established during the intensive workshop days, really proved its worth. It was not the views of the authors which were noted and acted upon, we merely became another voice in a discussion and not the authority.

The meetings have proved to be one of the most successful strategies developed in the projects. They fulfil two important functions viz. providing the continuing mutual support that the teachers need for them to act effectively as change agents in their schools, and enabling the *esprit de corps* generated at the intensive in-service course to continue throughout the life of the project.

SOME OUTCOMES OF THE PROJECTS

At this stage it would be premature in the extreme to produce any summative report about any or all of these projects. The State Education Department project has barely entered Phase 3 (and funding continues for Phases 1 and 2 until July 1991) and neither the I.S.B. or C.E.O projects have begun their respective 'in classroom' phases. However it is timely to reflect briefly on certain outcomes.

It seems obvious to us that an interactive model of in-service requires that data about in-service outcomes should be generated and collected interactively. Teachers who have learned to value the necessity of clarifying concepts, questions and procedures used in investigations before assessing the outcomes of these investigations, are not likely to respond kindly to being asked to "fill in the blanks" in a questionnaire framed in someone else's terms, and concerned with someone else's agenda. There are problems however in collecting, collating and analyzing relevant data, when the Sci-Tec Project has only one 0.5 time Project Co-ordinator and a couple of unpaid volunteers to do the work.

Early evaluations

During the in-college in-service week conducted at the end of the first six months of the project, a "participant evaluation" was conducted by Dr. Mike King (University of New England). He worked closely with all participants during the five days, interviewed twelve focus teachers and two principals, and had access to the newsletters, journal entries, written reports and agendas of Area meetings which had been collected from all participants throughout the project. This documentation had served well our aim of shared participant decision making and this process has been continued throughout.

Dr. King indicates on page 10 of his report that this information guided his evaluation of this early stage of the project:

> It became clear, very quickly, that the participants had enjoyed a carefully planned and very rewarding professional experience... From an evaluator's perspective it meant that it was possible to ignore the rather superficial "What went wrong?" aspect of an evaluation (as little to this point seems to have gone wrong) and to pass on to higher order issues of planning and future developments. (Note 2)

Subsequent monitoring of the project.

Following Dr. King's recommendation, on-going data collection and participant decision making have continued as key elements of Phases 1 and 2 of the project. Throughout this time all participants have decided collaboratively what data should be collected and how they could be collected and analyzed most effectively. An example of this lies in the listing of the ideas the focus teachers deemed most important when providing in-service education to teachers - dubbed 'Focus Folklore'. We began by asking participants what they had found most helpful. Eventually it came down to a list of eight items:

FOCUS FOLKLORE

1. Model what you want them to do (e.g. interactive approach).
2. Work alongside (neither pushing nor dragging).
3. Begin from their problems and what they want to do.
4. Make available the resources they want.
5. Encourage mutual support (on-going).
6. Model and encourage self-evaluation based on recorded classroom practice.
7. Seek overt and tangible support from Principal.
8. Find an ally.

Many pages of feedback from the focus teachers were reduced to these simple guidelines as the information was analyzed by the teachers involved in Phase 1 and 2 in-service. Thus, this process of shared decision making has produced powerful and succinct evidence of successful in-service.

REFLECTIONS

Similar outcomes have been evident in the early stages of all three projects despite the great differences between their purposes, funding and scope. This tends to indicate that the model works well in the introductory phase as teachers reflect on the range of activities, strategies and resources they need to teach science and technology in their classrooms in a manner which they, their colleagues and their pupils see as effective. Preliminary indications from the interim reports on Phase 2 which focus teachers submitted recently (based on criteria they selected), suggest that the model may also be effective in enabling teachers to feel competent and confident in providing in-service to their colleagues.

At the end of two years, only two focus schools have been forced (by substantial changes in key staff) to give up their focus school in-service function. In both cases this has been taken up immediately by a Phase 2 school in the District. Perhaps this, along with the avalanche of evidence showing that many more children are doing and enjoying materials-based science, is the strongest indicator of success so far.

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SCIENCE EDUCATION RESEARCH IN PAPUA NEW GUINEA 1978-1990

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ABSTRACT

This paper presents a science/science education bibliography, to assist science educationalists interested in Papua New Guinea. 392 articles were reviewed. The bibliography was then categorised in a number of ways to indicate patterns of research productivity in various areas of science education, and at different levels of education. A questionnaire was devised to obtain information from former and current researchers in the field about their own contributions. This exercise produced some surprising information about science education research in Papua New Guinea.

INTRODUCTION

For a country with a population of three million and a land area of 460,000 square kilometres, Papua New Guinea has a number of features which make it scientifically and educationally fascinating. Its scientific interest stems from the fact that in geological terms it is a very young and active area, because it is at the junction of two of the earth's major plates. This partially accounts for the country's mineral wealth and also for the amazing diversity of its flora and fauna. The country is made up of many islands, spread over a huge area. The archipelago possesses some beautiful unspoilt coral reefs and bountiful marine resources. The population of the territory is also extremely diverse, presenting administrators with unique educational problems when organising an educational system.

Because of the fundamentally interesting nature of Papua New Guinea's educational system and the country's scientific diversity, it was felt that the task of constructing a general scientific and science educational bibliography would be well worthwhile. This bibliography consists of a listing of articles/research relating to science education, agriculture, science, technology and society issues and pure science (generally comprehensible to a year 12 science student) for Papua New Guinea between 1978 and the present.

This paper describes the compilation of the bibliography and also describes the changing methods used in overviewing science education research, linking it to the methods used elsewhere. A second aim is to analyse the amounts of research produced in different periods in different topic areas with a view to observing if any patterns in research productivity can be found. Thirdly, the results of a questionnaire sent to researchers known to be or to have been interested in this area will be discussed. Finally, it is suggested that this study could be a model for a bibliography of science education research in Australia.

INTERNATIONAL RESEARCH ON SCIENCE EDUCATION

Internationally, there is considerable literature overviewing research into science education; this literature varies in style, purpose and methodology. Some of these overviews are broadly based whilst others relate to specific topics, branches of science or individual countries. The author will refer to a number of such surveys published over the past two decades, which he has found of interest and which allow the reader to see this paper in context.

An early overview by Whitfield (1972) defines chemical education research in a UK context. Modifying his definition, science education research can be defined as implying a dispassionate enquiry into any aspect of the teaching and learning of science at any stage of education.

The Kiel conference of 1977 produced some useful reports on the state of science education research in different European countries. Keohane (1977) overviewed European research in science education by categorising it into groups indicating major European projects being carried out in these categories. These categories proved to be a useful starting point for the current overview. Delacote (1977) points out the difficulties of career paths for science educational researchers in France at that time, many of which could equally relate to Papua New Guinea today. In the UK, Kempa (1977) stressed the need for the active translation by teachers of educational research findings into meaningful practical action. This proposition remains one which is difficult to apply in practice.

Articles about chemical education research include those by Johnstone (1978), Kornhauser (1979), Fensham (1984) and Dawson and Letton (1989). Kornhauser refers to some two hundred and fifty papers on chemical education whilst Dawson and Letton provide a bibliography of UK science education theses from the late sixties to the present time. Physics education research appears to excite less interest but Le Grande (1967), Larkin (1981) and Terry and Williams (1982) provide good starting points. Much biology education research of the 1970s is summarised in Ayres (1982), whilst for junior science a recent bibliography of integrated science teaching (Reay, 1990) is helpful.

Kempa (1976) suggests that the direction of science education research should not be dependent on curriculum development as a justification for its existence. In developed countries science education research is justified in its own right, though its major aim of improving the practice of science teaching should never be forgotten. In developing countries, generally and in Papua New Guinea, in particular, the curriculum development link remains powerful.

Recent papers by Shymansky and Kyle (1988) and Brunkhorst and Yager (1986) indicate the vastly increased scope and vision of science education as it is developing in the eighties. There have also been a number of recent single country or regional overviews of science education research, of which the current paper is one, such as Martin and Giordan (1989) (France), Tamir (1989) (Israel) and Fraser-Abder (1989) (Caribbean) with the two last-mentioned of these being particularly valuable.

Both these papers have attempted to list all the science education research carried out in a country or region and have examined the data produced to see what patterns or deficiencies in science education research may be observed. The author believes that this method offers considerable advantages over the more random surveys of the past and that it has the capacity to supply useful information which should be used to benefit science education.

RESEARCH IN SCIENCE EDUCATION IN PAPUA NEW GUINEA

A key conference for setting directions for educational research took place in 1982 at the Faculty of Education of the University of Papua New Guinea. The opening address by Roakeina (1983) (Acting Secretary for Education) laid the ground rules which for him as an administrator had to be very practical - he wanted research that was comprehensible to administrators and which could be used to help educate children more efficiently.

The main thrust of science education research has been towards producing materials for the Curriculum Unit of the National Department of Education and in broad terms this effort has produced about one third of the total science education effort. (An addendum of most curriculum unit materials, from 1978-1985, containing 134 references, has been prepared separately). Government thus sees science educationalists as being needed for basic curriculum tasks; indeed one conclusion of the 1982 Research Director's Conference was that educational research should be policy and action orientated (Guthrie & Currin, 1983, p 192).

A second influence on science education researchers can be traced from pure science research. In 1984 it was the turn of the science faculty of the University of Papua New Guinea to hold the Waigani Seminar. This acted as a stimulus for research, but also a stimulus for communicating the results of scientific research to the populace in general. The Seminar also pointed out that the government had no science policy for the country, but unfortunately the seminar was unable to persuade government to take any action on this matter whatsoever, and there is, to date, no national science policy for Papua New Guinea.

A SCIENCE EDUCATION BIBLIOGRAPHY: COMPILATION

Many bibliographies of either science or science education, some relating specifically to Papua New Guinea, already exist and the author has made use of a wide variety of sources. In particular, the following New Guinea references have been utilised: Wilson and Wilson (1978), Cleverley and Wescombe (1979), Wormsley (1981), Crossley (1985), Wilson and Wilson (1986) and King (1988). In addition, many journals have been searched for relevant articles and many conference papers from international and PNG conferences have been obtained. Outside Papua New Guinea, the author has searched likely journals; Current Contents in the physical sciences, biological sciences and agricultural sciences has been searched for the last few years; reference has been made to the bibliography in the Journal for Pacific History (1989); the British Educational Index, the Australian Educational Index, Wilson's Index, ERIC and the CSIRO science index have been searched; finally three computer searches have been made through A.E.I., B.E.I, and E.R.I.C. In addition, almost fifty science educationalists who were

known to have written about P.N.G. were sent a questionnaire asking for details of their own publications.
So far 392 publications have been identified; more are still coming to light. Some comment on the various methods used to find bibliographic material may be of interest. The Papua New Guinea educational bibliographies were an excellent starting resource. The three bibliographies cover the period 1979-1985 with increasing sophistication and coverage in each successive publication. The Wilson and Wilson (1978) science education bibliography, which was quite detailed up to 1977 provided a major reason for choosing 1978 as a starting year. The Wilson and Wilson (1986) select bibliography was also helpful, but it did not attempt to be inclusive. Current Contents provided pure science and pure agriculture usually outside the scope of educational indexes, but it is hoped that these references will be of value to educationalists wanting an overall view of P.N.G. science. Unfortunately only the more recent Current Contents have been utilised. The CSIRO science index was useful but ceased publication in 1984 with decreasing usefulness in the final years. The major standard developed country indices and the computer searches derived from them, exhibited the usual arrogance of developed countries in that they list comparatively little of the work going on in developing countries. Nonetheless each search produced one or more articles not listed elsewhere. It will be seen however that not all periods of time in all journals or indices, have been searched equally either through unavailability of resources or of time and this has been a weakness in the compilation of this bibliography.

The criteria used for selection have been difficult to utilise consistently so there will be a measure of idiosyncrasy in the bibliography. A general wide-ranging index was the aim, which should include all aspects of science, technology, agriculture and health as well as science education. Specialist science articles which were not too technically written were acceptable (being comprehensible to a year 12 student was the criterion) though in areas where no general articles were found more complex articles were accepted. Articles in popular geographic/scientific magazines were also acceptable and these are often written by research experts trying to communicate with the public. A further aim was to leave no scientific area of Papua New Guinea life unreferenced.

THE BIBLIOGRAPHY: SOME ANALYSIS AND BACKGROUND

The numbers of papers produced on a yearly and on a two-yearly basis were obtained after compiling a listing of articles by year of publication. A very rough estimate of the numbers of mentions of P.N.G. nationals as authors or part authors has also been made. It must remain only an estimate as the nationality of authors is not usually included in the articles, but it is important that the indigenous input of research of all areas including science education be included. There was a definite increase in output of relevant articles produced between 1978 and 1984, reaching a maximum in 1984-85. after which the annual numbers of articles published have declined rapidly, now being just above the 1978 figure. This could be a mere artifact of the method of compilation, as it could be argued that in earlier years less research was published, there being less emphasis on publication within universities at that time, whilst information about later publications has not yet become available. This is possible, but in the author's view the build-up in enthusiasm for science education was a real phenomenon with the 1984 Waigani Seminar encouraging both overseas and Papua New Guinean academics to engage in and publish research. This enthusiasm led to further conferences and it was also the time when the Papua New Guinea Institute of Chemistry (a major scientific society) was founded.

National academics have been very much a minority in P.N.G. tertiary education, but the proportion of nationals has steadily increased, particularly in recent years. In the early years, nationals held junior positions within tertiary education with the higher teaching loads and relative lack of opportunities for research that this entails. However this situation has changed with more nationals in senior positions but the amount of research done by nationals does not appear to have increased. Science education does have special difficulties in that the salaries and career structure available to nationals who are both good scientists and also good educationalists are better outside the tertiary education system. It has over the years, for example, proved excessively difficult to localise even some of the science faculty positions at Goroka Teachers College, so the training in research techniques of nationals involved in science education has yet to begin at that institution.

BIBLIOGRAPHY AND CONTENT AREA

As has been previously stated, the references listed in the bibliography contain varying proportions of pure science and science education. Generally papers which contain some educational component have been classified as science education, whilst only those papers with no educational component have been classified as pure science. Table 1 classifies all papers as being pure science or science education and also classifies them by broad content area. Overall 157 papers (about one third of the total) were classified as pure science papers, and the remainder were classified as science education. Papers were also divided into 17 subcategories relevant to the speciality within science being considered.

TABLE 1
NUMBERS OF PAPERS WRITTEN IN EACH CONTENT AREA BETWEEN 1978 & 1990

	Numbers of papers		
Field	Pure science	Science education	Total
Science	6	88	94
Agriculture	11	28	39
Biology	38	6	44
Environment	6	4	10
Chemistry	16	27	43
Physics	1	18	19
Technology	24	26	50
Food technology/nutrition	8	3	11
Health/medicine	13	4	17
Geology/geography	12	1	13
Mining	17	4	21
Astronomy	1	0	1
Psychology	2	6	8
History of science	0	4	4
General	1	2	3
Anthropology/pre-history	1	2	3
TOTALS	157	235	392

Areas where there has been a lack of educational research do become very clear from these data. Biological education is under-researched, which is surprising in that biology has been considered a more popular science amongst nationals than the physical sciences. Geology education, mining education, astronomy education, history of science and basic educational psychology as applied to science education, all appear to be neglected areas. One problem with this sort of analysis is that it is tempting to look at the number of publications in each area forgetting that it is not just the quantity of research that is important but also the quality.

One way of assessing quality would be to look at the form of publication of each of the papers. For research purposes an academic Ph.D thesis is likely to be the most useful form of publication for future researchers, then a Master's thesis, followed by articles in refereed journals, followed by conference papers, with articles in non-refereed journals generally being considered the least useful type of publication. Using these criteria there is some weakness in terms of the quality of educational research carried out in PNG. There are only eight theses relevant to science education over the past 13 years, two at doctoral level and the remainder at Master's level. Two of the Masters theses were obtained by PNG nationals and the remainder by overseas nationals. Science education is thus under-researched at this level. Of the remaining references probably about one third are from books or refereed academic journals, whilst the majority of all publications quoted are from non-refereed journals or are conference papers. However it is for the reader to extract further detail from the bibliography on a subject basis as this can provide further evidence of strength or weakness in particular areas.

Further analysis was carried out to investigate the amounts of educational research at each of the levels of education. If we look only at the science education research which was clearly focussed on a particular level of education (196 references), then at a primary (community school) level 13% of references related to this level whilst it may be pertinent to note that 63% of Papua New Guinean children of this age group attend school (Bray, 1984, p.74). At the lower secondary level, 17% of the age group attend provincial high school (ibid.) but 27% of the science education research is aimed at this level of education. At the Upper secondary/tertiary levels there is a concentration of science education research (59% of the total references) whilst the percentage of the age group attending institutions at this level is below 3% (an estimate from census figures and CHE 1983). The overall conclusion from these results is that not enough research is being done in science education at the primary level.

THE CONTRIBUTION OF SCIENCE EDUCATION RESEARCHERS

About fifty requests for information were sent to people who had been or currently are active in science education research in Papua New Guinea. Fifteen replies were received and these have been extremely helpful in providing additional items for the bibliography and particularly in producing information about articles about to be published. Generally researchers remain interested in science education in Papua New Guinea, though a number still see research as a luxury even though they may themselves have contributed towards research in a number of ways. The replies will be analysed in more detail later perhaps when a higher return is received.

CONCLUSION

The work described in this paper had four major aims. The first was to compile a wide-ranging science education bibliography for PNG. The second was to analyse the bibliographic data; limited analysis has been carried out which indicates that:

* the amount of publication in science education reached a maximum in 1984/85;
* national academics may not be keeping up the levels of publication achieved in 1984/85;
* science education research is attracting very few people into masters or doctoral programmes involving Papua New Guinea science education research;
* areas of weakness in science education research include biology education, geology education, mining education, history of science, astronomy education and basic educational psychology.
* primary science education is under-researched.

The third aim was to send a questionnaire to interested persons. This was accomplished but there was insufficient response to undertake a detailed analysis at present. The fourth aim was to indicate that useful findings can be extracted from publicly available bibliographic data, using the case of Papua New Guinea as an example. It is hoped that as a result of this paper others may share the opinion that the creation of an Australian science education bibliography would be a worthwhile task.

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ABORIGINAL STUDIES AND THE SCIENCE CURRICULUM: AFFECTIVE OUTCOMES FROM A CURRICULUM INTERVENTION

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ABSTRACT

The study of Aboriginal culture in schools is supported by an increasing number of educators and government committees. However, in the absence of substantial research evidence, it has been difficult to propose justifiable curricular recommendations. The results of this exploratory study suggest that student attitudes towards Aborigines and Aboriginal culture can be improved by a science program which features an Aboriginal Studies component. Further, it is suggested that there is scope for the development of up-to-date curriculum materials and more comprehensive studies.

INTRODUCTION

In the last decade, many Australian educators (e.g. Barlow, 1982; Larsen, 1977; Watts, 1981) have argued that the problems of racism and prejudice with respect to Australian Aborigines should be redressed by teaching all school children about Aboriginal culture in all subjects across the curriculum. However, in the absence of substantial research evidence, it has been difficult to propose justifiable curricular recommendations. This paper reports the results of an exploratory study on the impact of a science course which featured Aboriginal content, and proposes recommendations for further curricular development and study. Before addressing these issues, a rationale and brief outline of the curriculum intervention are described.

RATIONALE FOR INCLUDING ABORIGINAL CONTENT IN SCIENCE

The major reasons advanced for implementing courses about Aboriginal culture in schools have included: to foster a greater understanding and tolerance of Aboriginal society and culture (HRSCAE, 1985); to maintain a holistic and balanced view of Australian society (Scott, 1986); and, to enhance the perceived relevance of the school curriculum for Aboriginal students (Watts, 1981).

There is a wealth of interesting and relevant information available which could be used in science courses (Scott, 1986). For example, Young (Note 1) identified the areas of astronomy, technology, flight, and environment, all of which lend themselves to an Aboriginal perspective. A much more comprehensive list was provided by the ACT Schools Authority (1986). In the most recent discussion of science topics related to Aboriginal culture Bindon (1988) examined how Aborigines used fire, natural resources, and principles of what Europeans called physics, to cater appropriately for the exigencies of their lives. If science teachers included topics such as these in their courses, Scott (1986) argued, students might be able to reject folklore about Aborigines and appreciate the diversity of practices and lifestyles of the original Australians.

THE CURRICULUM INTERVENTION

The course was implemented in a senior (Year 12) Applied Science class over a 12 week period. This non-tertiary bound class was suitable for this exploratory course because the teacher had a great deal of flexibility in choosing the content for his students. The Australian Science Education Project (ASEP) (1974a) unit Australians - Past and Present, although outdated in places, was used as a basic students' resource because, as its name suggests, it contains a blend of traditional and contemporary Aboriginal emphases. This blend is considered desirable by several authorities (e.g. HRSCAE, 1985; Watts, 1981) who argue that by restricting Aboriginal Studies to a traditional perspective only, a distorted view of Aboriginal and Torres Strait Island people is presented.

The content and approach of the course were developed in recognition and respect for the minority group of Aboriginal students who were expected to participate. Therefore, some of the ASEP unit's activities (e.g. Activity 4: Nose Shape, pp. 30-31) required sensitive treatment in class and a number of other minor sections of text required corrections (i.e. p. 58 & p. 106 - reference to "little technology"). Several topics referred to briefly in the text were suitable for developing supplementary activities. One example of a supplementary activity developed for this course was Music from the "didjeridu" (Smith & Ellerton, 1988).

