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## Proceedings of the 21st annual conference of the Western Australian Science Education Association

Mark W. Hackling (Ed.)  
*Edith Cowan University*

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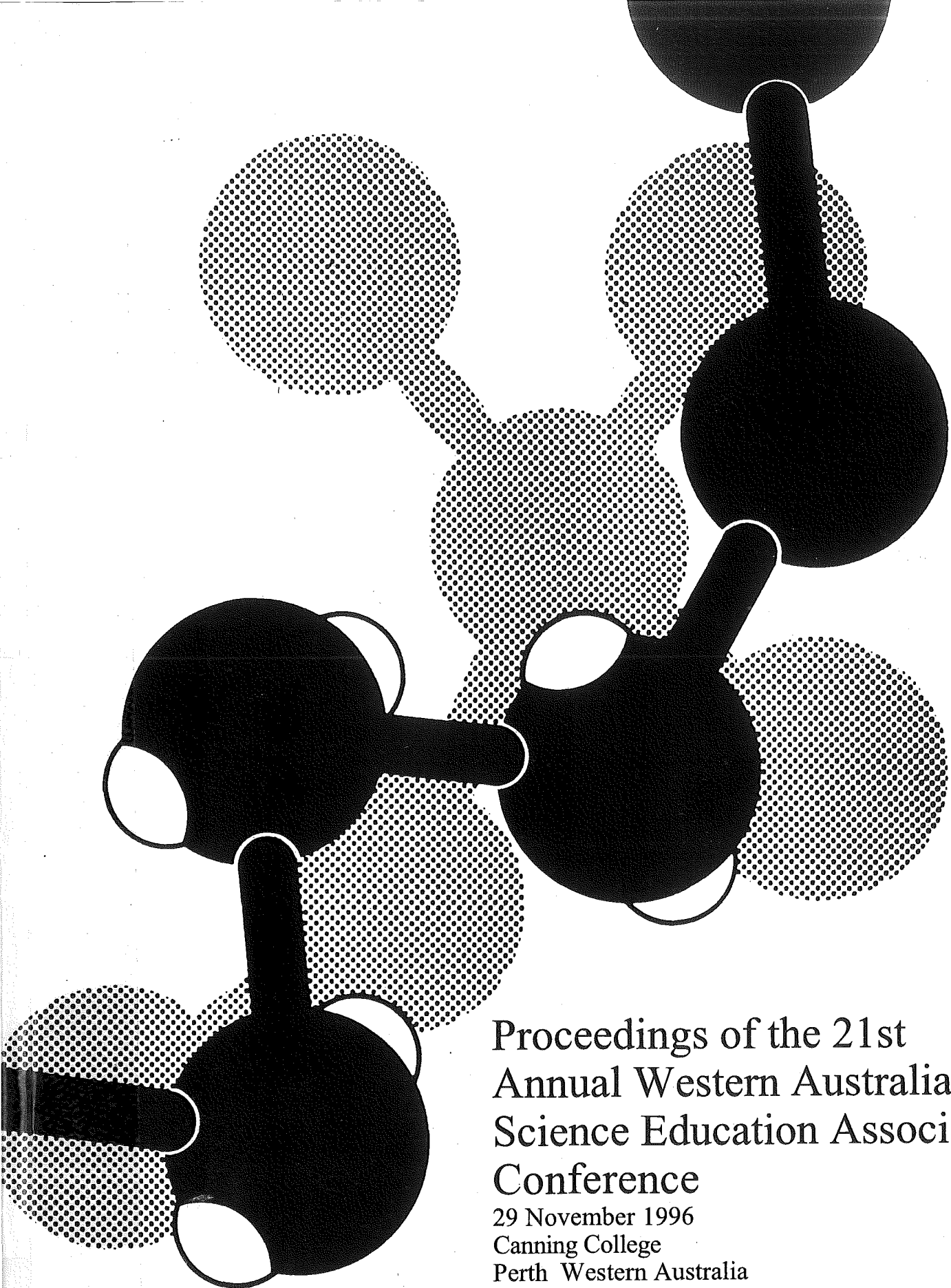
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# Proceedings of the 21st Annual Conference of the Western Australian Science Education Association

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29 November 1996

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Edited by  
Mark W Hackling

All correspondence about this publication should be  
directed to Dr Mark W Hackling  
Department of Science Education  
Edith Cowan University  
Bradford Street  
Mount Lawley, Western Australia 6050

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## **Preface**

The Western Australian Science Education Association (WASEA) is an informal group of science educators that meets annually for a conference at one of the Perth universities. The conference is organised by a committee of representatives from the universities and has contributed greatly to collegiality amongst the community of science educators in Perth.