Descriptions of the nature and impact of ASEP's philosophy and approach to science teaching have been well documented (ASEP, 1974b; Fraser, 1978; Owen, 1978), and therefore will not be discussed again here. In addition to the ASEP unit and supplementary activities, the volunteer teacher was provided with artifacts from the Queensland Museum to use in the course.

PURPOSES OF THE STUDY

Attitudinal outcomes have been the focus of concern for advocates of Aboriginal Studies courses (e.g. HRSCAE, 1985). However. the only empirical studies which have been published to date (Larsen, 1977; Tatz & Chambers, 1973) have been restricted to samples of student teachers undertaking compulsory race and culture courses in tertiary institutions. In these studies, significant and positive attitudinal outcomes towards Aborigines were measured. Results of the effects of Aboriginal Studies courses in secondary and primary schools have been limited to teacher anecdotal records. In an evaluation of an Aboriginal Studies course operating in a group of lower secondary classrooms in South Australia (Port Augusta Secondary Interschool Aboriginal Studies Faculty, 1982), for example, non-Aboriginal students were reported to have developed greater respect and tolerance for Aboriginal culture. Because none of these published Aboriginal Studies courses featured a science focus, it was important to explore widely the student attitudinal outcomes of the intervention. Therefore, the primary purpose was to document changes in students' attitudes towards Aborigines, Aboriginal culture, and the subject (of science) during their participation in the course.

Classroom environment has been an important predictor for the success of various science programs (e.g. Fraser, 1986). For example, dimensions of psychosocial environment were used to evaluate a science-bridging program, which featured similar approaches to ASEP units, designed for both Aboriginal and non-Aboriginal students (Ritchie, 1987). Improved perceptions of satisfaction for participating Aboriginal students were reported in this study. Lippmann (1978) also has argued that classrooms involving Aboriginal students are likely to foster harmonious interpersonal relationships when their teachers are warm and responsive and where the students plan and act together in a cooperative spirit. In recognition of the usefulness of assessing the impact of innovations on learning environments, the second purpose of this study was to document changes in students' perceptions of their learning environment during their participation in the course.

METHOD

Participants

A large urban high school was selected as the setting for this study not only because there have been few studies involving Aboriginal students in this context, but also because the staff were considered (by the Aboriginal and Islander Education Branch) to be generally sensitive to the needs of their Aboriginal students. A total of 17 students (9 male, 8 female) completed the course. Of these, four students were Aboriginal, three of whom were female.

Procedures

Two instruments (namely, the Personal Images of Aborigines and Social Distance scales) developed by Tatz and Chambers (1973) to measure student teachers' attitudes to Aborigines were administered pre- and post-intervention to participating students in this study. Analysis of data from these scales (not validated for the study participants) did not reveal any statistically significant changes in attitudes. This null result was contradicted by the results obtained from the qualitative procedures used thus suggesting a need to develop more sensitive and relevant instruments. The following qualitative procedures were used in this study:

Diaries The students were asked to record comments (e.g. difficulty, relevance) about the implemented course at the end of each option or theme in a diary. In this way, the immediate concerns of the students were recorded in some detail.

Interviews A representative sample of nine students were interviewed separately on completion of the course. Five of these students were girls of whom two were Aboriginal. While the interview format was fairly open ended, the questions asked reflected the nature of the purposes and the major issues raised by each student in his/her diary.

Observations. Eight lessons were observed during the course in order to document the classroom implementation of the course. Observation data provided a source of information from which some interview questions were developed.

DISCUSSION OF RESULTS

A number of comments made during the interviews suggest that, in a few cases at least, changes in attitude appeared to have occurred. One non-Aboriginal female reported that her relationships with Aboriginal people had changed as a result of her studies: "I'm not scared of them any more...I'm more confident with them." In another case, a non-Aboriginal male was able to appreciate the relatively advanced (i.e. context appropriate) nature of traditional Aboriginal material culture, just as Scott (1986) had predicted:

> [Before the course] I thought that they [Aborigines] were real primitive and that. Like they just sort of didn't do very much and that... When I did this [course] I found out that they were painting, sort of making all their tools and that and getting the right [mixtures] for their paint and that... For the age they were in, they were modernized.

The intervention seemed to have a slight positive impact on the attitudes of the Aboriginal students who participated. One of the female students admitted that she enjoyed reading about "things that I never even knew" such as "kinship and family relations." Both Aboriginal females interviewed suggested that they would like to learn more about Aboriginal culture in science, identifying areas such as traditional food, technology, and family relationships for further treatment. Perhaps there is a need for the development of up-to-date science materials which include these topics.

Seven of the nine students interviewed reported that they found the course interesting or satisfying. Analysis of diary entries provided additional supporting evidence. Similar results were obtained from an action research study (Ritchie & Kane, 1990) which focussed on the implementation of Aboriginal content in a Year 8 science program. Together, these results suggest that non-Aboriginal students as well as Aboriginal students are likely to find science related studies of Aboriginal culture interesting.

All students at one time or another (during interviews or through diary entries) commented that the work was conceptually easy. Student perceptions regarding the low level of difficulty in the course may have been exaggerated because the teacher was hampered initially by the late arrival of the ASEP units. Consequently, the pace of the course was slower than planned. Many students expressed a preference to be given more opportunities to work through the course materials independently. By encouraging students to work at their own pace, the level of difficulty of the course might have been perceived as more appropriate by these senior students. In spite of this recommendation, the course is likely to be more appropriate for younger, junior science students (i.e. for whom the ASEP unit was designed).

CONCLUSION

Although only a few students were involved in this study, the results provide a useful base from which to launch more comprehensive investigations. Before large-scale studies are designed, there is a need to develop relevant instruments to measure student attitudes to Aborigines and Aboriginal culture. The sorts of comments made by students in this study might be useful in guiding the development of appropriate items.

This study has provided some evidence to suggest that Aboriginal Studies in science, for some students, fosters attitudinal changes. Continued formal research into the effects of Aboriginal Studies programs might make a much needed contribution to developing a pedagogy appropriate for teaching Australian students about Aboriginal culture. Watts (1981, p. 1131) alerted researchers to the need for such studies by writing:

> We need to note the absence of a verified pedagogy appropriate to the teaching of Aboriginal Studies to Australian children of varying ages, belonging to various cultural groups, living in various socio-cultural environments, by teachers and community members of varying attitudes and backgrounds. The most well-conceived curriculum content will prove barren without its implementation through effective and appropriate teaching - learning experiences. In the coming decade then there is a strong case for the allocation of resources to development work in this area.

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EFFECTS OF BACKGROUND AND CLASSROOM CHARACTERISTICS ON THE SCIENCE ACHIEVEMENT OF 10-YEAR-OLD STUDENTS

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ABSTRACT

Effects of characteristics of science classrooms on the science achievement of students were examined in the context of a simple model. The model incorporated prior attributes of the students in terms of home background, sex, and verbal and quantitative ability.

The model was estimated by means of partial least squares multivariate procedures using data for 10-year-old Queensland students from the Second International Science Study. The results demonstrated the dominant influence of home background and verbal/mathematical ability. Female students tended to have lower scores after allowing for the influence of the other variables in the model. Students who stated that there were more student initiated activities in their science lessons tended to have lower achievement.

A MODEL OF ACHIEVEMENT IN SCIENCE

In pursuit of its aim to provide a comprehensive description of student learning in science, the Second International Science Study collected a range of information about 10-year-old science students in Australia, including students' perceptions of the activities that took place during science lessons. This article presents a simple model to examine relationships between these perceptions of classroom activities and the science achievement of the students. After describing the model, procedures for estimating the model are outlined and the results are discussed. The role of a model is to identify the factors that affect the criterion, and show the relative strength of the relationships between the factors and the criterion. In a causal model of the kind developed here, it is assumed that some of the factors cause or determine other factors. This involves setting the factors in a temporal sequence, so that factors earlier in the sequence are assumed to influence factors later in the sequence, but that later factors do not influence earlier factors.

The criterion used in this model is science achievement. The explanatory factors are deemed to influence the criterion of science achievement, both by means of direct links from the factor to the criterion and also by their indirect influence on other factors in the sequence. The model assumes that differences in the science achievement of the students initially depend on differences in their background, including their sex and the social-intellectual environment of their homes. These factors are therefore included in the model as part of the explanation of students' science achievement, representing basic circumstances of the students that the schools must consider when preparing instruction. The other background factor included in the model is the student's ability, which is largely influenced by home background. These three background factors - home background, sex and ability - represent attributes that the student brings to the school learning environment, influencing the student's capacity to profit from the learning experiences offered by the school. The final group of factors describe aspects of the instructional processes taking place in the science classroom.

MODEL ESTIMATION PROCEDURES

The process of estimating the model involves assigning variables to measure the factors, and then using statistical techniques to estimate the magnitude of the paths that link the explanatory variables to each other and to the criterion variable. The estimation of the model described here used a form of regression analysis termed 'partial least squares' (PLS). A detailed introduction to PLS is given by Sellin (1986), who indicates that: "In general, PLS is useful in research situations where exploratory model analyses without restrictive distributional assumptions would seem appropriate"(p. 194). In the terminology used by PLS, the model proposed for this study consists of several blocks of variables, which are termed 'latent variables'. A latent variable is one that cannot always be directly observed or measured, but which exists as a concept defined by the theory underlying the model. Associated with each latent variable are one or more 'manifest variables', which represent the observations or measurements collected for the purposes of estimating the model.

One aspect of the estimation of the model involves examining the relationships between the latent variables. This set of relationships is termed the 'inner model'. The strength of the relationships is shown by the standardised regression coefficients, with associated standard errors estimated by jackknife procedures. Another aspect refers to the 'outer model', which describes the relationships between the manifest variables and the latent variables with which they are associated. The loading for each manifest variable indicates its correlation with its associated latent variable. Standard errors for each manifest variable may also be estimated by jackknife techniques.

For each latent variable, the relationship with the constituent manifest variables is described as 'inward', 'outward' or 'fixed'. In an outward relationship, the manifest variables are considered to reflect the latent variable, analogous to the situation in factor analysis where a factor is defined to reflect the constituent variables. In an inward relationship, the manifest variables are considered to produce or determine the latent variable, analogous to regression analysis. Where only one manifest variable is used to describe a latent variable, the relationship is fixed.

POPULATION AND SAMPLES

The sample used for these analyses consisted of 10-year-old students in Years 4, 5 and 6 in normal schools in Queensland at the time of the testing program in October 1983. Students were selected by a two-stage probability procedure. Schools were selected at the first stage of sampling with a probability proportional to the size of the target population in each school. Students were selected at the second stage of sampling as a random cluster of 24 students from each of the selected schools. The achieved sample for Queensland contained a total of 780 students from 41 schools. Further information about the sample is in Rosier and Banks (1990), with more details in an associated technical report (Rosier, 1989).

COMPONENTS OF THE MODEL

Table 1 lists the latent variables used in the model, their constituent manifest variables, and the direction of the relationship. The criterion latent variable Science Achievement was established by the manifest variable Science Test Score, based on a 40-item multiple-choice test (Note 1). The variable Home Background was entered into the model as a composite variable, reflecting the occupation of the student's father, the education of the student's parents, and other variables associated with the intellectual environment of the home (Note 2). The variable Sex Of Student was entered as the second latent variable at the initial stage of the causal model. Home Background and Sex Of Student were assumed to be exogenous variables, influencing all subsequent latent variables in the model. The background characteristics that the students bring to the learning of science at school include their ability. Although still regarded as a background factor, ability was considered to be located at the next stage in the causal sequence after the home background and the sex of the students. That is, ability was assumed to be influenced by Home Background and Sex Of Student, but not to influence these two exogenous variables. For this model, two manifest variables were included in the latent variable Ability, measured by students' scores on two cognitive tests: Word Knowledge Test Score and Mathematics Test Score (Note 3).

TABLE 1

LATENT AND MANIFEST VARIABLES IN THE MODEL OF SCIENCE ACHIEVEMENT

Latent Variable	Manifest Variable	Direction
Home Background	Home Background (Low = 1, High = 5)	Fixed
Sex Of Student	Sex Of Student (Male = 1, Female = 0)	Fixed
Ability	Word Knowledge Test Score (Range: 0-40)	Inward
	Mathematics Test Score (Range: 0-20)	Inward
Practical Work	Students Do Practical Work (Often = 1, Sometimes = 0.5, Never = 0)	Outward
	Practical Work In Small Groups	Outward
Teacher Initiated Learning	Copy Teachers Notes From Blackboard (Often = 1, Sometimes = 0.5, Never = 0)	Outward
	Tests On Learning Science	Outward
	Teacher Makes Science Lessons Interesting	Outward
Student Initiated Learning	Use Of Library Books (Often = 1, Sometimes = 0.5, Never = 0)	Outward
	Students Have Choice Of Topics	Outward
	Teacher Uses Student Ideas For Lesson	Outward
Science Achievement	Science Test Score (Range: 0 to 40)	Fixed

Three latent variables were included to measure students' perceptions of aspects of their science lessons: Practical Work, Teacher Initiated Learning and Student Initiated Learning. The manifest variables corresponding to these latent variables were based on students' responses to the Description of Science Learning questionnaire. Students were presented with a list of activities that typically took place during science lessons. They were asked to indicate for each activity whether it occurred 'often','sometimes' or 'never' during their science lessons. In this model, no causal relationships were specified between the three latent variables reflecting the instructional processes (Note 4).

DISCUSSION OF THE ESTIMATED MODEL

Table 2 sets out basic statistics for the inner model after the deletion of non-significant paths. The table shows the path coefficients between the latent variables, together with the standard errors and the zero-order correlation coefficients. Path coefficients have only been retained in this version of the model where they were more than twice as high as their standard errors; that is, where they were significant at the 95 per cent confidence level. The inner model is summarised as Figure 1.

TABLE 2

PATH COEFFICIENTS BETWEEN LATENT VARIABLES IN THE MODEL OF SCIENCE ACHIEVEMENT

Dependent Latent Variable/ Predictor Latent Variable	Path coefficient	Standard error	Zero-order correlation
Ability			
Home Background	0.178	0.034	0.178
Practical Work			
Ability	0.291	0.038	0.291
Teacher Initiated Activities			
Ability	0.477	0.040	0.477
Student Initiated Activities			
Home Background	-0.098	0.034	-0.093
Sex Of Student	0.103	0.035	0.099
Science Achievement			
Home Background	0.112	0.030	0.235
Sex Of Student	0.186	0.028	0.157
Ability	0.555	0.033	0.534
Teacher Initiated Activities	-0.091	0.038	0.142
Student Initiated Activities	-0.186	0.031	-0.218

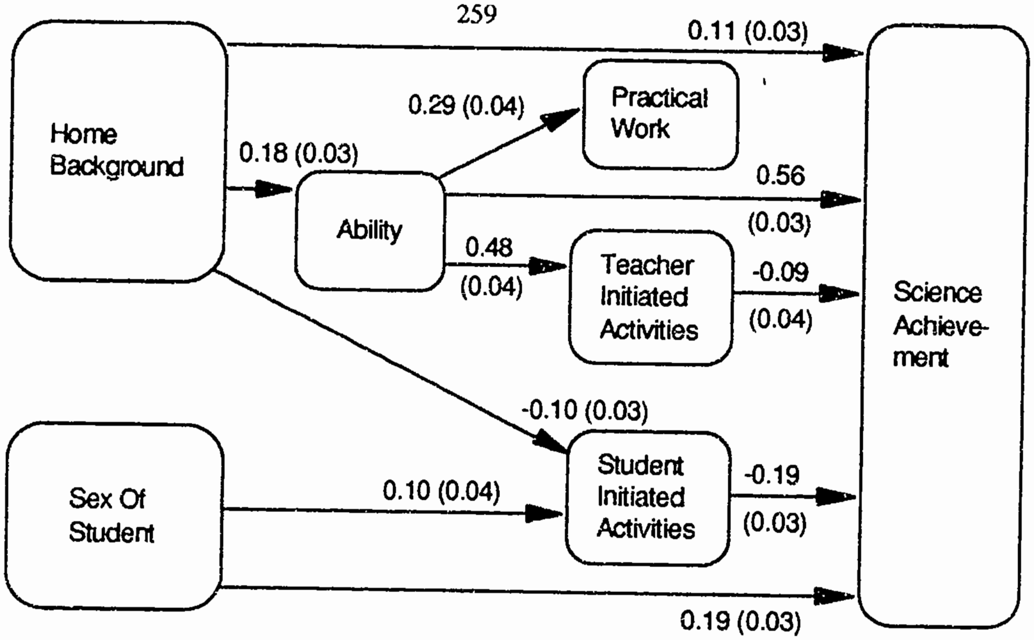

Fig. 1 A Model of Science Achievement: Queensland 10-year-old Students

Ability was the strongest latent variable (path coefficient = 0.56) influencing the criterion of Science Achievement. Home Background acted directly on the criterion (0.11) as well as indirectly due to the strong path from Home Background to Ability (0.18).
The relative contributions of the various manifest variables within each latent variable may be seen from the loadings in Table 3. The table does not include latent variables based on only one manifest variable, for which the loading was 1.00. For the latent variable Ability, the relative contributions of the Word Knowledge Test Score and the Mathematics Test Score were essentially the same.

Within the latent variable Practical Work, the two manifest variables reflecting the extent to which students did practical work and the extent to which they worked in small groups had similar loadings. Within the latent variable Teacher Initiated Activities, the two manifest variables with higher loadings reflected students views about the extent to which they copied teacher's notes from the blackboard, and the extent to which the teacher made the science lessons interesting. Within the latent variable Student Initiated Activities, the more important manifest variable reflected the extent to which students perceived that they were able to choose the topics to be studied.

There was a positive path (0.29) from Ability to Practical Work, but there was no consequent path to the criterion. There was a strong positive path from Ability to Teacher Initiated Activities (0.48). This meant that higher ability students perceived that their science lessons contained higher levels of teacher initiated activities. However, there was a negative path (-0.09) from Teacher Initiated Activities to Science Achievement.

TABLE 3

FACTOR LOADINGS FOR MANIFEST VARIABLES
IN THE MODEL OF SCIENCE ACHIEVEMENT

Latent Variable/ Manifest Variable	Factor loading	Standard error
Ability		
Word Knowledge Test Score	0.938	-0.001
Mathematics Test Score	0.886	0.033
Practical Work		
Students Do :actical Work	0.864	0.015
Practical Work In Small Groups	0.801	0.009
Teacher Initiated Activities		
Copy Teachers Notes From Blackboard	0.722	0.046
Tests On Learning Science	0.559	0.050
Teacher Makes Science Lessons Interesting	0.786	0.039
Student Initiated Activities		
Students Have Choice Of Topics	0.872	0.070
Teacher Uses Student Ideas For Lesson	0.676	0.072

There was a negative path from Home Background to Student Initiated Activities (-0.10), and a subsequent negative path (-0.19) to Science Achievement. That is, students with lower home background ratings tended to participate more often in lessons where they had a choice of science topics to study, but in turn they had lower achievement on the science tests used in the study.

There was a positive direct path (0.19) from Sex of Student to Science Achievement. Since the coding for Sex of Student was male = 1 and female = 0, the positive path meant that, after allowing for the effects of the other variables in the model, male students tended to have higher achievement scores. There was also a positive path (0.10) from Sex of Student to Student Initiated Activities, but there was then a negative path (-0.19) to Science Achievement.

Table 4 sets out the percentage of variance explained at each stage of the model, with 37.9 per cent of variance in science achievement explained by the model. An index of the stability of the model was computed using the Q^2 statistic (Note 5). The ratio between Q^2 and R^2 was used to summarise the stability of the model parameters at each stage of the model. The high ratios indicated that the omission of single cases would not produce any marked changes in the regression coefficients shown in Table 2 or the percentage of explained variance shown in Table 4.

TABLE 4

INNER MODEL SUMMARY FOR THE MODEL OF SCIENCE ACHIEVEMENT

Latent Variable	R^2	Q^2	Q^2 / R^2
Ability	3.2%	2.7%	0.84
Practical Work	8.5%	8.0%	0.94
Teacher Initiated Activities	22.8%	22.2%	0.97
Student Initiated Activities	1.9%	1.2%	0.63
Achievement	37.9%	36.6%	0.97

Note: The Q^2 statistic is a measure of predictive relevance. Higher values of the ratio Q^2 / R^2 indicate that the model is more stable. See Note 5.

SUMMARY

This article has examined a simple model of science achievement. It assumed that some of the differences between students may be explained in terms of their perceptions of lessons, after making allowance for home background and ability. The strongest factor explaining differences in achievement was their ability, defined in terms of verbal and quantitative skills. The home background (socio-educational level) of the students was the next most important factor, both in a direct sense, and also indirectly through its influence on the ability of the students. Female students tended to have lower achievement, even after making allowance for the influence of the other factors in the model. Factors dealing with activities in classrooms had less effect on achievement after controlling for the influence of the background factors. The strongest of the school factors dealt with the extent to which students initiated classroom activities, but the effect on achievement was negative. Students who stated that they had a greater choice of topics and who considered that their teachers made more use of their ideas in planning lessons tended to obtain lower scores on the achievement tests used in this study.

This implies that science lessons conducted in response to students' selection of topics were not leading to achievement outcomes as measured by the tests used in this study. Unless conducted by teachers with a good background in science, a responsive approach to the development of a curriculum may result in an unbalanced coverage of aspects of science. There is no argument with the proposition that science lessons should be adaptable rather than rigid, and should capitalise on students' interests. The risk in this approach is that, by the end of their science course, the students may not have received a systematic coverage of topics and concepts from major areas of science.

REFERENCE NOTES

Note 1. More precisely, the science test score used as the criterion was the Combined Science Test 1 Score. Details of this test and of the other manifest variables are included in Rosier and Banks (1990). The test items are in Rosier (1988).

Note 2. Details of the composition and construction of the Home Background index are set out in Rosier and Banks (1990, p. 216-223), where it is referred to as the Socio-Educational Index.

Note 3. The Word Knowledge Test and the Mathematics Test were administered at the same time as the Science Test. Strictly, the scores on these tests should not be placed at this early stage of the causal model. However, for the purposes of the model, ability was conceptualised as a stable characteristic of the student, with the scores on these two basic cognitive tests being postulated to be surrogate measures of ability.

Note 4. In this model, the variables Practical Work, Teacher Initiated learning and Student Initiated learning were defined as student level variables, reflecting the students' perceptions. The model as articulated assumed that these three variables were influenced by the prior variables concerned with background characteristics of the students. An alternative model could be proposed at the level of the class group or school. The meaning of the three variables aggregated to the group level may then change, being interpreted as the consensus by the students in the group about characteristics of the science lessons or the science teachers.

The issues of causality raised in Notes 3 and 4 highlight the need for the analyst to be specific about the model being considered, and to concede that alternative models may be proposed to deal with the same data. The usefulness of a model depends both on the statistical characteristics of the estimation, and on the extent to which the structure of the model reflects prior knowledge and common sense about the way in which schools function.

Note 5. The Q^2 statistic is based on jackknife estimation of the Stone-Geisser test of predictive relevance (Sellin, 1986, p. 193). In effect, one case is omitted at a time and the model parameters are re-estimated for the remaining cases. The omitted case values are then reconstructed or predicted using these parameters, and compared with the actual values. The results of these estimates are summed across all cases. Higher values of Q^2 indicate that the model is stable, with high predictive relevance.

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A RESEARCH METHOD USING MICROCOMPUTERS TO ASSESS CONCEPTUAL UNDERSTANDING AND PROBLEM SOLVING

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ABSTRACT

Important goals in science education include the elucidation of how students develop a world view, reason about new information, and solve problems. This paper focuses on a research strategy using microcomputers that is directed towards elucidating conceptual understanding and problem solving strategies used by subjects interacting with an open-ended genetics simulation. The field method employed in this study is termed "structured observations". The use of this method facilitated the generation of data during problem solving sessions by subjects in a think aloud protocol. Three sets of synchronized information of subjects' interactions with the software were obtained: a video image which provided the sequence and duration of computer screen displays, a video image of subjects, and an audio track of verbal commentaries. The verbal protocol data, complemented by synchronized visual data, were analyzed using software tools for qualitative analysis. The use of these kinds of software programs aided researchers in the analysis of complex, qualitative data. The data were subjected to codings as text files, searches for patterns, and retrievals of patterns among coded variables. Frequency tables of the codes and patterns were generated for further interpretation. By these means, patterns of operations can be identified and inferences made about problem solvers' conceptual understanding.

INTRODUCTION

Ongoing research studies in science education are needed to enhance understanding of how learners engage in problem solving, including how learners employ and develop concepts during problem solving. It has been specifically recommended that "researchers need to explore in greater detail such questions as how students develop a world view, reason about new information, and solve problems in science" and that "research in science education should reflect and respond to real instructional needs (Linn, 1987). Detailed studies of problem solving tasks in physics and genetics have been carried out (Champagne et al., 1982; Chi et al., 1981; Smith & Good, 1984; Larkin et al., 1980). These studies have involved closed data sets in which all relevant data were implicitly or explicitly given in the problem statements. Fewer studies have addressed problem solving in settings where subjects work in an interactive computer-based medium (Rivers & Vockell, 1987).

Computer-based problems have the potential to involve more open-ended tasks, in which the solution depends on the generation of relevant data by the problem solver.

Extracting, analyzing, and comparing common and unique characteristics of problem solvers in settings of this nature should complement findings from studies which have employed more traditional and constrained problem tasks. Information about problem solving in interactive, computer-based settings may result in important information about the cognitive behaviours and patterns of learners. This information can potentially lead to models to guide research in conceptual development and problem solving, and have significant implications for teachers and their classroom practices.

RESEARCH QUESTIONS

Research questions, such as 'What patterns and generalizations can serve as the organizers for theoretical models in research and development?' and 'How do learners extract relevant information to aid in problem solving?' can stimulate more detailed research which is directed towards elucidating conceptual understanding and problem solving. The nature of studies on conceptual change during problem solving warrants the use of a research methodology capable of assessing the dynamic character of subjects' cognitive skills and their application of scientific concepts, and of elucidating aspects of their mental processes (Larkin & Rainard, 1984). To aid in studying these kinds of questions, a research strategy using microcomputers with science simulation programs and qualitative data analysis programs was employed.

RESEARCH METHOD

Computer simulation

A microcomputer-based simulation, KANGASAURUS, was selected as the vehicle for examining subjects' genetics concepts and problem solving strategies as they interacted with a model of transmission genetics (Kinnear, 1989). In one mode of operation, this program allowed users to specify a genetic system through their decisions regarding a number of genetic parameters. For example, they had to decide on the numbers of autosomes of the organisms, the sex chromosome system (mammalian, avian, insect), the traits which are controlled by each gene, the number of alleles for each gene and their dominance relationship, and the chromosomal location of each gene. In the case of gene linkage, the problem solver selected the distance between gene loci and the precise linkage phase (cis or trans). Having specified a genetic system, problem solvers could formulate hypotheses about gene action and interactions, and then select parents to be crossed.

The use of an imaginary organism, the 'kangasaurus', meant that subjects were required to focus on genetic principles and could specify a genetic system which was free from constraints imposed by their prior knowledge of specific genetic facts concerning a 'real world' organism, such as Drosophila, as for example, the known dominance of one wing shape phenotype over another phenotype, or the known X-linkage of a gene controlling eye colour. During their interaction with the computer simulation, problem solvers controlled the choice of variables, the genetic models to be constructed, the problem solving strategies to be tested, and the data to be extracted for generalizations about principles and patterns governing inheritance.

Structured observations

Naturalistic research studies entail the use of field methods such as case studies, clinical interviews, analysis of documents, and unstructured observations (Easley, 1982). The field method employed in this study is termed "structured observation" (Krajcik et al., 1988). The use of this method facilitated the generation of data by subjects during a "think aloud" protocol. From these data, patterns of behaviours and strategies were extracted for comparisons between individuals and between groups of subjects. This method enabled researchers to study: 1) how learners develop certain concepts, 2) how learners solve problems, 3) how learners interact with instructional software, and 4) how software can be more effective in terms of design and use. In addition, "structured observations" provided information that suggest research hypotheses to be tested subsequently by experimental methods.

To gain insight into how people solve problems, an approach focusing on intensive studies of a small number of individuals was employed. A group of problem solvers with varying levels of expertise in genetics was selected as subjects for this study. The subjects included five professors and five graduate students in biology and science education.

During "structured observations", two types of recordings of subjects' interactions with KANGASAURUS were made. One type of recording made use of a video cassette recorder interfaced with a microcomputer. This recording stored both the video output from an Apple IIgs microcomputer and the subjects' verbal commentaries, and captured subjects' verbal utterances and positioned them simultaneously with the computer monitor displays which subjects were viewing. This recording gave detailed information of both the sequence of the computer screen displays and the duration of each display.

In a second type of recording, three sets of synchronized information were obtained. These three sets of information, video images of the computer monitor displays, video images of the subjects, and a sound track containing subjects' verbal commentaries, were integrated onto a single videotape. The two video images were arranged to form a composite picture, with the image of the subject occupying the major area and the image of the monitor screen displays inserted in the upper right hand corner (Fig. 1). This type of recording supplied the major source of data relating to the subjects' inferred conceptual understanding, their problem solving skills, and their nonverbal behaviours. Data for triangulation and analysis of subjects' understanding of concepts were also obtained from written documents (pretests, posttests, and notes made by the subject during problem solving tasks).

One difficulty during the "structured observation" resulted when subjects were reluctant or forgot to speak aloud. Two subjects required more prompting to speak aloud than the other ten subjects. In this situation, the researchers prompted subjects with comments such as "Please tell us what you are thinking or doing". The researchers provided technical aid to subjects only when difficulties with the hardware or software occurred.

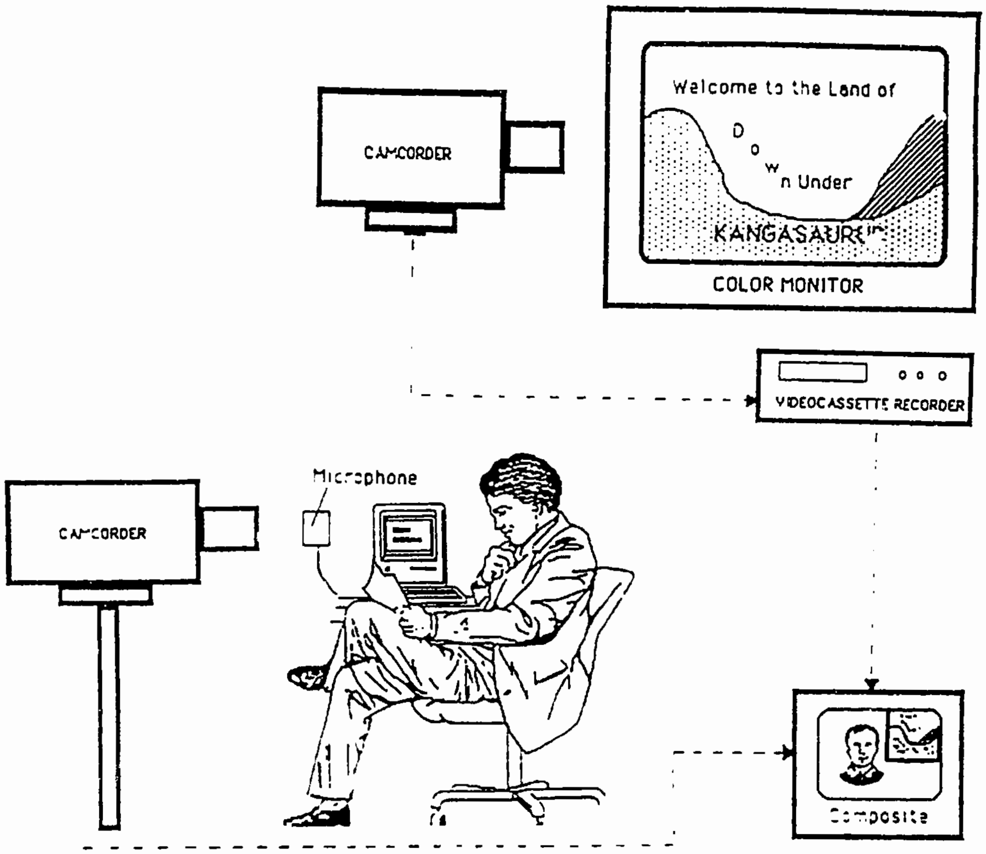

Fig. 1 Setup for composite videotaping procedure

To familiarize subjects with the computer program, each subject undertook an initial pencil-and paper exercise involving a simple monohybrid cross. The researchers then demonstrated to the subject how the computer program could be used as part of "solving the problem". After subjects indicated they felt comfortable with the operation of the program, they were given two open-ended problems to solve using KANGASAURUS. In this phase of the study, subjects were required to construct a genetic system which drew upon their conceptual knowledge and procedural knowledge. An example of one type of problem assigned was problem P3:

Two parents are identical to each other in appearance. Their offspring are of three kinds. One kind is identical in appearance to the parents. Set up a genetic system and carry out a cross that shows this pattern.

DATA ANALYSIS

Microcomputer software programs available to aid in coding and analyzing verbal protocol data included: WORDPERFECT, ETHNOGRAPH, HYPERQUAL, and TEXT ANALYSIS PACKAGE (TAP). A word processing program, such as WORDPERFECT (available for Apple or IBM), can be employed to serve as a database for coded verbal phrases and statements. Recently, other computer programs have been developed to aid in coding and analyzing qualitative data, such as the verbal and visual recordings generated by the study described in this paper. HYPERQUAL (Padilla, 1989) employs note cards which can be constructed with HYPERCARD. With these note cards, protocol data can be coded and analyzed according to various schema. ETHNOGRAPH (Seidel et al., 1988) involves coding segments or entire passages of transcripts for analyses. TAP (Drass, 1986) consists of sets of computer program procedures which allow the user to code text files, search for and retrieve patterns among the codes, and generate frequency tables of the codes. An added feature of TAP is its utility of working in any word processing program, converting a file to ASCII, and analyzing the converted file. The use of the microcomputer and these kinds of computer programs can aid researchers in analyzing verbal protocols by using a variety of coding schemes.

The verbal commentaries of subjects' interactions with KANGASAURUS were transcribed into text files, using the IBM WordPerfect word processing program. These text files were converted into TAP text files with the relevant software. The verbal transcripts were analysed and the videotapes were viewed by a group of four science educators who carried out three types of coding. The codes identified the computer screen displays, the inferred problem-solving stages, and non-verbal behaviours displayed by the subject. Codes were entered at appropriate points in the text files for later analysis.

Computer screen display codes recorded some of the subject-initiated changes in key screen displays as subjects worked with the computer simulation during problem solving.

Inferred stages of problem solving, as identified by various researchers (e.g. Hayes, 1981; Newell & Simon, 1972) were based on the verbal patterns of subjects recorded on the videotape. Problem-solving stages were agreed by the group of science educators who viewed the composite videotapes and had access to the pronted transcripts. The stages of problem solving that were inferred and coded included: problem identification, problem restructuring or representation, strategy planning, strategy implementation, and solution evaluation. Problem representation was interpreted according to Chi et al. (1981), that is, as a cognitive structure relating to the problem that is an outcome of the initial categorization of the problem on the basis of the solver's domain related knowledge and its organization. For example, the following utterance: 'Try to set up a genetic system and carry out a cross that will allow you to demonstrate independent assortment to your friend. . . OK. . . independent assortment. . . what you want to work with is a gene that has two alleles on it that are going to assort independently of each other . . . Hmm. . .' was agreed to be part of the problem representation stage for one subject. The utterance: 'Now if I'm going with this . . .I have to figure out some way to still get all four . . . combinations but alter the frequency . . . with which they appear . . . so if I have . . . one gene preventing the appearance of the other for example epistasis . . . Uh . . . i think that won't work . .'

included episodes of both strategy planning and strategy evaluation. In addition to the major stages, episodes of reflective problem solving behaviours (reflecting on the problem, the strategy, the solution, or the implementation of the strategy) were found to occur concurrently with other stages of problem solving.

The transcripts allowed for inferences to be made about subjects' conceptual understanding by identifying how subjects used concepts during problem solving that required both a knowledge of the concepts as well as an understanding of its translation as seen in operational consequences (Kinnear & Simmons, 1990). The transcripts also revealed that, in some cases, subjects refined their conceptual understanding during and as a result of the problem-solving process. For example, one subject attempted a problem that entailed an understanding of the concept of sex-linkage. After two unsuccessful attempts involving different incorrect interpretations of this concept, the subject at a critical decision point stated: 'OK. . . OK. . . OK. . . what you need to do now is think. . . I'll put it on the father's X chromosome . . . . . This time this is not on the father's Y chromosome.' This episode provides evidence that the subject had clarified his understanding of the concept of sex linkage, particularly its operational consequences, since from this point, he confidently proceeded to a successful resolution.

The composite videotape recording allowed for the identification of specific nonverbal behaviours (Note 1). Nonverbal behaviours have been widely studied (Drucman, Rozelle & Baxter, 1982), and it has been shown that facial and vocal cues communicate emotional states (Ekman, 1982). In this study, however, an ethological approach was used so that non-verbal behaviours were objectively recorded as motor actions, such as 'furrows brow', 'raises eyebrows', or 'covers mouth with hand', rather than as subjectively interpreted behaviours such as 'looks surprised' or 'appears confused'. Nonverbal behaviours were found to be predictable and idiosyncratic in some cases, and some were associated with critical points of decision-making during problem solving. For example, hand-to-face movements by one subject preceded the selection of specific problem-solving strategies. Among the nonverbal behaviours which signalled subsequent critical decision-making points were furrowing the eyebrows, and touching the face with the hand. Further analysis of these non-verbal behaviours is in progress.

Fig. 2 shows an excerpt from a converted TAP file with codes for problem solving stages, nonverbal behaviours, and computer screen displays inserted. The excerpt illustrates part of the solution implemented by an expert subject in response to problem P3. The subject had previously read the problem aloud, repeated critical cues (phrases) within the problem, represented the problem, decided on a solution, and was then employing the computer simulation to set up a genetic system that would generate the required pattern of offspring. The left side of Fig. 2 shows the coding that was associated with the subject's utterances that are shown on the right.

The first line of the excerpt, comprising the utterance "OK T for... uh" occurred as the subject decided on a letter symbol for the alleles of the gene involved, and was associated with the nonverbal behaviours of 'bl' (bites lower lip) and 'lp' (long pause). The utterance, "toe number on chromosome one", has the associated codes 'n' to indicate that the subject had advanced to the screen display for gene locus choice, and 'hn' to denote head nodding in an up-down direction. The subject then selected parental genotypes. The nonverbal behaviours associated with this choice included hand-to-head motion (hh), bites lower lip (bl), another hand-to-head motion, and a hand-to-face-to-mouth motion (hfm). When coding was completed, the entire TAP file was analyzed, and frequency tables of the codes for all or parts of the transcript were generated by the software package.

Subject: danielta LINE: 270

CODES				TRANSCRIPT
bl	lp			OK. T for ...uh huh
				OK then right where you are
				continue
n	hn			toe number on chromosome one
				continue
				um hum
				so basically the problem can be answered right now
				You can see the two types of parents
hh	bl	hh	hfm	one of which is four...two toed
				the other one which was four toed
				If those were the homozygous parents then you'll have
				heterozygous with three toes

Fig. 2 Sample excerpt from transcript showing codes

Table 1 shows a summary of the most commonly occurring nonverbal behaviour codes from a longer section of transcript. The most frequent nonverbal behaviours exhibited by the subject during this episode were long pauses (lp) and head nodding in an up-down direction (hn). Occurring with lower frequencies were eyebrow flashes (ef) and body movement in a backward motion from the screen (bb). Summaries of coded behaviours indicated that the subject exhibited various idiosyncratic behaviours during the think aloud protocol. Searching through the coded file for a specific behaviour, such as head nodding, revealed that the subject exhibited the head nodding behaviours during or following a critical decision point in setting up the variables for his genetic model. This feature of the TAP and Ethnograph programs enables researchers to examine and sort blocks or segments of transcripts containing specific codes with concurrent utterances. The context of the codes can then be examined and summaries compiled into data tables for comparisons of patterns.

TABLE 1

SUMMARY OF NONVERBAL CODES OBTAINED
USING TEXT ANALYSIS PROGRAM(TAP)

Code	Frequency	Percent of Total (N=78)
lp	18	23.08
hn	10	12.82
ef	5	6.41
bb	4	5.13

ef = eye flash hn = head nod
lp = long pause (>3 sec) bb = body back movement

IMPLICATIONS FOR RESEARCH

The richness of verbal protocol data, complemented by synchronized visual data, can be explored more efficiently and effectively by searching for emerging or significant patterns. For example, the sequencing of subjects' evaluation strategies can be coupled with the conceptual organizers they employ during their evaluation strategies. Research strategies which employ microcomputers, simulation software, and data analysis programs, as described in this paper, can reveal if subjects exhibit predictable behaviours during problem solving. Studies of problem solving in such interactive settings can provide important information about the cognitive behaviours and cognitive patterns of learners. This valuable information can lead to powerful models guiding research in conceptual development and problem solving.

REFERENCE NOTE

Note 1. Unpublished paper presented at Annual Meeting of National Association for Research in Science Teaching, Atlanta, 1990 by P.E Simmons and J.F. Kinnear on Verbal and nonverbal behaviours of 'experts' during computer-based problem solving in genetics.

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INTEGRATION OF TECHNOLOGY IN THE SCHOOL CURRICULUM

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ABSTRACT

This paper describes, chronologically, the deliberations of a school staff in their decision-making to place technology education in their school. The outcome of these deliberations is a curriculum model whereby objectives of technology awareness, technological literacy, technological capability and transferable skills are integrated with all subjects in the school. The desired outcome is that students at this school will gain a technological education by, for example, attending classes in English, Home Economics, Mathematics, Social Studies, Science and Art. The implementation process is ongoing, is being evaluated and has already experienced senior staff changes and industrial disruption without loss of vigour or intent.

INTRODUCTION

Technology has the potential to become an important part of education in the school curriculum. However, how the subject is to be covered on the individual timetables of all students during their schooling is a source of great debate. This debate is perhaps nowhere better explained than in the publication of the Association for Science Education (ASE) in England (Woolnough, 1988)entitled Technology education and science in schools. The various tensions in school subject departments, such as science and craft, over which area should claim technology for their realm, carry with them different views of the nature of technology and what technology education should be.

Woolnough (1988, p.10) explains how technology in England has developed along four different lines, each with its own traditions and character. The National K-12 Technology Curriculum Mapping Project Team (Note 1) has shown that a similar approach exists in Australian schools. These different lines have involved firstly an approach dominated by craft teachers, secondly an approach focussing on "hi-tech" advances such as computers and electronics, thirdly an approach whereby school students learn engineering as a prerequisite to further tertiary courses, and fourthly the scientific approach where science teachers see technology as a subset of science.

For numerous reasons which are eloquently argued by Woolnough (1988), none of these four approaches are in themselves satisfactory for a technology education for all students. The debate in England evolved to a point when the ASE set up a working party concerned with the future of technology in schools and it concluded that, rather than continue the debate about the definition of technology, it would focus on the view that there were four interrelated strands that needed separate consideration: technological literacy, technological awareness, technological capability and information technology. The ASE further argued that the hidden curriculum of the school should convey a technological ethos to the students.

INTRODUCING TECHNOLOGY EDUCATION IN SECONDARY SCHOOLS

In Australia, technology education in secondary schools has received increasing attention over the last four years; (see for example the Australian Science Teachers Journal, August, 1990, 36(3). This attention has come about partly as a result of industry realising the need for closer links with education, but more as a result of the encouragement of the Australian Federal Government such as has been articulated in many statements and documents. Whether this reasoning for including technology in the curriculum is morally or educationally acceptable is a matter for debate but for now it is the direction being taken by state, territory and federal governments. In Western Australia, one of the manifestations of a desire to implement technology education in schools was the decision in 1987 for the Ministry of Education to invite proposals from schools about how they might introduce technology into the curriculum. Following a review process, successful proposals from six schools were funded for two years. The way each school proposed to include technology depended on their definition of technology as well as the knowledge and skills of particular staff members. An evaluation is currently going on in order to gain as complete an understanding as possible of the way the schools introduced technology and achieved their objectives (Treagust & Rennie, 1989).

DEBATES ABOUT TECHNOLOGY EDUCATION AT KENT STREET

As in the debate in England, the four different approaches that could be taken were discussed at length. These discussions concerned the different ways technology could be implemented in the school, the technological process, a preferred definition of technology to guide deliberations and finally the decisions about how to integrate technology in the curriculum of each subject in the school timetable.

Observable outcomes of technology education

The recipients of the grant at Kent Street Senior High School believed that their efforts to introduce technology in the school would result in observable educational outcomes in students. Staff were interested in achievable outcomes for technology education as shown in Fig. 1. These outcomes were produced from the New Jersey Department of Education (Fricke, 1987) and used by Kent Street as a focus for their aims.

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* Ability to use the problem-solving model and critical thinking skills.
* Ability to use models to simulate real situations.
* Ability to make real world decisions concerning the impacts and consequences of technology.
* Ability to demonstrate how feedback is used to control social, political, economic, ecological, biological, and mechanical systems.
* Ability to use the 'tools' of technology to solve real world problems.
* Ability to recognise the relationship between mathematics, science, social studies, language arts and the humanities with technology.
* Ability to question the possible effects of technological 'improvements' on the society (environmental, political, economical, cultural, etc.)
* Ability to weigh the merits and risks of new products and processes.
* Ability to recognise that technology will create new possibilities for society.
* Ability to trace and analyze the effects of technology on society from an historical perspective.
* Ability to analyze the effect of technological advancements upon career choice and to realise that education is a life-long endeavour as a result of rapidly changing technology.

Fig. 1 Intended impact on students of implementing technology education in a school

Different ways of including technology in the curriculum

Broadly speaking technology can be introduced into the curriculum as a separate subject or integrated within existing subjects to differing degrees. This same dilemma faced the staff at Kent Street.

Technology as a separate subject. Technology could be taught as a separate subject in the curriculum on a voluntary or compulsory basis. However, who should teach such a subject is a problem since there are no teachers specifically trained to teach technology. Another problem in introducing technology as a separate subject is deciding the relative proportions of knowledge and skills to be included for a course of study.

Technology as a topic within different subject areas. Technology could be treated as a topic within different subject areas and the technology topic would link with the philosophy of the subject in which it was integrated. Problems arose concerning who would write and teach such topics and whether these topics and the units with which they were linked would be a compulsory or voluntary part of the curriculum. Further, should these technology topics be incorporated into selected subjects in the curriculum like Art, Craft and Design or Science or should technology be incorporated into every subject? How this was to be done, what should be done and who would take responsibility for it were topics for serious debate.

The technology process

At Kent Street, the technology process has become an underlying aspect of all teaching about technology. Acknowledging and emphasising such a process have the advantages of developing a consistent approach to problem solving, using subject content as the vehicle and encouraging students to have greater interest over their own learning. The technology process used in a science unit at Kent Street is presented in Fig. 2; the initial development came from the Education Department of New Jersey (Fricke, 1987).

A preferred definition of technology

The school staff sought a definition of technology with which they could all agree and from which they could develop their curriculum. The school chose the UNESCO definition, attributed to Vohra (1987),

> Technology is the know-how and creative process that may utilize tools, resources and systems to solve problems, to enhance control over the natural and man-made environment in an endeavour to improve the human condition.

By concentrating on the phrases 'creative process', 'solve problems' and 'enhance control' the school deliberately moved away from a definition of technology which emphasises artifacts. The acceptance of this definition has resulted in a technology education which concentrates on helping students become aware of the cognitive process involved in developing technology and understanding how they think and solve problems for themselves.

THE TECHNOLOGY PROCESS

This process is applied in most subject areas of the lower school curriculum. This example shows the process applied to a Science unit, Matter.

The Science objective for this part of the unit is 'Describe and demonstrate methods of separation such as decantation, filtration, evaporation distillation and chromatography.'

The technology objectives are that students should
- be able to function independently
- have developed practical problem solving skills
- be innovative
- be able to investigate technology-related problems
- be able to design processes and artifacts that can be used to solve technology-related problems
- be able to make artifacts that can be used to solve technology-related problems

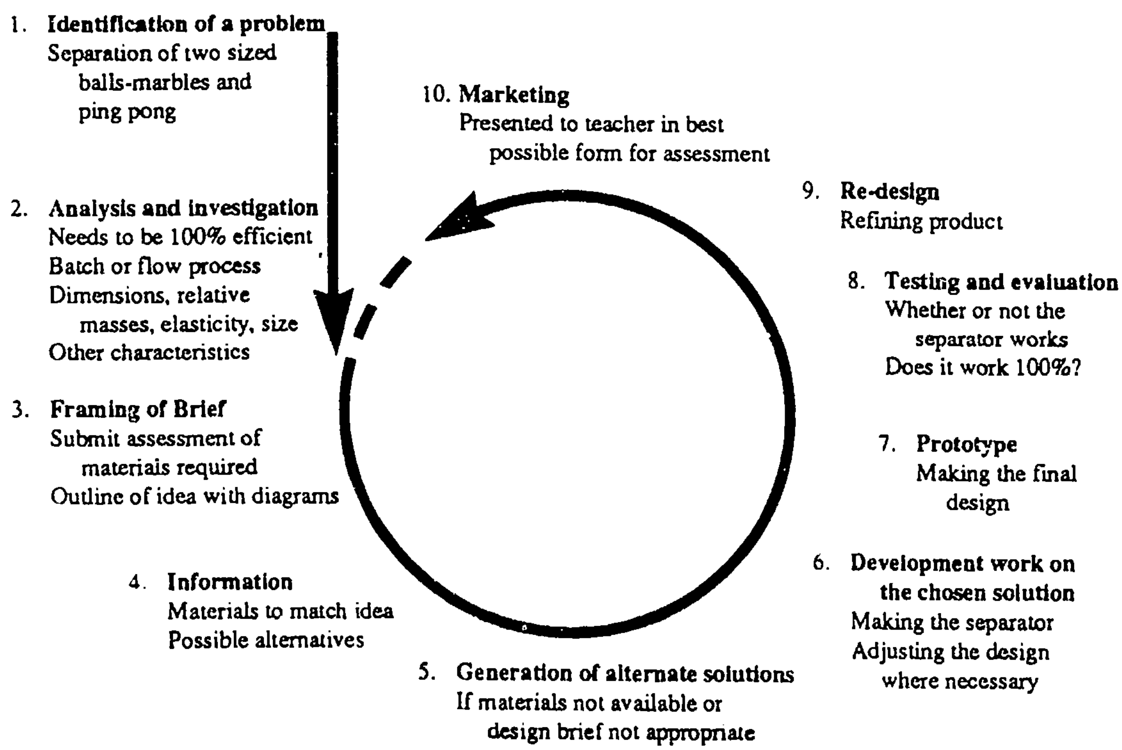

Fig. 2 The technology process used at Kent Street Senior High School for all teaching about technology

Four aspects of technology education

The four aspects of a technology education described by the ASE (1988) were considered by the school staff.

Technological Awareness involves the development of a perspective view of the history of technological development of humans and motivates students to apply the knowledge of past technological development to new and future technology.

Technological Literacy is the development of a technological vocabulary, display of a working knowledge of technological terms, and employment of a wide range of communication skills including writing, recording, drawing, modelling and speaking.

Information Technology refers to the application of computers and how these affect the world of leisure and work.

Technological Capability refers to the competence of individuals to engage in practical activities and perform tasks such as designing and building an animal enclosure. To effectively engage in these practical activities, students require to learn about design and problem solving and acquire resources of knowledge and intellectual and physical skills which need to be called upon when carrying out technological activities.

Following a workshop for teachers concerning the implementation of technology in the curriculum, a decision was made to accept that four areas of technology education should be incorporated within different subject areas. However, Transferable Skills was substituted for Information Technology since such an integration of transferable skills was seen as being central to the goals of the school. Subsequently, the fourth component of a technological education was added:

Transferable Skills are those skills required in a technological society that are transferable across a wide range of work situations.

The process of integrating the four components of technology in the curriculum was similar to that described by Woolnough (1988) although it is not identical since the Woolnough paper was not available during development. Students in the first three years of secondary schooling (Years 8-10) are experiencing the four components of technology education to varying extents in varying subjects as they progress through their schooling. Information Technology was considered to be an integral component of all aspects of a students education at Kent Street and this aspect is encouraged in all subject areas.

DEVELOPMENT OF A TECHNOLOGY EDUCATION CURRICULUM MODEL

In Western Australia, the Unit Curriculum (Ministry of Education, 1987) introduced into schools in 1988 breaks all subjects into units of 40 hours instruction. These units can be taught in one or two 10-week terms, depending on school policy. Each unit has specified objectives but there is the opportunity to change 20% of the objectives and indeed much of the remaining 80% can be modified. Subsequently, the working group developed a curriculum model consisting of a list of generalizations and specific objectives, some of which could be included in the curriculum objectives of the majority of units, and certainly those studied by all students. Table 1 shows how these four components, generalisations and a sample of objectives fit together.

TABLE 1

THE FOUR COMPONENTS, GENERALIZATIONS AND SELECTED OBJECTIVES FOR TEACHING TECHNOLOGY EDUCATION ACROSS THE CURRICULUM AT KENT SCHOOL SENIOR HIGH SCHOOL

Generalizations	Selected Objectives
Component: Technology Awareness	
• Technology is a force that is, in part, shaping the evolution of society • Technology is a discipline in its own right with its own history and methodology	Students should be aware • of the importance of technology in the evolution of human society • of the relevance of technology to everyday life • that technology has its own methodology.
Component: Technological Literacy	
• Technology is dependent on communication	Students should • develop a technological vocabulary • develop and employ a wide range of communication skills including reading, writing, modelling
Component: Transferable Skills	
• Technological change is occurring rapidly and as a result skills that are required in a technological society must be transferable across a wide range of work situations.	Students should • develop confidence in their ability to function in a technological society • developed creative thinking skills
Component: Technological Capability	
• There are skills that relate closely to technological development. • There are skills that relate closely to the use of technologies. • There is a body of technological knowledge. • The ability to make sound, reasoned judgements and subsequent actions is required in a technological society.	Students should be able to • investigate technology-related problems • make artifacts that can be used to solve technology-related problems • apply technology assessment skills • distinguish between technology and technique • investigate the impacts of particular technologies on selected spheres of life

The decision to develop a curriculum model rather than just provide teachers with a list of technology objectives arose from three needs. Firstly, a curriculum model could be used by staff, several of whom were inexperienced in curriculum writing, for incorporating the new technology objectives in their subject. Secondly, the model ensured a consistent approach to integrating technology across the curriculum as the same objective could be identified in the teaching of, say, Science, Mathematics and English. Thirdly, the model could be used to ensure that the different objectives for the four components had been adequately covered in more than one unit.

Technology curriculum writers in the school selected the technology objectives from the model, which were most appropriate to each unit in their subject area. They then had the choice of either integrating or including the technology objectives in the unit objectives, and then using the content or knowledge objectives of that unit as a vehicle to teach the technology process objectives. Writers exercised their option of replacing 20% of the existing unit objectives. The subject areas which initially were successful in rewriting objectives for units to incorporate the newly written technology objectives were Home Economics and English. These areas of the school curriculum included different objectives from the model, with Home Economics focusing more on technological awareness and technological capability and English on technological literacy.

Integrating technology objectives in science

The science staff decided that not all Year 8-10 units would have technology objectives integrated into them. The preference was for the inclusion of selected technology objectives in units taken by all students in Years 8, 9 and 10. For the science unit, "This Chemical World", the objective shown in Table 1 under Technological Capability -- students should be able to investigate the impacts of particular technologies on selected spheres of life -- is taught primarily using the curriculum investigation dealing with disposable nappies, taken from the SATIS (1988) materials. In this investigation students are required to plan a method of comparing different brands of disposable nappies and make decisions based on the reliability and effectiveness of their results.

IMPLEMENTATION OF THE CURRICULUM MODEL FOR TECHNOLOGY EDUCATION

The deliberation process about the sort of technology education students at Kent Street were to have and how this was to be implemented began in 1988, and by the end of 1989 curriculum objectives for technology and associated curriculum materials were written for English, Home Economics, Social Studies and Science. Other areas, such as the Library Information Skills Program have incorporated technology objectives during 1990 and these are currently being taught.

The success or failure of the implementation is not yet able to be categorically stated since the monitoring and evaluation of this process is incomplete though an interim report (Treagust & Rennie, 1989) is available. However, some important points can be made about aspects of technology education at this stage of implementation. These points are based on direct observations of some classes and on discussions with teachers involved in both writing and teaching the technology-based curriculum.

* The technology coordinator in the school changed at the end of 1988 due to the transfer of the initial technology coordinator. This did not affect the direction or the commitment of the technology curriculum implementation process.

* A new senior teacher for Science was appointed in 1990 and he has continued to support the development and introduction of technology education components in the science curriculum.

* The period during which the technology curriculum was being implemented was one of unusual teacher disquiet and considerable union action involving working to a regulation six-hour day and no work being taken home. Despite this situation which lasted for six months or so in 1989 the implementation process continued unabated.

* Student involvement in the technology aspect of their curriculum has been encouraging. The manufacture of clothes in a Home Economics unit illustrated an increased understanding of the role of technology in all aspects of clothes making and manufacture. In English classes the students wrote articles for a school newspaper showing the change in technology involving the printed and electronic word. In Science students were given the task of producing a liquid bubble-blowing solution which was as well packaged, as good as the presently commercially available solution and at the same or lower cost. This task was accomplished with interest, commitment and in many cases enthusiasm.

* The Social Studies department has experienced two almost complete changes in staff since 1987. However, because the technology curriculum is well documented, the technology objectives continue to be addressed.

* In the subjects where the writing began, teachers are now revising the activities they use for teaching technology, fine-tuning them for a better product in the classroom.

* The whole project can be seen as a way of updating a curriculum. Many of the writers have seized on the opportunity to do this. For example in Mathematics, objectives have been put in place to encourage the integration of computer software.

* Having established a lower school technology curriculum, the school is now establishing close links with industry and the process skills of Information Technology are being emphasised across the upper and lower school.

* New objectives have necessitated new teaching strategies. Because these objectives are predominantly process objectives, students have become involved in classroom activities which require a higher level of thinking skills than under the previous curriculum, and which often bring excitement and stimulation to the classroom.

* The management structure for the project has been highly organized and well documented. This has helped keep the personnel involved "on task". For example, the Technology Management Committee meets fortnightly to discuss a set agenda and make decisions.

* On the negative side, the writing has not been done in Manual Arts and Physical Education. At various times over the last two years staff have been released from some teaching commitment to perform this task, but this has not occurred.

* Staff development has been deliberately on an incremental basis working on the principle that an understanding which occurs over a period of time will be more comprehensive.

CONCLUSION

This paper has described one approach for integrating technology education into the school curriculum. The staff at Kent Street debated various issues involving technology and adapted information in the literature to develop a curriculum model to meet the school's needs. Certainly other approaches for integrating technology in the curriculum are possible and each school would benefit by experiencing a curriculum implementation process to meet specific school needs. The importance of the curriculum endeavour described in this paper is that it has the potential to be transportable to other secondary schools throughout Australia with a minimum of disruption to the timetable but requiring a sound commitment by the teaching staff to ensure that they are implementing a desired technology education in the school. In an uncertain future the one thing which is certain is that the future will be more complex, more information-rich and with more sophisticated technology. If students are to have control over their lives in the future, if they are to leave school with the transferable skills which will empower them to have this control, they need to have had an educational experience which encourages them to think on the deepest possible level for each individual. Technology education, as it is being taught at Kent Street Senior High School, has the potential to do this through each component of the curriculum.

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Note 1. National K-12 Technology Curriculum Mapping. (1990) Map of technology education in Australian government education systems. Unpublished document (pp. 137 - 151).

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"WHAT'S YOUR SCIENCE TEACHER LIKE?" : USING STUDENTS TO APPRAISE TEACHING AND TEACHERS

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ABSTRACT

The evaluations of teacher performance as carried out in most schools are brief, superficial affairs involving a few moments of classroom observation, followed by the completion of an evaluation report form which is read and signed by all interested parties, filed away and never referred to again. Such cursory processes do very little to promote the professional development of teachers, and yet the use of alternative schemes for appraising teaching or providing feedback to teachers is still not widespread in Australian schools. Students can play a role in providing feedback to teachers, yet whether this feedback is valid and welcomed is still a contested issue. Some published research shows that it can be a valid and valuable exercise. This paper reports some work-in-progress in which students in secondary science classes in Tasmania were interviewed, with some very insightful responses being provided. Broader issues associated with "Teacher Appraisal" are also discussed.

INTRODUCTION

Teacher appraisal is a central part of many of the award restructuring negotiations which are taking place around Australia, especially at state levels. This is causing a great deal of anxiety within teacher ranks because the purposes behind the introduction of teacher appraisal schemes are frequently confused and misunderstood. The history of teacher evaluation in Australia is narrowly defined, being almost exclusively directed towards accountability (appraisal for promotion purposes or for the certification of probationary or beginning teachers). The evaluations of teacher performance as carried out in most schools are brief, superficial affairs involving a few moments of classroom observation (usually by the principal or a designated deputy), followed by the completion of an evaluation report form which is read and signed by all interested parties, filed away and never referred to again (Stiggins & Duke, 1988). Such cursory processes do little to promote the professional development of teachers; instead they reinforce a very powerful belief held by teachers that evaluation is something done to them. An example is described by Gitlin and Smyth (1989); "When he [my principal] does his evaluation, he comes in, he watches me, we sit down and he tells me what I did. I don't have to tell him anything. I don't have to explain why. I don't ever have to say anything to him.(p. 78)"

In this form of evaluation, teachers will put on a show, strive to conceal weaknesses from an observer/evaluator and will choose to avoid serious discourse. The evaluator is assumed to be the expert as well as the "fault-finder" while the observed teacher is the needy recipient. When dialogue is based on the observational findings or report of one person, there is a tendency for the observer to ask questions and for the teacher to respond. These roles emphasise evaluation as a monological and hierarchical system which is oppressive to teachers (op.cit., p.79). Existing strategies of uncoordinated oneshot visits into classrooms by people who bear the labels of "supervisors" are ineffectual because they fail to get behind the superficialities and the habitualness of classroom practices (Goldhammer et. al., 1980). It was this perception which had prompted Goldhammer to devise his method of "Clinical Supervision" (Goldhammer, 1969), a method which has since been modified in various ways (see Acheson & Gall, 1980; Turney et. al., 1982a,b; Garland, 1982; Smyth, 1984)

Clinical Supervision involves a four stage procedure:

* a pre-observation conference between the observer/supervisor and the teacher during which the focus for the observation will be determined.
* an observation period.
* an analysis stage for reflection on the data collected.
* a post-lesson conference between the observer/supervisor during which some aspects of the lesson are reviewed.

Despite the wide acceptance of this model in recent years, it is still seen in most cases as involving an observer collecting data which can be drawn only from the visible or observable aspects of a lesson, and which ignores the background or presage variables which the teacher and the students bring to the lesson as well as the context of the teaching. For this reason alone, the use of a surveillance model of teacher evaluation which uses the observer-expert to comment on teacher performance is an inappropriate method of appraising teacher competence (Gitlin & Smyth, 1989; Scriven,1986, in Simons & Elliott, 1989), especially if teacher growth is desired. In fact, Scriven is quite harsh in his reference to the classroom visit as a means of evaluating teachers: "Classroom visits not only violate every tenet of sampling theory (too small, non-random, reactive, biased observer etc.) but can only look at what is essentially irrelevant in all but the most bizarre cases, namely teaching style" (Scriven, 1986 in Simons & Elliott, 1989, 57).

House and Lapan (1989) believe that classroom visits can play an important role in overall evaluation if properly done as part of a more global strategy, but the time required to plan, collaborate and actually carry out the classroom observation is simply not available for personnel in schools today. I was interested in finding a method of evaluation which might involve teachers being given more professional opportunity to reflect on their own performance and hence conduct their own evaluation. At the same time, I recognised that clinical supervision is not something that teachers can do on their own - there is a need for some collaboration. The notion of "Peer-mediated Self Appraisal" (Barber, 1990), incorporated into the Clinical Supervision model seemed to offer a strategy which met my requirements. In addition, I wished to consult students in the classes being taught about the teaching that they were receiving. How could teachers be encouraged to engage in this activity without threat and in an open and honest manner?

TEACHER PROFESSIONALISM

One of the ways that persons best suited to teaching can be attracted into the teaching profession and retained, is to strengthen the professional role of teachers in schools. Governments, the administration, the public and the teachers themselves must be willing to accept the fact that the position of "teacher" is a professional position of importance. To accept this fact is to accept the further assumptions that teachers are:

* professionals who can judge their own worth,
* professionals who strive for excellence in their work,
* individuals who can and should assist in their own evaluation and the evaluation of their peers, and
* individuals valuable enough to the community to justify the expenditure of public funds to upgrade their skills (after Barber & Klein, 1983).

The dilemma for Australian teachers is a system which fails to distinguish between formative and summative evaluation, and hence to cause them to feel threatened by all evaluative activity. This difficulty has existed for historical reasons as only relatively recently have educational systems moved away from the inspectorial or bureaucratic forms of "top-down" evaluation. Clearly, evaluation can be used for two primary purposes; firstly, to provide accountability for personnel management decisions and secondly, to promote the professional development of teachers. Unfortunately, because Australian educational systems have very limited experience with the second form of use of the term, evaluation is usually seen to mean "accountability". In this context, the purpose is summative evaluation, and the activity provides information for personnel decisions (promotion and salary increases). A teacher evaluation system involving peer-mediated self appraisal would allow teachers to share ideas and insights with other teachers. The intended outcome is for all teachers to gain information about their own strengths and weaknesses so that appropriate retraining can be planned based on self-perceived needs.

The introduction of such a peer review scheme proves very uncomfortable for many teachers and will not be implemented easily, although my experience with a volunteer group (see below), provided a pleasant surprise in that the trust and openness developed in the group quickly (within 3 weeks). Considerable periods of time are probably needed for teachers to feel secure enough and to develop trust in the strategy. There is very little evidence in the literature of successful growth-orientated systems of teacher evaluation in Australian education, but the success of the PEEL project at Laverton High School in Melbourne has a number of important indicators for future work (Baird & Mitchell, 1986). The significant outcome of this project in so far as it relates to teacher appraisal is the way that teachers were prepared to share their findings about their own and each other's teaching in an open and honest reflective manner. This was in line with the main thrust of the project, which was to encourage pupils to reflect openly and honestly about their own learning. Gitlin and Smyth, (1989) stress that pupils will only be open and honest about their learning and learning styles if teachers are open and honest about their teaching styles. I wanted to provide a means to foster genuine discussion between teachers, and to allow them to gain feedback on their teaching in a non-threatening manner. I also wanted to involve students in the professional development of their teachers. This paper describes a first attempt to do this.

BACKGROUND

In 1987, I had encouraged a group of post-graduate science teacher education students enrolled in the Diploma of Education program in the University of Tasmania to gather feedback on their own performance in as many different ways as possible. Suggested ways were self-appraisal, peer-appraisal, supervising teacher's appraisal and student appraisal. This subsequently became a mandatory assignment for the student teachers to complete during a Practice Teaching program in 1988. I was especially pleased with the positive reactic ı from and competence of the stuaent teachers in evaluating their own teaching, and to using their own classes of science students to evaluate their teaching. I have used the same assignment in 1989 and again in 1990.

A literature review had shown that students can play an important part in providing feedback to teachers, and some published research shows that it can be a valid and valuable exercise. Moses (1985; 1989) suggests that university students can evaluate presentation, course management and teaching-related tasks, but should not be asked to comment on course content. Marsh (1987) supports Moses, but he suggests that caution is necessary before widespread adoption at school level can proceed. Cashin (1988) cites evidence to show that student ratings have been found to be reliable, valid and relatively ıree of bias, and Coburn (1984) found that students can effectively discriminate between teaching effectiveness and other affective dimensions, such as "popularity". Barber (1990) contends that "self-assessment" is an important tool to be used in teacher appraisal considerations. He proposed the notion of "peer-mediated self appraisal", a strategy which I decided would be worth developing with pre- and in-service teachers. From these sources, and as a result of the experience with the Diploma of Education students, I decided to (i) investigate secondary school students' appraisal of their science teachers, and (ii) devise a strategy to enable teachers to reflect on (and appraise) their own teaching performance in a non-threatening environment. I wanted to see whether (i) and (ii) would yield data which might guide further research. This paper will report on these two methods of appraisal, but the major emphasis is on (i) above.

METHOD

After reading the assignments set in 1988, I decided to ask a group of nine teachers (all in the same school), to trial a questionnaire (Student Opinion Form), with their classes which sought opinions from their students about their own teaching. This questionnaire is reproduced in Appendix 2. Four of these teachers were science teachers. I believed that the questionnaire would not only provide feedback to teachers from students but would also act as a key strategy to generate discussion among these nine teachers.
I also interviewed a number of students about their regular science teachers using a structured interview schedule, recorded the responses using audiotape and derived a transcript of comments from these tapes. The interview schedule is shown in Appendix 1. The students interviewed were not taught by any of the teachers referred to above.

DISCUSSION OF RESULTS

The Student Opinion Form, Self-Appraisal and Teacher Reflection: None of the nine teachers had ever gathered feedback on their teaching from their students, and they were apprehensive about using the Student Opinion Form (SOF). We discussed the SOF at a group forum before they used it. This meeting yielded the best discussion of questions about teaching that I had ever experienced before in working with teachers. The meeting, scheduled for 1.5 hours, extended to 3 hours. A number of modifications which satisfied all teachers were made to the form. Each teacher subsequently trialled the SOF with their classes and reported back seven days later to a further meeting which considered the value of the feedback that they had gained. Two of the teachers had decided to use the form with all of their classes and had carefully analysed the different responses from each class, and each teacher had suggested reasons why the responses differed from one class to another, that is, they had subjected their lessons to detailed self-appraisal. One teacher had written a detailed self-appraisal. The major surprise to me was that the teachers wanted to share their findings from the form, and were eager and enthusiastic to discuss their interpretations with the larger group after only three sessions. The provision of the SOF provided a focus for a discussion which was very rich and stimulating, and it was this discussion which has affirmed my confidence that self-reflection and self-appraisal can be an integral part of any growth-based teacher appraisal strategy. This was a biased sample of teachers since they had all volunteered to engage in a professional development activity in their own time, but it offers some hope that it might be applicable to all teachers.

Gitlin and Smyth (1989) report a similar result with teachers engaged in clinical supervision during a post-observation conference: "All of a sudden, boundaries disappeared and we just started talking about things in common....justifying why we did these things or saying that perhaps we shouldn't be doing them..." (p.80)

The Interview

The transcripts of interview provided an insightful source of data. It became obvious while conducting the interviews that students are very aware of many aspects of teacher competency, and are continually assessing their teachers. Eleven students were interviewed. Though the interview asked questions related to science, many of the students made comments of a more general nature which will also be referred to below.

Six of the eleven students were males (with five male and one female science teachers), and five students were females (with two male and three female teachers). I disregarded the sex variable as a factor in my question schedule. The students attended four different schools, with only two students studying in the same class. Five students were attending a secondary college (Years 11 and 12 only), and they were studying elective science subjects.

In answer to the question "Do you like Science?", 8/11 students said "Yes", but only 4/11 said that they looked forward to science lessons. In each of the four cases, students looked forward to the science lesson because of the teacher. For example, "She makes biology interesting by putting it into the global perspective. She goes beyond the syllabus and makes it really interesting because she doesn't put any limits on us" and, "He is really organised and manages time really well...you get the feeling that he really wants to teach it and enjoys it and wants us to enjoy it too".

Of the seven students who did not look forward to science lessons, a number of reasons were given, not all of which related to the subject: "It is obvious that she doesn't know her work, and she rambles on and on and can't answer most of the questions that we ask her". [This student liked science, but not science lessons]. "My teacher doesn't like teaching science, and he told us that the principal told him he had to teach it because they are short of science teachers. Would you like to be in that sort of a class?"
"My teacher sounds like a tape recorder, and has got no sense of humour. Science is boring and I hate it".

"What is your science teacher like?" drew forth a range of responses which often did not relate specifically to the subject but more to the inter-personal communication skills of the teacher. "My physics teacher is too serious. He never smiles and he seems to be only interested in physics and that's all, but at least he knows his stuff and how to teach it well". "My science teacher calls students stupid if they don't answer questions properly. We don't like him much". "My teacher gets very excited about science, and she obviously loves it. She gives us lots of projects to do, and she seems really keen for us to find our own things out. She helps us get excited too. I like science because of my teacher, and I think I am learning a lot too". "My teacher is too hung up about techniques. He won't let us have any fun".

There were very interesting responses to the question relating to the amount of knowledge possessed by the teacher. Students believed that they were able to gauge whether their teacher knows much science, but many based their judgements on the competence exhibited by the teacher: "She really cares about us, and is really dedicated to teaching. She is such a good teacher that she must know a lot of science". "My teacher is competent, good-natured and knowledgeable. He stays back after school to help us if we can't understand it". "She has helped me in Biology because she has told us how she did honours in zoology so she must know a lot about it".

The research into the "good" teaching of invalid information (Happs, 1987) is supported by comments such as those reported above made by students about their teachers' knowledge of science. Students' faith in the validity of knowledge provided by a "dynamic, forceful and convincing teacher" can result in student misunderstandings which might be difficult to change (Tobin & Fraser, 1987, p. 204). The question about the ideal science teacher yielded a range of responses: "A teacher can be extremely clever but if he cannot teach effectively, he is still not a good teacher". "The ideal teacher teaches beyond the textbook and syllabus, and uses lots of examples to make sure that students understand the concept. He also needs a sense of humour". "An ideal teacher would be competent, easy-going and caring"

The final question "Would you like to become a secondary science teacher?" yielded a totally negative response. None of the eleven students wanted to become a teacher, and eight of them indicated that it was their science teachers who were persuading them to consider other jobs: "I would not want to be a teacher because the work is hard and nobody appreciates you. My teacher reckons I should look at something else". "You have to teach immature juveniles and you get too much criticism from parents and students. Also, preparing experiments all the time is too much hard work". "Teachers get blamed for everything these days".

The interview responses could be summarised into three categories: students have strong affective reactions to teachers which in turn affect their perception of the cognitive demands of the subject; students appear to believe that they can tell whether a teacher "knows" much science, and ideal science teachers needs to know their subject and relate it to the "outside world".

How do the two bits of research reported above relate to the broader issues of teacher appraisal? How can teachers make better use of students to gain feedback on their performance?

SUMMARY

It is apparent that in the immediate future, teachers must face the likelihood that some indicators of the quality of their performance will be mandated in some form or other by government. Unless teachers take the initiative at this time and become more active in monitoring their own performance and responding to any deficiencies which might be identified, they will "cede, by default, hard-won professional territory to school councils or other bodies in which lay persons may play the dominant role in defining what constitutes competent teacher performance" (Hewitson 1986). The consequence for lack of immediate action may be a scheme for evaluation which places emphasis on an "accountability" model instead of a "teacher development" model, and it is the "simple-minded conceptions of accountability (which) will supplant investment in teacher training and development" (Ingvarson, 1989, 142). An accountability model demands that teachers reach levels of "minimum competence". It is clearly not "legal" nor sensible to compel teachers who are minimally competent (most teachers) to participate in teacher development programs. Teachers are not normally required to demonstrate skills above the level of minimum competence. The motivation to participate in growth-orientated systems must come from within each teacher. For all teachers who can find that inner motivation, there is the promise of positive impact.

My research in this area has shown that teachers must be willing to engage in professional growth programs if the program is to have any impact. I suggest that teachers with this motivation should establish within their own school a group with a desire to improve the quality of their teaching. They should agree to gather some feedback from their own classes as a first step in assessing their impact on students' learning and on the quality of their teaching, and to write self-appraisals of their teaching based on this feedback from their students. Teachers should be prepared to share these written self-appraisals of their teaching with the group, and be prepared to explain their decisions, strategies, and routines under challenge from the group. If the environment is supportive and the group is genuinely interested in the formative evaluation of teaching, then this strategy will afford considerable assistance to the improvement of teaching and learning.

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APPENDIX 1
INTERVIEW SCHEDULE

Interviewer:

I am going to ask you some questions about your Science Teacher, and about your science lessons. I will be the only person to hear your responses, and I don't even want to know your name. I want you to tell me exactly how you feel about science and how you feel about the way that your teacher teaches you.

1. Is your teacher a man or a woman?

2. Do you like science? Do you look forward to science lessons?

3. Why do you like/look forward to (or why don't you) science lessons?

If teacher is mentioned in 3 or 4, go to 5.
If not, then ask 4. Is it anything to do with your teacher?

5. What is your teacher like? Describe him/her to me.

6. Follow up the responses to elicit more information.

7. Do you think that he/she knows much science?

8. What sort of science teacher would you like to have if you had a choice? Describe what he or she should be like.

9. Would you like to become a secondary science teacher? Why? Why not?

APPENDIX 2
STUDENT OPINION FORM

This form should be returned directly to the teacher

Directions:
This is an attempt by the teacher to improve the class by listening to your reactions. Please respond to each statement below by ticking one of the columns to the right. Be as honest as possible. Do not sign your name.

	Most of the Time	Some-times	Hardly ever	No Opinion
1. This teacher has encouraged me to be interested in the subject.				
2. I try to take an active part in class.				
3. This teacher begins class promptly without wasting time.				
4. This teacher seems to know the subject that we are studying.				
5. This teacher is well organized.				
6. Homework is worthwhile and is not just to keep us busy.				
7. I am assessed fairly in this class.				
8. This teacher avoids treating certain students as favourites.				
9. This teacher is reasonable in what students are expected to do.				
10. This teacher shows understanding and concern for students.				
11. This teacher respects the expression of different opinions.				
12. This teacher talks too much about personal problems that should not be brought into the classroom.				
13. This teacher explains lessons clearly.				
14. I have opportunities to express myself in class.				
15. This teacher spends too much time talking.				
16. This teacher seems to understand how much I know and helps me learn.				
17. This teacher uses different methods and teaching aids to help me learn.				
18. This teacher goes over our written work and returns it to us.				
19. This teacher listens and tries to understand what we're saying.				
20. This teacher keeps the class under control enough to allow us to learn.				
21. This teacher tries to make the course interesting.				
22. This class is a place I like to be.				

(adapted from Duke, D. (1987) School Leadership and Instructional Improvement. New York: Random House. Page 118)

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CHEMISTRY CONCEPTS AND GROUP COGNITIVE STRUCTURE: A STUDY OF UNDERGRADUATE NURSING STUDENTS

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ABSTRACT

The long term aim of this study is to document changes in the nature and level of conceptual understanding revealed by a cohort of undergraduate nursing students. The outcome of such a study may be used in future review and redesign processes by curriculum planners. Conceptual understanding of physiology and pharmacology, areas which are central to nursing studies depends, in turn, on an understanding of certain chemical concepts. This paper describes the group cognitive structure of 60 first year preservice nursing students, with respect to 21 basic chemistry concepts. Group cognitive structure is represented by non-metric multidimensional scaling of data obtained from individual concept maps prepared by students. The impact of prior studies in chemistry on the level of understanding revealed is discussed.

INTRODUCTION

With the transition of nurse education from hospital schools of nursing to universities, considerable changes have occurred in the nature and conceptual level of chemistry in the curriculum. Chemistry concepts form the basis for many areas of study in undergraduate nursing programmes, viz, physiology, pathophysiology and pharmacology, but not all students entering such programs have studied chemistry to Year 12.

Curriculum design processes must take into account the background of students entering such a course, and monitoring of the changes in students' understanding resulting from instruction is desirable for their future review. Programme evaluation can examine changes in understanding of individuals or whole groups, and provide information about desirable entry requirements, the need for bridging courses or remediation for certain entrants and changes to the curriculum itself. This paper will describe an analysis of students' understanding of chemistry concepts on entry to a tertiary nursing program.

Cognitive approaches to learning theory emphasize the interaction of the learner with the environment and the construction, through experience, of a set of concepts and schemata. Networks of these concepts form the cognitive structure of the individual (Ausubel et al., 1978; Anderson, 1980). Shavelson (1985), cited by Jonassen (1987), demonstrated that correspondence between a student's cognitive structure and subject matter structure increases with study and is related to achievement.

Various techniques based on the idea of semantic proximity of concepts have been used to map cognitive structure. It is assumed that the more closely two concepts are related in a person's cognitive structure, the more closely they will be placed in a semantically oriented task. Hambleton and Sheehan (1977) studied associations yielded by a free sort of concepts by the subjects; Gorodetsky and Hoz (1980) used concept profile analysis and later (1985), a free sort of concepts followed by latent partition analysis. Diekhoff and Diekhoff (1982) used paired associations analysed by multidimensional scaling (MDS) and Jonassen (1987) based a study of physics concepts on an analysis of patterns noted by non-metric MDS. A matching task was used to establish relational links between propositional statements and skills in chemistry by West, Fensham and Garrard (1985). Changes in group cognitive structure following instruction in chemistry have been described by Gorodetsky and Hoz (1985) and in physics, by Champagne, Gunstone and Klopfer (1985).

AIM

The long-term aim of this study is to identify and record changes in the individual and group cognitive structure of 60 undergraduate students of chemistry over 2 years of a 3 year Diploma of Health Science (Nursing) programme. This paper will report on the first year of the study in which comparisons have been made between the group cognitive structure of students entering the programme with Year 11 or 12 chemistry or equivalent and those with no study of chemistry since Year 10. Comparisons will also be drawn between achievement levels of students who have studied chemistry and those who have not, the details of which were recorded as well as age and gender.

METHODS

Assessing individual cognitive structure

Mapping technique: To generate a map of group cognitive structure, the technique of concept mapping (Novak & Gowin, 1984) was used. Students were given prior instruction on the technique of concept mapping, using examples unrelated to chemistry. Each student was handed an envelope containing 21 separate pieces of paper, each bearing the label of a concept to be mapped (Table 1) and a sheet of paper to which the labels were to be attached.

TABLE 1

CONCEPTS USED IN CONCEPT-MAPPING TASK.

Energy	Salts	Food
Electrolytes	Matter	pH
Electrons	Water	Chemical Reactions
Hydrogen	Health	Atoms
Solution	Solvent	Nitrogen
Carbon	Oxygen	Enzymes
Human Body	Molecules	Ions

Students were instructed to position the concept labels in an hierarchical arrangement with the most inclusive concept at the top and relationships between concepts indicated by arrows bearing a linking word descriptor. Figures 1 and 2 represent two examples of such student concept maps.

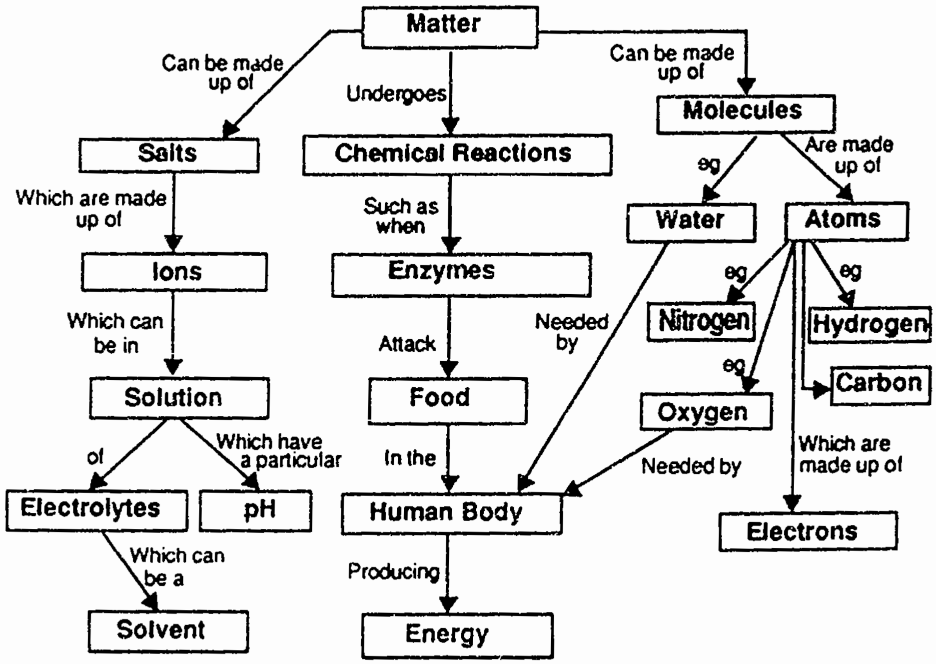


Fig. 1 A concept map drawn by a student with Year 12 Chemistry

Scoring technique: The scoring protocol adopted followed that suggested by Novak and Gowin (1984). All valid propositions labelled with an appropriate linking term were given one point. Any valid cross links between segments of the concept hierarchy were allocated two points but no points were given for the establishment of hierarchies. Each individual student was thus given a total map score.

Generating a representation of group cognitive structure

Data were pooled for each of the two groups of students (with and without chemistry) and the frequencies with which any two concepts were joined by an arrow in a top/down relationship were counted: thus two separate matrices of total paired associations between concepts were assembled. The PROXIMITIES command of SPSS-X (Norûsis/SPSS Inc., 1988) was used to generate proximity matrices from the raw frequency data, using specified proximity measures. Non-metric multidimensional scaling using ALSCAL (SPSS-X) produced two-dimensional representations of the 21 concepts where the distance between them represented the frequency of their paired associations in the original data. ALSCAL uses the alternating least-squared approach proposed by Takane, Young and deLeeuw (1977) and modified by Young, Takane and Lewyckyj (1978). The scaling model used in these analyses was the Euclidean distance model.

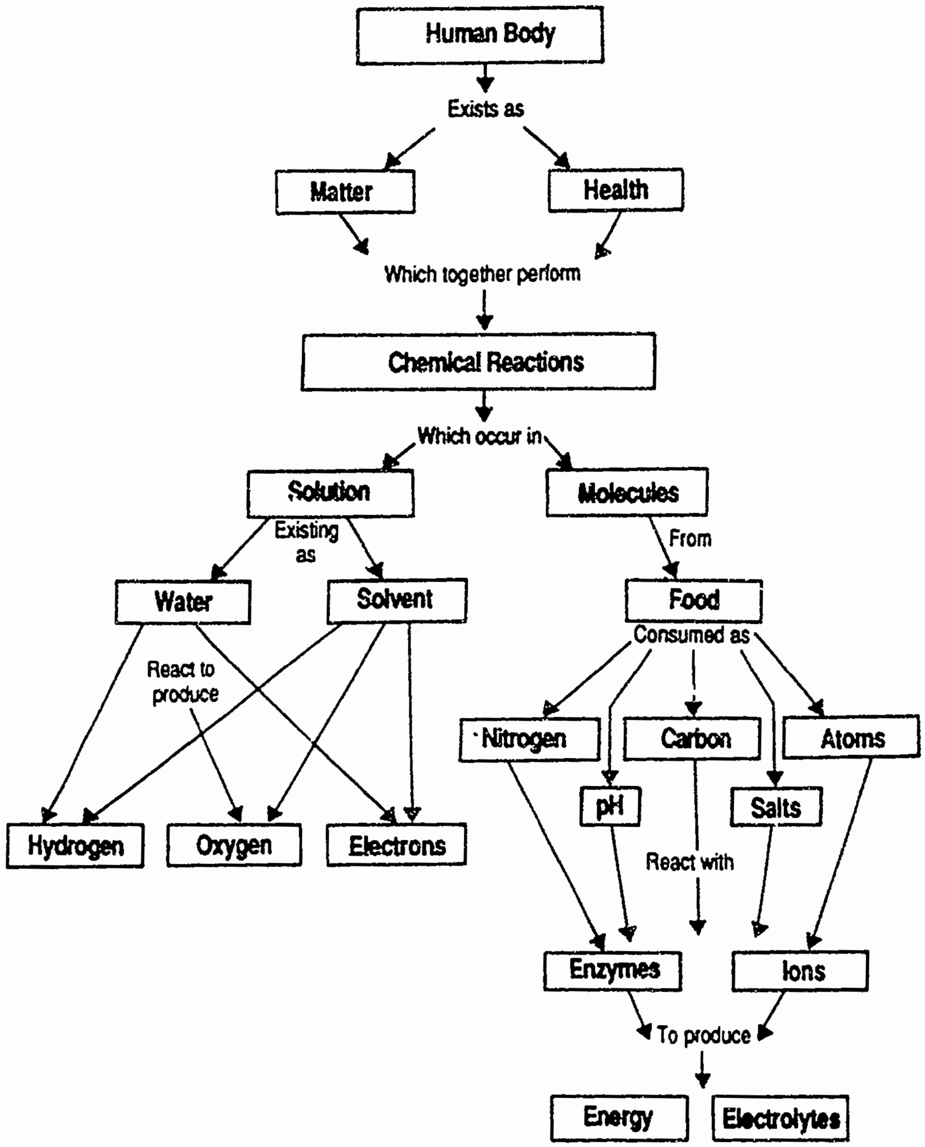


Fig. 2 A concept map drawn by a student without chemistry to Year 12

As data input to the program were at the nominal level of measurement, the options for analysis were limited. The frequency data were used to generate a dissimilarity matrix for input to ALSCAL. The PROXIMITIES command standardized the values within each case (preceding or top concept) and proximity measures were computed between cases.

The program generated a two-dimensional solution with very high measures of "fit" for each input matrix, i.e. Kruskal's STRESS and the squared correlation RSQ (Kruskal, 1964).

The Students

The concept-mapping task was completed by 60 (51 female, 9 male) students on their first day of semester 1, in the Diploma of Health Science (Nursing) at Australian Catholic University (Queensland), formerly McAuley College; 16 were classified as mature-aged entrants and 44 as school leavers. Only 13 students had completed Years 11 and 12 Chemistry, although two others had undertaken TAFE bridging courses.

As the satisfactory completion of at least one science subject to Year 12 was a requirement for entry to the course, all school-leaver entrants had completed Biological Science and three also had studied Physics. The students' results on the mid-semester and end-of-semester examinations involving chemistry became available in due course.

RESULTS

Analysis of student scores

Significant differences between the mean individual conceptual map scores for students entering the program with chemistry ($X = 19.1 \pm 3.6$) and without chemistry ($X = 11.6 \pm 1.6$) were revealed by the "t" test ($t = 3.07$, d.f. = 58, $p < 0.01$). Similarly, students with chemistry achieved mid-semester results ($X = 72 \pm 2.73$) significantly higher than students without chemistry ($X = 57 \pm 3.07$), ($t = 10.63$, d.f. = 58, $p < 0.001$). End-of-semester results followed a similar pattern ($X = 70.5 \pm 5.1$ and 60.6 ± 3.0; $t = 3.2$, d.f. = 57, $p < 0.05$).

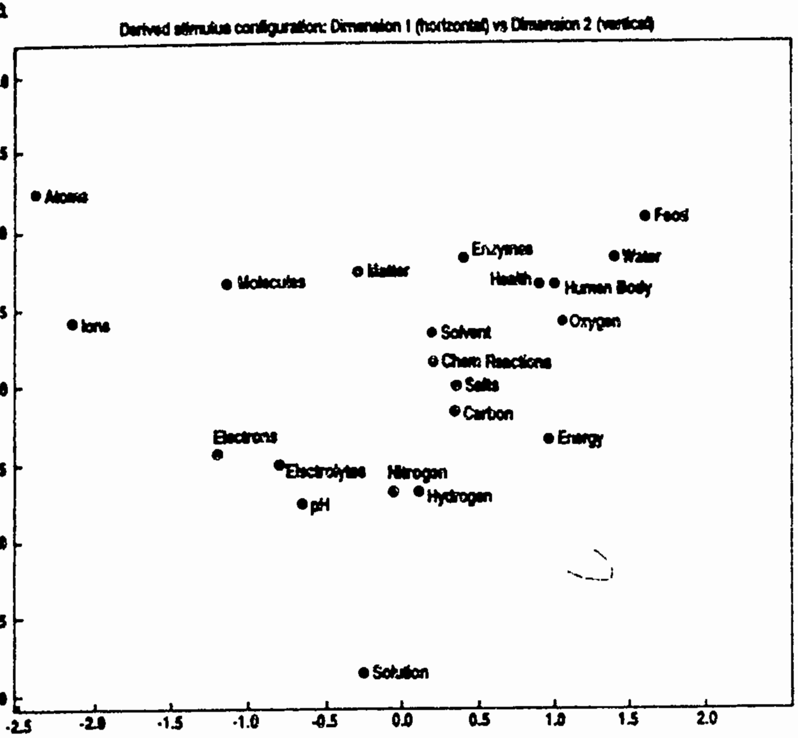
Analysis of paired associations of concepts

The technique of non-metric multidimensional scaling represents the association between the concepts as derived distances, plotted on a two-dimensional figure. The more closely the points are represented on the figure, the more frequently they have been associated in the raw data.

Fig. 3(a) represents the pooled data obtained from students who have not studied chemistry since year 10; most of these have studied biology to year 12. The configuration of concept labels in the two-dimensional solution reflects the frequencies with which students have linked the words in the concept mapping task.

Individual concept maps revealed that the majority of the students without chemistry chose either human body or health as the most inclusive concept, closely followed by the words associated with human needs, i.e.'food','water','oxygen'. This tendency is also apparent in the group map in Fig. 3(a). 'Enzymes' and 'energy' were often linked to human body by words indicating their association with living material. More distantly placed concept labels such as 'atoms', 'ions','molecules','matter' were associated with each other but not with the human body/health labels. The word 'solution' is isolated from others, apparently as a result of the semantic interpretation used by a number of students i.e. that a solution is that which leads to the solving of a health related problem. The group cognitive structure revealed by this technique shows a clear conceptual orientation to health and the human body as organizing constructs.

a



b

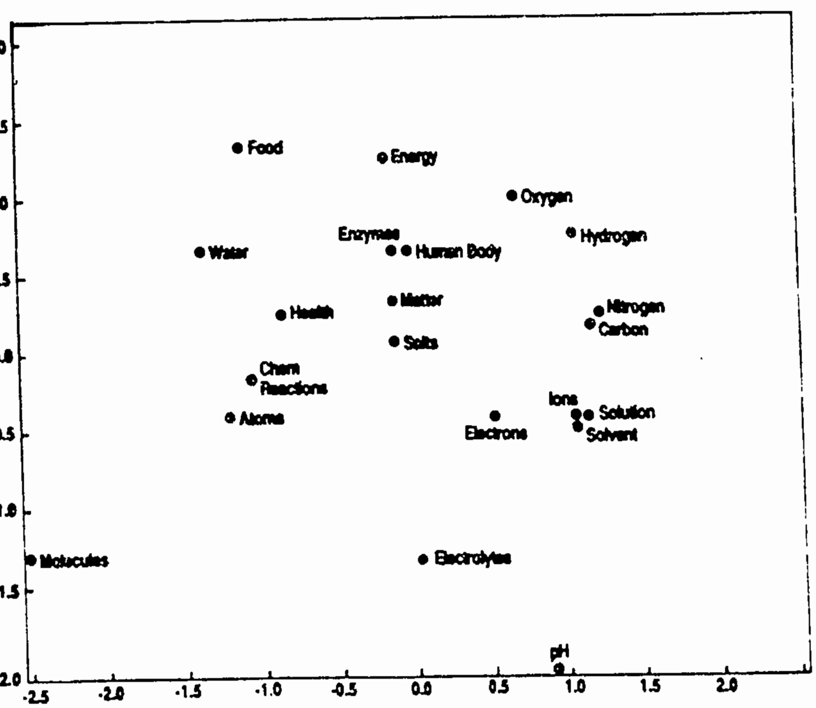


Fig. 3 A two-dimensional configuration showing associations between concepts, from non-metric multidimensional scaling:
(a) by students without chemistry to Year 12;
(b) by students with Year 12 Chemistry

Fig. 3(b) represents the pooled data from students who had studied chemistry to year 12. The configuration obtained from the analysis reveals a structure more closely aligned to the structure of the discipline. In most cases individual students had chosen the word 'matter' as the most inclusive concept and closely linked words such as 'oxygen','hydrogen','nitrogen' and 'carbon' as examples of forms of matter. Nearly all these students linked 'solution' and 'solvent' together and 'ions','electrolytes' and 'pH' were associated. 'Enzymes' were seen as components of the body and 'food' as the source of energy for the body.

The most obvious differences between the two groups of students related to their choices of the most inclusive concept, and their ability to establish valid relationships between concepts. Students with chemistry represented concepts with a surprising degree of concordance which reflected a discipline orientation. The non-chemistry students showed a high level of similarity in the initial stages of their concept maps involving health, the human body and its needs. As the individual concept map scores revealed, many non-chemistry students were not able to nominate valid propositional links between paired concepts and these were linked almost at random.

DISCUSSION

This study has demonstrated that prior knowledge of chemistry can have an important influence on student achievement and the way in which knowledge in constructed in an undergraduate nursing program.

Prior studies in chemistry have been shown to significantly influence two dimensions of student performance. Students entering with previous study of chemistry achieved examination results that were significantly higher than those without chemistry. Secondly, those entering with chemistry were able to prepare a concept map with a significantly greater number of valid propositional links.

Qualitative differences in the organisation of individual concept maps suggest that the two groups of students, bring with them on entry to the program, different views and different levels of understanding.

One group, the majority, has a human/health centred view while the chemistry minority has a matter/chemical reaction orientation. Recognition of such differences between the groups may provide educators planning a curriculum with a basis upon which to proceed; to adopt the concepts of health and the human body as the organizing constructs in a curriculum designed to introduce chemical concepts. This may help to dispel some of the negative attitudes which students without chemistry can sometimes bring to nursing programs.

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HOW CONFIDENT ARE PRIMARY SCHOOL TEACHERS IN TEACHING SCIENCE?

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ABSTRACT

The recent national Discipline Review of Teacher Education in Mathematics and Science outlines the lack of confidence of many preservice primary school teachers in teaching science. This study explores the attitudes of 170 primary school teachers in a Perth school district.

By means of a simple questionnaire the perceptions and attitudes of these teachers about the following aspects have been examined: (1) background understanding of science; (2) preservice training; (3) interest in teaching science; (4) skill in teaching science; (5) confidence in the plant, animal, matter, energy areas, and (6) time spent teaching science. Besides compiling frequency responses for all teachers on these aspects comparisons have also been made on the basis of: (1) gender; (2) time of graduation, and (3) grade level taught.

INTRODUCTION

While there are a number of primary school teachers who teach science with enthusiasm, the general impression one gains is that this is the exception rather than the rule. A common reason given for this situation is that primary school teachers lack confidence in teaching science.

The recent national Discipline Review of Teacher Education in Mathematics and Science (DEET, 1989) also outlines the lack of confidence of many preservice primary school teachers in teaching science especially in the physical sciences.

THE STUDY

The purpose of this study was to explore the level of teachers' confidence through a simple tick response two page questionnaire. The questionnaire items are outlined in Table 1. Some of these items were refined from part of a questionnaire developed by Rennie, Parker and Hutchinson (1985). The target population was primary school teachers in the Cockburn School district, part of the Perth metropolitan area. The questionnaires were distributed and collected through the principals and science co-ordinators. To preserve anonymity teachers returned the completed forms in a sealed envelope to the principals/co-ordinators. Of 24 schools, 21 returned questionnaires; 170 teachers responded, an 88% return rate.

The survey attempted to examine the teachers' perceived background understanding, training, interest, skill and confidence in teaching science. These factors were also examined in terms of the teachers' gender, time of graduation and grade level taught.

RESULTS AND DISCUSSION

Responses to the items are expressed as percentages in Table 1. Information on item 2, which was 'grade level taught' and item 3 'graduation year' were not included on this table.

Although most teachers indicated that they were confident with their understanding of background information, a substantial percentage (27%) said some preparation was needed. A similar large percentage (34%) felt the training they received to teach science was inadequate.

The statistic of most concern was that more than one quarter of teachers (28%) were not motivated to teach science.

As to confidence in teaching the various components of science, only a small percentage of teachers lacked confidence in teaching Plants (7%) and Animals (8%). As one would expect the lack of confidence was much higher for the physical sciences with a substantial number not confident with Energy (32%) topics compared with Matter (19%).

Despite the lack of interest and confidence of teachers it was perhaps surprising to find almost all teachers (94%) indicated they taught science each week with the average time being one hour per week.

TABLE 1
PERCENTAGE OF TEACHERS' RESPONSES TO ITEMS

Respondents: N = 170

Item No.	Response	Percentages
1. (Sex)	Male	30.6
	Female	69.4
4. (Understanding of background)	Extensive	15.3
	Adequate	57.6
	Some preparation needed	27.1
5. (Training in Science Teaching)	Extensive	7.7
	Adequate	58.2
	Inadequate	34.1
6. (Interest in Teaching Science)	Very Motivated	18.8
	Motivated	53.5
	Not really motivated	27.7
7. (Skill in Science Teaching)	Highly competent	8.2
	Competent	77.1
	Struggling	14.7
8. PLANTS (Confidence with Science Components)	Highly confident	33.5
	Confident	59.4
	Not confident	7.1
MATTER	Highly confident	20.0
	Confident	60.6
	Not confident	19.4
ANIMALS	Highly confident	37.6
	Confident	54.7
	Not confident	7.6
ENERGY	Highly confident	18.2
	Confident	49.4
	Not confident	32.4
9. (Time teaching Science weekly)	0 Min	5.9
	30 Min	12.4
	60 Min	64.7
	90 Min	12.4
	120+ Min	4.7

TABLE 2

MEAN VALUES FOR SURVEY ITEMS 4 - 8 BY GENDER

Item No.	Response	Weighting	Mean Values Male	Mean Values Female
4.(Understanding of background)	Extensive	3		
	Adequate	2		
	Some preparation needed	1		
			2.10	1.79
5.(Training in Science teaching)	Extensive	3		
	Adequate	2		
	Inadequate	1	1.79	1.71
6.(Interest in teaching Science)	Very motivated	3		
	Motivated	2		
	Not motivated	1	2.17	1.80
7.(Skill in teaching Science)	High competent	3		
	Competent	2		
	Struggling	1	2.12	1.86
8.(Confidence with Science components)	Highly confident	3		
	Confident	2		
	Not confident	1		
PLANTS			2.21	2.29
MATTER			2.31	1.87
ANIMALS			2.19	2.35
ENERGY			2.17	1.72

Table 2 outlines the responses between male and female teachers. Since each of the items required the teachers to choose from a three point scale, the responses have been valued as 1,2, or 3 as indicated in Table 2. The mean values for female teachers are all less than those for male teachers with the exception of confidence in teaching plants and animals.

Although the mean values differ, "t" tests indicate none of these differences was significant at the 5% level. The difference between males and females was closest to significant in the areas of interest in teaching science ($p=0.13$) and confidence in teaching the physical sciences of Matter ($p=0.058$) and Energy ($p=0.066$).

TABLE 3

EXAMINATION OF SURVEY ITEMS 5, 6 AND 8 BY
DECADE OF GRADUATION FROM TEACHER TRAINING

Decade of Graduation	Training Item 5	Interest Item 6	Plants Item 8 Mean Values	Matter	Animals	Energy
1950/59	1.64	2.08	2.23	2.15	2.39	1.77
1960/69	1.89	2.04	2.39	2.00	2.32*	1.97
1970/79	1.78	2.00	2.25	2.03	2.33	1.87
1980/88	1.76	1.73	2.24	1.93	2.26	1.81

* Three respondents failed to indicate graduating year.

In Table 3 the teachers' responses are examined in terms of their time of graduation. None of the results is significant. However the mean value of the interest aspect of teachers who graduated in the eighties is slightly less than those who graduated earlier.

TABLE 4
EXAMINATION OF SURVEY ITEMS 6 AND 8
BY YEAR LEVEL CURRENTLY TAUGHT.

Year Level	Interest	Plants	Matter Mean Values	Animals	Energy
Junior Yrs 1,2,3	1.74	2.35	1.85	2.38	1.71
Middle Yrs 4,5	2.03	2.24	2.15	2.24	1.95
Upper Yrs 6,7	2.08	2.15	2.12	2.23	1.98

The responses to the teachers' interest and confidence in teaching science are examined in Table 4 relative to the year level which are taught by them. Junior primary school teachers would appear to be less interested in teaching science and less confident with the physical sciences. This is not unexpected since there are a greater proportion of female junior primary teachers. These results, however, are not significant at the 5% level.

CONCLUSIONS

The results of this study reinforce the concerns about the teaching of science in our primary schools. It is important for strategies to be found to tackle the problems associated with teachers' lack of interest and lack of confidence in teaching science (especially physical science) in the primary school.

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THE INVESTIGATION OF SCHOOL EFFECTS ON STUDENT ACHIEVEMENT IN SCIENCE: A MULTILEVEL ANALYSIS OF EDUCATIONAL DATA

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ABSTRACT

The Second International Science Study provides a large Australian data base for the purpose of secondary analyses. This data base consists of a large number of student and school level variables which were examined with reference to the students nested within the schools. Multilevel analysis involves the use of the hierarchical linear model to adequately compensate for variability between-schools, as well as within-schools. The role of the school organization and effects such as the average student ability and average social factors were found to substantially influence student achievement in science. These school effects were also found to influence boys and girls differently with respect to their science achievement as measured by the tests in this study.

INTRODUCTION

The Second International Science Study was conducted for the International Association for the Evaluation of Education and coordinated by the Australian Council for Educational Research. This paper presents some results of the study which reveal significant relationships between school effects and student performance. The importance of school effects on student performance has been underestimated by the general community of educational researchers. As Keeves and Cheung (1990) have pointed out, educational researchers have continued to use simple random sampling methodology to test complex samples and simple regression procedures which do not account for differences between group (such as schools or classrooms) characteristics influencing student performance.

The First International Science Study focused on the home and school environment and student achievement, using the student as the unit of analysis (Husen, 1967). This type of analysis did not adequately address the issue of school level differences contributing towards statistical significance tests. Studies in the United States tried to compensate for this problem by looking only at school level differences. For example, Coleman et al. (1966) used the school as the unit of analysis.

The analysis of gender differences in science achievement and attitudes between different school types (government, Catholic and independent) should account for variations between schools. Raudenbush and Bryk (1986) point out the fallacies of research findings which ignore the potential effects of the school or classroom as sociological units, citing many research studies with doubtful inferences. Their reanalysis of data from a random sample of US high schools illustrates technical and conceptual advances facilitated by hierarchical linear modelling and shows that the relationship between socioeconomic status and mathematics achievement varies substantially across US high schools, and that much of this variation is attributable to school type (public versus Catholic). Distinguishing between micro parameter variance (such as school or classroom) and the sampling variance was possible with this model. Raudenbush and Bryk were able to partition the socioeconomic effect into within- and between-group components which yielded an estimate of the school type effect substantially different from earlier estimates. Similarly, Lee's (1986) reanalysis of data from the High School and Beyond study (Coleman et al., 1966; Haertel et al., 1987) revealed that differences between public and Catholic schools in the United States were attributable to the curriculum and the discipline policies of the schools.

THE HIERARCHICAL LINEAR MODEL

The Hierarchical Linear Model (HLM) provides a strategy for handling problems such as aggregation bias in standard error estimates and erroneous probability values in hypothesis testing of school effects. The HLM can be used to deal with two types of research: (1) school effects and (2) growth curve applications: time-series observations within individuals. The purpose of this research was to focus on those school effects predicting student performance. The use of regression coefficients estimated within units of analysis as outcome variables in a regression between units is described as follows by Raudenbush and Bryk (1986). The within-unit model specifies the relationships among the various student level characteristics, X_{ijp} (termed the within-unit model in the HLM), and an outcome variable of interest y_{ij}. We have a separate regression equation for each school (within-unit) of the form:

$$y_{ij} = \beta_{j0} + \beta_{j1}X_{ij1} + \beta_{j2}X_{ij2} + \ldots + \beta_{jP-1}X_{ijP-1} + R_{ij}$$

where, y_{ij} = the outcome score or scale for student i in school j;
X_{ijp} = the values of the student level characteristics p for student i in school j;
R_{ij} = the random error
β_{jp} = regression coefficients that characterize the structural relationships within school j;
for, i = $1 \ldots n_j$ students within school j;
j = $1 \ldots K$ schools; and
p = $1 \ldots P\text{-}1$ independent variables in the first stage model.

In addition, the random errors R_{ij} are assumed to be normally distributed within each school with a mean of zero and constant variance s^2 (the residual sampling variance). This is a standard linear model with one major exception: the within-school regression coefficients, β_{jp}, are allowed to vary across schools. The variations between schools has a between-unit model of the form extended from the school regression coefficient β_{jp}

$$\beta_{jp} = q_{0p} + q_{1p}Z_{1j} + q_{2p}Z_{2j} + \ldots + q_{Q-1p}Z_{Q-1j} + U_{jk}$$

where, U_{jk} = represents random error in this school level equation;
Z_{qj} = values of the school level variables (termed between-unit variables in HLM) for school j;
q = $0 \ldots Q - 1$ independent variables in the school level model; and
q_{qp} = the regression coefficients that capture the effects of school level variables on the within-school structural regression coefficient, β_{jp}.

This HLM, first proposed by Burstein (1980), enables researchers of school effects to achieve several important objectives:

1. The decomposition of Hierarchical Linear Model relationships into between- and within-school components. The model permits estimation of both an average within-school and a between-school regression equation.
2. A multivariate formulation for examining the effects of between-school factors on within-school phenomena (e.g., the socio-educational level and achievement

relationship).

3. The estimation of within-school regression coefficients that are adjusted for other confounding variables within schools.
4. The estimation of regression coefficients that are weighted in proportion to their precision in the regression against school level factors.
5. More accurate estimation of within-school regression coefficients than are available through a traditional regression model which uses only the data from school j. (Burstein, 1980)

THE SAMPLE

The data consisted of three sample groups: 10-year-old, 14-year-old and Year 12 students. Each data base consisted of a stratified random sample. In Australia, strata were formed by sampling according to the individual states/territories and school types (government, Catholic, and independent). This paper focuses on only one population, 14-year-old students, the sample consisting of 4917 students in 233 schools. This study examined some characteristics of schools which appeared to promote higher achievement and a more equitable distribution of achievement across social strata of students and between male and female students. The effects of schools on student performance are multilevel in nature, making standard methodology both inadequate and misleading, and usually under-estimating the effects of the school. The HLM was used to investigate the effect of the social class of the school and the school organization, and the average verbal and quantitative ability of students in the school, on the achievement of students in the school.

MULTILEVEL ANALYSIS IN THIS STUDY

Of the three science achievement variables, sex differences in student performance were found to be greatest in physics achievement. Boys appeared to score higher than girls in physics sub-tests in all populations. For this reason, the multilevel analysis was performed using physics achievement as the student outcome (dependent) variable, in order to explain differences in science achievement. The use of the HLM in order to investigate the role of the organizational structure of the school influencing student performance has been documented by Bryk and Raudenbush (1989, pp. 159-204), Lee and Bryk (1989) and Raudenbush and Bryk (1986). This study sought to examine the role of school effects in explaining differences in science achievement and sex differences in science achievement.

Research on school effects involves a set of data analyzed at the individual student level, with the assumption that classrooms and schools affect students equally. However, when the effects vary among individuals and their contexts, this type of statistical analysis can be misleading (Bryk & Raudenbush, 1987). Ordinary least squares analysis provides information about the total variance, but not the between-and within-school effects. This paper endeavours to explain variations in student outcomes by first decomposing observed relationships into between- and within-school components.

THE EXPLANATORY MODEL

The software package HLM2 (Bryk et al., 1989) was used in an attempt to explain student differences in science achievement in terms of academic organization and socio-educational level of schools. School effects on sex differences in student attitudes towards science were aso investigated.

The within-school model representing the physics achievement (y_{ij}) for student i in school j is a function of various student background characteristics (x_{ijk}) and random error e_{ij}:

$$y_{ij} = \beta_{j0} + \beta_{j1}x_{ij1} + \beta_{j2}x_{ij2} + \beta_{j3}x_{ij3} + \beta_{j4}x_{ij4} + \ldots + \beta_{jk-1}x_{ijk-1} + R_{ij}$$

The β_{jk} regression coefficients are structural relations occurring within school j which indicate how the physics achievement in each school is distributed with regard to measured student characteristics. Each structural relation β_{jk} varies across the schools as a function of the school-level variables w_{ij} and random error U_{jk}:

$$\beta_{jk} = \gamma_{0k} + \gamma_{1k}w_{1j} + \gamma_{2k}w_{2j} + \gamma_{3k}w_{3j} + \gamma_{4k}w_{4j} + \ldots + \gamma_{p-1k}w_{p-1j} + U_{jk}$$

A school effective in equalizing the distribution of achievement would have a high average level of achievement, β_{0j}; negligible differences in socio-educational level, β_{1j}; strong differences in achievement for male and female students, β_{2j} ; weak differences in attitudes towards the importance of science, β_{3j}; and similar quantitative abilities, β_{4j}. Each of these parameters is hypothesized to vary across schools as a function of school-level differences in organizational structure. For this reason, a separate between-school model is hypothesized for each of the β coefficients. School characteristics which promote an equitable distribution of achievement among male and female students should demonstrate a positive relationship to average school achievement, a negative effect on the socio-educational differences (i.e. the school variables weaken the relationship between individual socio-educational and achievement) and a negative effect on the attitudinal and verbal abilities differences.

RESULTS

Variance Components

For the 14-year-old student population, three science sub-test scores and five attitude scales were analysed for variations in student outcomes as shown in Table 1. The three science achievement mean percent scores revealed greater student variations in physics achievement. The variation in physics achievement was 88.2% due to student differences and 11.8% due to differences in school characteristics. Of the five attitude scales, variations in attitude appeared to be associated with student characteristics, with only 3.2 to 4.0% variance due to school characteristics.

TABLE 1

VARIANCE COMPONENTS ANALYSIS FOR SCIENCE ACHIEVEMENT AND ATTITUDE SCALES FOR 14-YEAR-OLD STUDENTS (POPULATION 2).

Dependent Variable	Mean School Score	Within Schools Variance	Between Schools Variance	(%)	Total Variance
Sub-test					
Biology achievement	63.37%	497.85	60.59	(10.8)	560.13
Chemistry achievement	59.03%	1102.31	95.08	(7.9)	1201.47
Physics achievement	64.69%	370.24	49.99	(11.8)	422.35
Attitude Scale					
Enjoyment of school	0.0076	0.3138	0.0129	(3.9)	0.3267
Beneficial aspects of science	0.4059	0.1747	0.0057	(3.2)	0.1804
Harmful aspects of science	-0.1237	0.1927	0.0079	(3.9)	0.2006
Career in science	0.0054	0.2544	0.0083	(3.2)	0.2627
Difficulty of science	0.0471	0.3042	0.0128	(4.0)	0.3170

The Unconditional Model

The partitioning of variance in physics achievement among students into the within- and between-school components was achieved using the HLM program (Bryk, Raudenbush, Seltzer & Congdon, 1989) where only a random average physics achievement was specified for the within-school model:

$$Phys_{ij} = \beta_{0j} + R_{ij}$$

for 14-year-old students and an unconditional between-school model was also specified:

$$\beta_{0j} = \mu_j + U_j$$

The within-school variance was estimated as 370.24 and the between-school variance was 49.99 for 14-year-old students. The proportion of the total variance accounted for between schools was 0.118. An unconditional or random regression coefficient model was then fitted for physics achievement among 14-year-old students (TOT2PHYS). The student level characteristics which appeared to contribute towards variations in physics achievement were socio-educational level, sex, attitude towards the beneficial aspects of science, verbal ability and quantitative ability. These variables were fitted without any school effects variables in order to (1) determine the effects of sex upon the multilevel model by inclusion and exclusion of sex and (2) investigate the amount of variance reduction when only student level variables are included. Preliminary exploration of other attitude scales and student characteristics did not reveal substantial contributions towards variations in physics achievement.

The initial unconditional model (with no school level variables included at this stage) consisted of the following regression variables:

$$TOT2PHYS_{ij} = \beta_{0j} + \beta_{1j}SEL_{ij} + \beta_{2j}SEX_{ij} + \beta_{3j}GOODSCI_{ij} + \beta_{4j}TOT2V_{ij} + \beta_{5j}TOT2Q_{ij} + R_{ij}$$

where TOT2PHYS represents physics achievement, SEL represents socio-educational level index, SEX represents sex of the student, GOODSCI represents the students' attitude towards the beneficial aspects of science, TOT2V represents the verbal ability of the student and TOT2Q represents the quantitative ability of the student. The beta coefficients are described as:

β_{0j} = mean physics achievement for students in school j.

β_{1j} = the degree to which socio-educational differences among students in school j is related to their physics achievement.

β_{2j} = the degree to which sex differences in physics achievement related to their physics achievement.

β_{3j} = the degree to which attitude towards the beneficial aspects of science differences among students in school j is related to their physics achievement.

β_{4j} = the degree to which differences in verbal abilities among students in school j is related to their physics achievement.

β_{5j} = the degree to which differences in quantitative abilities among students in school j is related to their physics achievement.

Variables which had t statistics less than 1.5 were not included in this model. The chi square table below Table 2 presents the variance of the beta coefficients and the degrees of freedom. The same model was also investigated without sex in order to examine the differences between the two models and the role of sex differences in determining achievement. The estimated within-schools variance for the model with sex was 255.28 (Table 2). Table 2 revealed that the average adjusted school physics achievement among 14-year-old students was 64.63 percent, with the average gender gap of 6.08 (i.e., the average school difference between male and female achievement was 6.08 points); the average social class differentiation (the average within-school SEL achievement slope) was 2.74; the average school attitude towards the beneficial aspects of science differentiation was

4.15; the average verbal ability differentiation was 0.64; and the average quantitative ability differentiation was 2.11. These mean effects were adjusted for other variables in the model and were statistically significant at probability levels less than 0.05 (where computations for standard errors and significance tests in HLM is based upon the number of schools, rather than the number of students). Overall, this unconditional model was successful in reducing the within-schools variance from 370.24 (Table 1) to 255.28 (Table 2). This reduction in total variance in physics achievement was 31.05% leaving 68.95% residual variance unaccounted for by the unconditional model.

TABLE 2

UNCONDITIONAL MODEL FOR SEX DIFFERENCES IN PHYSICS ACHIEVEMENT AMONG 14-YEAR-OLD STUDENTS.

Slope	Beta β	Standard Error	T Statistic	p - Value
Base	64.63	0.53	121.30	0.000
Sel				
Base	2.74	0.71	3.86	0.000
Sex				
Base	6.08	0.63	9.63	0.000
Goodsci				
Base	4.15	0.63	6.59	0.000
Tot2V				
Base	0.64	0.05	12.28	0.000
Tot2Q				
Base	2.11	0.08	26.92	0.000

Within Schools Variance Sigma squared = 255.28

Chi Square Table

Random Parameter	Estimated Parameter Variance	Degrees of Freedom	Chi Square	p - Value
Base	55.68	198	1066.7	0.000
Socio-educational Level	10.40	198	199.49	0.457
Sex	20.94	198	267.25	0.001
Beneficial Aspects of Science	14.44	198	236.25	0.032
Verbal Ability	0.01	198	199.06	0.466
Quantitative Ability	0.17	198	220.59	0.130

<u>The Contextual School Effects Model</u>

The purpose of the contextual school effects model was to reduce the between-schools variance as much as possible in order to explain away the variance in physics achievement. Exploratory analyses were performed in order to determine which school effects explained the maximum amount of variance. The unconditional model for physics achievement among 14-year-old students was determined earlier to be:

$$TOT2PHYS_{ij} = \beta_{0j} + \beta_{1j}SEL_{ij} + \beta_{2j}SEX_{ij} + \beta_{3j}GOODSCI_{ij} + \beta_{4j}TOT2V_{ij} + \beta_{5j}TOT2Q_{ij} + R_{ij}$$

Each student level variable in the unconditional model was investigated for school effects and the following school effects model was found to fit well:

$$\beta_{0k} = \gamma_{0k} + \gamma_{1k}SEL_j + \gamma_{2k}Tot2v_j + \gamma_{3k}Mathxsel_j + \gamma_{4k}Tot2q_j + U_{jk}$$
$$\beta_{1k} = \gamma_{0k} + U_{jk}$$
$$\beta_{2k} = \gamma_{0k} + U_{jk}$$
$$\beta_{3k} = \gamma_{0k} + U_{jk}$$
$$\beta_{4k} = \gamma_{0k} + U_{jk}$$
$$\beta_{5k} = \gamma_{0k} + U_{jk}$$

The variance in physics achievement among 14-year-old students was estimated by the unconditional model to be 55.68 (Table 2). When the school effects were added to this model, the estimate of physics achievement variance was reduced to 19.17 (Table 3); this was a 65.57% reduction explaining the differences in physics achievement in terms of the average school socio-educational level, the average school verbal ability and the average school quantitative ability. The interaction between school quantitative ability and school average socio-educational level was not significant for the 14-year-old students, although it did make a contribution to explaining or reducing the variance. The reduction in variance indicates that school effects influence achievement to a greater extent than at first anticipated. These results suggest that the variation in physics achievement can be explained by not only the student level variables, socio-educational level, sex of the student, attitudes towards the beneficial aspects of science and quantitative ability, but also by the school effects variables average socio-educational level of the students in the school and average verbal and mathematical ability of the students in the school.

DISCUSSION

This study attempted to explain differences in student performance in science achievement. In addition, sex differences, found to be greatest and most consistent among student performance in physics achievement and in student attitudes towards school enjoyment, were investigated using a hierarchical model which accounted for variations in student characteristics as well as school level variables. The first stage in the multilevel analysis technique was to establish how much variation in physics achievement was due to school differences (between-school variance) and student level differences (within-school variance). Schools appeared to contribute approximately 10% towards variance in achievement among the 14-year-old students. The second stage in the investigation of sex differences in achievement was to establish a consistent and valid unconditional model. This model consists of student level variables only, which most efficiently explain the maximum amount of variations in achievement. Two types of analyses were performed: the first was a model consisting of socio-educational level of the student, sex of the student, an attitude variable (beneficial aspects of science), student verbal ability and quantitative ability. The second type of analyses involved estimating the model without the use of the sex variable. Instead, the model was applied to the students overall and then boys and girls separately. The unconditional model was found to explain 31% of variance in physics achievement among 14-year-old students. When the model was reestimated without sex, there was little difference in variance; sex appeared to account for 4 percent of the variance in physics achievement among 14-year-old students. The model appeared to fit 14-year-old boys and girls differently. The third stage in the multilevel analysis of sex differences in science achievement was the estimation of contextual models. Contextual models included school effects found to contribute significantly towards the explanation of differences in physics achievement and chemistry achievement. The school level variables found to contribute significantly towards explaining these differences were the average student socio-educational level within the school, the average verbal ability of the students within the school and the average quantitative ability of the students within the school. A contextual model was fitted for the 14-year-old students and appeared to fit boys and girls similarly in explaining 60 percent of the differentiation in physics achievement after the unconditional (student characteristics) model had been fitted. There was negligible difference in the variance explained by the model when sex was excluded from the model. This model left more unexplained variance among 14-year-old boys relative to 14-year-old girls.

TABLE 3

CONTEXTUAL SCHOOL EFFECTS MODEL FOR SEX DIFFERENCES IN PHYSICS ACHIEVEMENT AMONG 14-YEAR-OLD STUDENTS.

Slope		Gamma γ	Standard Error	T Statistic	p - Value
Base	β_0				
Base		23.66	4.77	4.96	0.000
Avsel		17.17	10.99	1.56	0.118
Tot2v		0.86	0.18	4.89	0.000
Mathxsel		-0.60	0.77	-0.79	0.431
Tot2q		1.52	0.30	4.99	0.000
Sel	β_1				
Base		2.59	0.71	3.64	0.000
Sex	β_2				
Base		6.03	0.63	9.53	0.000
Goodsci	β_3				
Base		4.15	0.63	6.58	0.000
Tot2V	β_4				
Base		0.64	0.05	12.21	0.000
Tot2Q	β_5				
Base		2.11	0.08	27.05	0.000

Within Schools Variance Sigma squared = 255.47

Chi Square Table

Random Parameter Value	Estimated Parameter Variance	Degrees of Freedom	Chi Square	p -
Base	19.17	194	516.60	0.000
Socio-educational Level	10.52	198	199.08	0.465
Sex	21.45	198	267.21	0.001
Beneficial Aspects of Science	14.53	198	236.08	0.033
Verbal Ability	0.01	198	199.05	0.466
Quantitative Ability	0.16	198	220.43	0.131

The HLMs presented in this study attempted to investigate those student and school characteristics which explain variations in physics achievement among 14-year-old students. In addition, sex differences in physics achievement were examined. The proportion of explained variance (R^2) for each HLM is computed by examination of the proportional reduction in original parameter variance ($Var(\beta_0)$) for the random parameter (mean achievement) shown in the corresponding unconditional models (the residual parameter variance from the chi-square tables presented earlier). The difference in parameter variance is the percentage of explained variance.

TABLE 4

SUMMARY OF RESULTS FOR PROPORTION OF VARIANCE EXPLAINED BY THE CONTEXTUAL ANALYTIC MODEL AMONG 14-YEAR-OLD STUDENTS.

	Mean Physics Achievement	
Model	$Var(\beta_0)$	R^2
Unconditional	55.68	-
Sector effects	33.36	40.1%
Sex composition effects	33.44	39.9%
Final model	19.17	65.6%

The percentage of variance explained by the sector effects model was substantial for the 14-year-old students (40.1%) as shown by Table 4. The final explanatory model explained 65.6% of the variance left unexplained by the unconditional model among 14-year-old students. There were negligible differences between boys and girls when the model was estimated separately, with the model explaining 65.6% of the unexplained variance among 14-year-old students, and with the explained variance being similar for the final explanatory model (63.2% for girls, 59.4% for boys).

CONCLUSIONS

The size of sex differences in science achievement among boys and girls participating in the Second International Science Study in Australia was found to be greater in physics achievement among 14-year-old students. Student characteristics found to influence significantly variations in science achievement were the home background of the student (socio-educational level), the attitude of the student towards the beneficial aspects of science (for 14-year-old students), the verbal ability of the student and the quantitative ability of the student. These student level characteristics appeared to explain a substantial amount of variation, but left a significant amount of variance unexplained.

The significance of this study was the exploration of school level characteristics which appeared to explain a greater portion of unexplained variance among 14-year-old students. The school effects found to contribute significantly towards variation in achievement included the average home background of students in the school, the average verbal ability of students in the school and the average quantitative ability of students in the school. Of note was the finding that the school effects influenced male and female achievement differently. The contextual model including similar school effects appeared to be similar for male and female 14-year-old students, removing a large amount of the differences between male and female physics achievement. The importance of student characteristics and school effects in influencing student performance has been demonstrated in this study. The so-called biological differences between male and female performance in science need to be reassessed in the light of these results, which demonstrate that the characteristics of the school not only influence student performance, but that this influence is quite probably different for boys and girls.

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EVALUATION OF A COURSE DESIGNED TO TEACH PHYSICS TO STUDENTS OF PHYSIOTHERAPY

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ABSTRACT

This paper describes the development and evaluation of a course in physiotherapy whereby the physics fundamental to the modalities of cold, heat and ultrasound therapies was integrated in lectures and actual physiotherapy activities. The design of the course is described together with the perceptions of physiotherapy students regarding the organisation of the course, safety aspects and how well the integration contributed to their understanding of the physics involved in electrotherapy.

INTRODUCTION

Until 1987 Physics had been taught for many years to students in the School of Physiotherapy as two first year service units (Physics 125 and 126), one in each of the two semesters. The physiotherapy students attended lectures in the Department of Applied Physics on the main Bentley campus; the students' core subjects were taught in the School of Physiotherapy which is located approximately 13 km away in Shenton Park. The content of the service physics units comprised topics which included non-calculus fundamentals of Mechanics, Electricity, and Wave Theory; together these topics provided the physics base for three advanced Physiotherapy courses in Electrophysical Agents at the second and third year levels. Three major problems emerged from this organisation of the curriculum. Firstly, the material taught in the Physics courses was not applied until six to eighteen months later; secondly, as a consequence of this time lag and the location of the teaching, there was a perception by the first year students that physics was not relevant to their studies or needs as students or practitioners of physiotherapy; and thirdly, the compartmentalization of knowledge inhibited the application of that knowledge from one discipline to another.

The situation was addressed in 1988 by Drs. M. Leggett and G. De Domenico by retaining one first year Physics course (Mechanics and Basic Electricity) and integrating the second course with Electrophysical Agents to form three new units called Electrophysical Agents and Applied Physics 251, 252 and 351 (Leggett et al., 1989). Furthermore these units were taught by two lecturers - one from the Department of Applied Physics and one from the School of Physiotherapy. The lectures were alternated and physics laboratory work was performed in the room where the traditional electrotherapy was carried out where the plinths were used as lab benches. This was a deliberate attempt to remove both the intellectual and geographic boundaries between the disciplines of physics and physiotherapy. Further, clinical equipment used routinely in the 251 modules were incorporated, wherever possible into the experiments, again to emphasise the relationships between clinical practice and the relevant physical principle.

Singer and Zadnik (1990) have continued to modify both the content and the organisation of the these units in response to questionnaires and other sources of student feedback, with special emphasis on safety aspects and problem-solving. In addition, greater significance has been given to the recently published Clinical Professional Standards in the area of electrophysical agents (Australian Physiotherapy Association, 1990). A major revision of laboratory-oriented physics experiments was conducted by Simpson (Note 1) who developed a laboratory manual for the Electrophysical Agents and Applied Physics 251 unit, incorporating existing experiments and suggested improvements solicited from students. The course consists of a weekly one hour lecture and two hour laboratory/therapy practice session. In the first semester of 1990 there were 83 students enrolled in this unit.

This paper briefly describes the development of the curriculum for the unit Electrophysical Agents and Applied Physics 251, outlines the method used to carry out the evaluation of the implementation of the curriculum and presents both qualitative and quantitative data based on student responses to informal interviews and questionnaires about the perceived integration of physics and physiotherapy in the unit.

METHOD

Curriculum Design

The present Electrophysical Agents and Applied Physics 251 unit consists of three therapy modalities - Cryotherapy, Heat Therapy and Ultrasound Therapy. The physics content emphasises heat transfer mechanisms, heat capacity, latent heat, and production and properties of ultrasound waves, such as reflection and impedance matching. The physiotherapy component of the course reviews the application of elementary heat and cold therapies, along with the physical treatment modality of ultrasound. The clinical use of these traditional electrotherapy treatments is discussed within the context of determining the appropriateness of administering the modality. This is based on a knowledge of the indications for each treatment, determining the patient's sensory discrimination, reviewing relevant contraindications, and providing an explicit warning of the possible risks prior to initiating the treatment. Learning is effected through demonstration, supplemented with audio-visual material and finally student practice on peers.

The laboratory sessions were used to demonstrate the underlying physics of the modalities again with particular emphasis on safety aspects and problem solving. Students worked in groups of three and were required to design an appropriate experiment to answer a general question or problem. Detailed description of experimental procedures was avoided and students were encouraged to discuss experimental design and procedures with a minimum of guidance being provided.

There were typically six to eight different experiments from which to choose. The experiments could be broadly described as belonging to one of five categories, namely, basic physics, monitoring treatments, investigating therapy equipment performance, modelling parts of the human body, and consumer reports (Leggett et al., 1989) A single page listing the available equipment and the area to be investigated, with the aim or aims often written in the form of a question or series of questions, was all that was provided for the students. Thus the course deliberately moved away from the more traditional "cook-book" style of laboratory work to a more open-ended problem - solving style. While some students enthusiastically accepted the challenge of designing their own experiments, other students complained about the lack of guidance and direction. As there were a number of different experiments in progress in any one session, each group was asked to appoint a spokesperson at the end of the session to summarise their experiment and its relevance to physiotherapy. The groups were given one week to complete a written report using guidelines similar to those for authors to the Australian Journal of Physiotherapy. The reports were worth 15% of the final grade. Reinforcing the integration aspects of the course necessitated much of the equipment being transported to the Shenton Park campus. Wherever possible actual equipment used in electrotherapy was used for the physics laboratory. Lecturers from both disciplines were present at both physics and the physiotherapy sessions and in oral practical (Continual Assessment Practical) examinations, further stressing the integrated nature of the course. The final written examination also contained questions from both disciplines.

Student sample

Students entering the School of Physiotherapy are typically a high achieving group though they are not necessarily competent in their knowledge of physics. The 1989 student intake to the course which comprise the sample in the present study had a minimum Tertiary Entrance Examination (TEE) score of 402 out of a possible 510, making this the most competitive entry standard at Curtin University. The average age of two thirds of the group was 17-18, while the remaining one third had ages ranging from 19-23. Approximately 66% of the sample had studied physics for the TEE, while 95% had studied a minimum Maths 1, the easiest mathematics unit which is acceptable to be used in the TEE score.

Evaluation Procedures

In order to gauge the effectiveness and student acceptance of the integrated course, a variety of sources of data was collected from questionnaires and interviews. The two questionnaires, Evaluation of EPA Courses, and Student Opinion Questionnaire, were administered at the end of the semester prior to the final examinations. The implementation of the updated laboratory sessions was continuously monitored by one of the authors (I.S.) during the semester and this information was fed back to the course developers and presenters during the semester. A fourth means of evaluating the outcome of the integrated course involved a series of informal interviews conducted by one of the authors (D.T.).

The data from the Evaluation of EPA Courses questionnaire were used to examine the perceived effectiveness of the integrated physics and physiotherapy laboratory program by asking students to respond to 10 questions on a 5-point Likert scale (where Strongly agree was coded 5 and Strongly disagree was coded 1). The questionnaire was divided into four categories; two items addressed organisation of the integrated course, three items addressed safety, four items addressed understanding and one item addressed interest. Each item consisted of three parts dealing with the three modalities of the physics labs, namely, conductive heating, cryotherapy and ultrasound modalities. The Student Opinion Questionnaire consists of eight sections which can be used by all lecturers at Curtin to evaluate their courses. The complete instrument was used for the course evaluation, but for the purposes of this paper those aspects are reported which are directly relevant to the integrative nature of this innovative course. The data presented in this paper deal with the four categories of general design and organisation, subject material, lectures and laboratories.

EVALUATION OUTCOMES

The evaluation of the course is initially presented from the four evaluation sources, followed by a discussion about the overall evaluation.

Evaluation of EPA Courses

Based on the data shown in Table 1, student responses indicate that they were in agreement about all aspects of the integrated course meeting the aims of the authors. The total instrument had a very high reliability of 0.92 measured by Cronbach's alpha so we can be confident of the claims being made about the outcomes of this evaluation.

TABLE 1

MEAN STUDENT RESPONSES (N = 80) ON ITEMS FROM THE *EVALUATION OF EPA COURSES* QUESTIONNAIRE.

Item	Modality		
	Conductive Heating	Cryotherapy	Ultrasound
Organization			
1. Physics and Physiotherapy clearly integrated in the labs	4.19(.53)	4.21(.52)	4.09(.81)
2. Labs were well organized	4.13(.72)	4.04(.77)	3.98(.84)
Safety			
3. Safety aspects more easily understood	3.95(.91)	3.85(.93)	4.15(.92)
4. Physics knowledge is necessary for safe physiotherapy practice	3.98(.99)	3.98(1.03)	4.31(.91)
5. Physics knowledge is relevant to safe physiotherapy practice	4.21(.82)	4.21(.84)	4.34(.79)
Understanding			
6. My understanding of physics has improved with these integrated labs	3.34(1.16)	3.30(1.11)	3.33(1.17)
7. My understanding of physiotherapy has improved with the integrated labs	3.86(.79)	3.85(.76)	3.93(.79)
8. Lecture and laboratory material complement each other and enhance my understanding the physics involved in physiotherapy	3.66(.79)	3.69(.80)	3.69(.87)
9. Lecture and laboratory material are not well integrated and I find it difficult to understand the physics involved in physiotherapy	2.16(.77)	2.16(.75)	2.30(.86)
Interest			
10. Integration makes the course more interesting	3.46(1.02)	3.43(1.04)	3.58(1.06)

Note: Responses based on a 5-point Likert scale: 5 - strongly agree to 1 - strongly disagree. Figures in brackets indicate standard deviation.

Organisation: Students agreed that the three modalities clearly integrated physics and physiotherapy (means ranged from 4.09 to 4.19) and that the labs were well organised (means ranged from 3.98 to 4.13).
Safety: Students agreed that the safety aspects of physiotherapy were more easily understood with the integration of physics and physiotherapy presented in this unit (means 3.85 - 4.15), that physics knowledge is necessary for safe physiotherapy practice (means 3.98 - 4.31) and relevant to safe physiotherapy practice; with this knowledge being more relevant in the case of the ultrasound modality (means 4.21 - 4.34).
Understanding: On the four items which examined students' understanding, all were in agreement that the integrated laboratory course had had a positive effect. For all modalities, students claimed their understanding of physiotherapy (means 3.86. 3.85, 3.93 for the modalities of heat, cryotherapy and ultrasound respectively) had improved with the integrated labs. Student responses indicated that their understanding of physics had improved, but to a lesser extent than was the case for physiotherapy (means 3.34, 3.30, 3.33 respectively for the three modalities) The large standard deviations of these scores, being more than unity in each case, indicated a wide range of student perceptions of their understanding of physics. Based on the responses to item 8, students were in agreement that the lecture and laboratory material complemented each other and enhanced their understanding of the physics involved in physiotherapy (means 3.66 - 3.69). Item 9 sought the reverse of these ideas by posing a negative question. Students *disagreed* (means of 2.16, 2.16, 2.30 for the three modalities) that the material was not well integrated and that they found difficulty understanding the physics involved in physiotherapy.
Interest: The single item evaluating students' interest indicated that the integration made the course more interesting (3.46, 3.43, 3.58 respectively for the three modalities) but the standard deviations were greater than unity indicating a broad range of responses to this item.

Student Opinion Questionnaire
The data shown in Table 2 from the general course evaluation questionnaire provide strong support for the responses shown in Table 1. Based on a four point Likert scale, student mean responses were in the "agree" category, similar to the previous data .

General Design and Organisation: The four items shown in this category indicate that the unit is well organised (mean - 3.1), that the unit made realistic expectations about prior knowledge of the subject (mean - 2.8), that the types of class sessions have been suitable (3.0), and that the various sessions have been linked effectively with each other (mean - 2.9).
Subject Material: The two items in this category indicated that the students had been able to understand the content of the unit (mean - 3.0), and that applications of the material were seen to be relevant to the intended area of employment (mean - 3.4).
Lecturers: Students indicated that the lecturers had presented the material clearly (mean - 3.1) and had used relevant material and examples.
Laboratories: Responses to this category received a consistently high rating, which agreed with the findings presented in Table 1. The intended purpose of the labs was clearly specified (mean - 3.1), the staff were well prepared for the labs (mean - 3.2), the necessary information had been clearly presented (mean - 2.9), and an increased knowledge of the subject had occurred through these sessions.

TABLE 2

STUDENT MEAN RESPONSES (N = 79) ON THE
STUDENT OPINION QUESTIONNAIRE FOR THE EPA COURSE

Item		Mean Student Response
A.	**General Design and Organization**	
1.	The unit is well organized	3.1 (.40)
2.	The unit has made realistic assumptions about my prior knowledge of the subject	2.8 (.50)
4.	The types of class sessions have been suitable	3.0 (.41)
5.	The various class sessions have been linked effectively with each other	2.9 (.45)
B.	**Subject Material**	
1.	I have been able to understand the content of this unit	3.0 (.48)
5.	I see applications of this material in my intended area of employment	3.4 (.58)
D.	**Lecturers**	
1.	The lecturer has presented the material clearly	3.1 (.48)
2.	The lecturer has made use of relevant material and examples	3.0 (.39)
F.	**Laboratories**	
1.	The intended purpose of the labs has been clearly specified	3.1 (.58)
2.	The staff involved have been well prepared for the labs	3.2 (.51)
3.	In the labs the necessary information has been clearly presented.	2.9 (.43)
6.	I have increased my understanding of the subject through these sessions	3.2 (.52)

Note: Responses based on a 4-point Likert scale: 4 - strongly agree to 1 - strongly disagree. Figures in brackets indicate standard deviation.

Monitoring the Laboratories

During the semester, one of the authors (I.S.) attended all lectures and labs in order to become familiar with the course. While the students were performing the lab work, he helped them with any queries and asked students to complete a brief questionnaire on the experiment they had just done. Based on this information together with discussions with the instructors (M.Z. and K.S.), the laboratory outlines were upgraded so that more information had been added to the labs without there being any reduction of the original problem-oriented focus of the labs. At a laboratory session later in the semester students were asked to compare the original and new laboratory outline. Students tended to agree on the improved nature of the rewritten laboratory manual.

Informal interviews with students

During the final major practical session, the students were interviewed by one of the authors (D.T.) as they conducted their experiments. Based on interviews with students, four aspects about the laboratories' integration of physics in a physiotherapy context became apparent. Firstly, the students readily acknowledged that as a result of the labs, they understood the reasons for selecting a particular modality for a treatment and consequently, they were much more aware of the safety issues involved in the particular modalities. As an example to illustrate this point, several groups of students who were independently performing an ultrasound lab where the transducer needed to be continually moved around the skin explained the reasons for doing so and without any encouragement from the interviewer emphasised the safety aspects of the procedure.

Secondly, students were differentiating in their comments of the labs. In laboratory sessions where the physiotherapy aspects were readily apparent, most students acknowledged the importance of the physics in their education as future physiotherapists. On the other hand, those labs which were less obviously related to physiotherapy received a wide range of remarks. For example, some students claimed having difficulty seeing the relevance of the ripple tank experiment to physiotherapy, but other students had quite a different view. In the ripple tank experiment one female student who had not studied physics in high school explained: "The lab's really good, I'm a physics retard and this makes the physics really clear to me - it's fun!" It was apparent that some students looked for the physiotherapy issues in the physics and, if this was not too obvious, did not see the lab in a very positive light. These findings from the interviews are also supported by the open-ended questions on the *Evaluation of EPA Courses* questionnaire.

Thirdly, the students acknowledged the importance and necessity to have a knowledge of physics to study physiotherapy and be a competent therapist. Some students believed that a knowledge of physics should be a prerequisite to being admitted to the School of Physiotherapy, while others believed if they had a better knowledge of physics they would understand the physiotherapy better. However, a number of students were keen to differentiate the importance of the physics concepts themselves, which sometimes seemed simple in comparison to the mathematical aspects for which they did not see any purpose in their education.

Fourthly, many students acknowledged the importance of the open-ended nature of experiments saying that in high school, they have been spoon-fed and that they can easily become lazy in the lab work. This manner of lab work was seen to be better. Nevertheless, several students admitted that the actual physics had a low priority in their studies. In a related aspect to illustrate the importance of the open-ended nature of the labs, one group of students explained that the conversation with the interviewer enabled them to see more clearly what they were doing and to appreciate better the physics involved and the safety issues.

CONCLUSION

This study evaluated students' perceptions of a course especially designed to integrate physics with physiotherapy. Based on the data described in this paper, students perceived that the course provided them with an understanding of the physics underlying the physiotherapy modalities and enabled them to have a clear understanding of the safety aspects necessary for performing the different kinds of physiotherapy treatments. Overall, the change from the standard service physics course to one which had the special focus described in this paper would appear to have enhanced student perceived knowledge of both physics and physiotherapy and has not had any critical feedback from students to suggest anything other than that this course should be continued in its present form in subsequent semesters.

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RESEARCH NOTES

READING, 'RITING AND 'RITHMETIC: BEING LITERATE IN SCIENCE AND MATHEMATICS

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1990 is International Literacy Year. 'Literacy' is on everyone's lips....or, at least, in many peoples' minds. Traditionally, 'literacy' has been associated with 'reading' and 'writing'. What about the person who is scientifically and mathematically literate: how do we recognise such a person?

In 1990, the Centre for Mathematics Science and Technology Education at Murdoch University was awarded $80 000 for the project Secondary Literacy Inservice Package for High School Science and Mathematics. This project is funded by the Australian Government's International Literacy Year Programme through the Department of Employment, Education and Training.

The science education community has contributed to the area of language use in science education. For example, in the U.K., the early Science Teacher Education Project (STEP) materials included a discussion of this topic: an overview, entitled "Language and communication in science lessons" (Sutton, 1974) highlighted the importance of oral and written language in science classrooms. In the U.S.A., Lemke has written extensively on this topic. For example, in his "Talking physics" (1982) he points to the crucial role played by language in developing students' understanding (or lack of understanding) of science.

In Australia, Gardner (1974) published his work on "Language difficulties of science students". The ASEP team took up the specific problem of readability and designed each module so that its readability level was two grade levels below that of the intended audience. (Thus a year 10 module had a readability level that was suitable for year 8). Such an approach, which had the worthwhile aim of giving students an easy introduction to the language of science had the unintended effect of avoiding the problem. Students who studied a large number of ASEP modules were not being exposed to much formal science language which characterises the majority of science textbooks. Students must be given the skills which will enable them to extract meaning from their traditional science textbooks: it is this skill (among others) which will help them to become "scientifically literate".

Some in the "language/literacy" community argue that it is possible for a person to be 'literate' in a general sense. Others argue that it is not possible to be 'literate' without reference to some context: thus it is only possible to speak of a person who is 'literate' in science or history or mathematics. In an earlier age, to be 'literate' was to be 'well read'. Today, some (for example, Green, 1988) argue that to be literate is to have a set of subject-specific literacies.

The project is based on the belief that language skills are part of what gives a person access to the language of science. People who simply regurgitate information are not 'literate'. They must understand how to "read", "write" and "talk" science and mathematics. These principles are part of the underpinnings of our project.

Ultimately, the visible result of the project will be a series of modules dealing with different aspects (reading, writing, listening, talking) of literacy in science and mathematics.

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APPENDIX

TWENTY YEARS OF RISE
A CUMULATIVE INDEX 1971-1990

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It seems appropriate that this twentieth edition of RISE contain a listing of the contributions made to the journal since its inception. The first attempt to prepare a consolidated list was made in 1983, but this is the first time that such a list has been published as part of the journal. The categories which seemed appropriate then appear to be less useful now but have been retained to organise the 1990 review. What follows is a reminder of the significant effort that has been made to science education research by the Australasian Science Education Research Association (ASERA). Others may wish to re-classify the articles and develop more useful categories for organising our work. The index certainly provides the basis for further research.

Contributions are arranged alphabetically by author.in the following categories:

1. Theories of instruction
2. Nature of the learner
3. Classroom interaction
4. Curriculum evaluation:
   a) General issues
   b) Materials
   c) Implementation
   d) Outcomes
5. Research techniques/Test development
6. Reviews of research and curriculum development
7. The nature of science/science education
8. Science teacher education
9. Curriculum and teaching (1986 onwards)

Table 1 shows the numbers of papers in each category for each year.

TABLE 1

RISE PAPERS CLASSIFIED BY YEAR AND CATEGORY (1971-1990)

CATEGORY	1971	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87
1. Theories of instruction	1	3	1	1	2	0	3	1	5	2	5	1	1	1	2	2	0
2. Nature of the learner	2	1	1	2	2	3	4	5	5	7	5	7	10	11	9	10	7
3. Classroom interaction	0	1	0	1	0	1	1	1	0	4	1	2	1	1	2	2	1
4. Curriculum evaluation	4	2	4	5	6	2	7	3	6	3	2	1	2	3	4	0	1
5. Research techniques/ test development	0	1	6	10	3	1	4	4	1	1	1	2	4	0	1	0	1
6. Reviews of research and curriculum	2	3	4	3	3	2	0	3	3	1	5	1	2	3	5	2	8
7. Nature of science/ science education	0	0	0	3	4	2	6	3	2	1	3	1	1	0	1	1	4
8. Science teacher education	1	0	0	0	1	2	0	0	0	0	2	5	3	6	0	2	3
9. Curriculum and teaching																8	6
Total	10	11	16	25	21	13	25	20	22	19	24	20	24	25	24	27	3

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