The first meeting of WASEA was held at the Churchlands College of Advanced Education in 1975 and has been held each year except in 1979 and 1991 when the WASEA meeting was incorporated into the meeting of the Australian (now Australasian) Science Education Research Association.

These Proceedings comprise edited papers from the 21st meeting held in 1996. This collection of papers has been made available internationally through the Educational Resource Information Centre (ERIC). Enjoy them.

Mark W Hackling  
Editor

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Western Australian Science Education Association**

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# **Students' Understanding of Upper and Lower Fixed Points of a Thermometer and it's Influence on their Proportional Reasoning**

Ayo H. Akatugba and John Wallace  
*Science and Mathematics Education Centre  
Curtin University of Technology*

## **Abstract**

This paper delineates students' understanding and interpretations of the upper and lower fixed points of a thermometer which emerged during an investigation of their use of proportional reasoning. The influence of these interpretations on their proportional reasoning ability are also discussed. A qualitative and interpretive case study was carried out with six students from a co-educational urban high school for five months. Research techniques such as dialectic discourses, interviews, video and audio recordings were employed to generate, analyse and interpret data. The findings indicated that in practical terms, students interpreted the upper and lower fixed points of a thermometer to mean the upper and lower limits of any thermometer scale. This made it difficult for the students to solve thermometry tasks using proportional reasoning. In this paper the sources of students' interpretations are explored and the implications for teaching high school physics are discussed.

## **Introduction**

This paper explores one of the outcomes of a study which investigated aspects of students' use of proportional reasoning in physics. The study adopted an interpretivist framework to understand the meanings, actions, interpretations and constructions of some high school students as they solved physics tasks requiring proportional reasoning. The investigation focused on the various social and psychological aspects of students' use of proportional reasoning within their immediate high school physics classroom contexts. This paper delineates one of the socially and experientially based students' joint constructions which evolved during the study. That is the association between students' understanding of the concept of the upper and lower fixed points of a thermometer and their proportional reasoning.

Many of the concepts traditionally taught in secondary school physics are highly abstract and hence require the students to function at the level of formal operations to attain comprehension (Herron, 1978; Shayer & Adey, 1982; Williams & Cavallo, 1995). Several studies have shown that one of the formal reasoning patterns important to students' academic success in high-school science courses, especially physics, is proportional reasoning (Akatugba, 1995; Fleener, 1993; Guckin & Morrison, 1991; Heller, Ahlgren, Post, Behr, & Lesh, 1989; Lamon, 1993; Lawson, Karplus, & Adi, 1978; Whitmer, 1987). However, high school students have difficulty using proportional reasoning (Hart, 1978; Heller *et al*, 1989; Lamon, 1993). Many high school students have difficulty understanding physics concepts and often have misconceptions (Williams & Cavallo, 1995). A misconception is a preconception, an alternate conception, or an understanding that differs from the understandings held by experts in the field (Hestenes, Wells, & Swackhamer, 1992).

Several studies have shown that the problems students have in learning science concepts are as a result of their difficulty with proportional reasoning in general and in transferring it to the unfamiliar contexts in science (Guckin & Morrison, 1991; Heller *et al*, 1989; Linn, 1982; Whitmer, 1987). This suggests that understanding formal concepts may be difficult among students who have not developed proportional



reasoning ability. When students attempt to learn formal concepts, a mismatch occurs between their proportional reasoning ability and that needed to understand the concept (Williams & Cavallo, 1995). There seems to be an association between students' proportional reasoning ability and their understanding of formal concepts. Most previous works in this area have focused on how students' difficulty with proportional reasoning makes it difficult for them to understand most physics concepts. However it is also clear that, inadequate understanding (or misconception) of physics concepts makes it difficult for students to use proportional reasoning. Hence students' understanding and interpretation of physics concepts also influence their use of proportional reasoning.

The concept of the 'upper and lower fixed points' of a thermometer is an important aspect of the high school physics curriculum. Most physics textbooks define the 'upper fixed point' as the temperature of steam from pure water boiling at normal atmospheric pressure ( $100^{\circ}\text{C}$ ) and the 'lower fixed point' as the temperature of the melting-point of ice ( $0^{\circ}\text{C}$ ). An appropriate understanding of this concept is necessary for successful and meaningful solving of thermometry tasks in physics using proportional reasoning. Explaining the association between students' understanding or interpretations of this concept and their use of proportional reasoning is one of the purposes of this paper. The study investigated aspects of students' use of proportional reasoning in physics problem solving during which students' misconception of the concept of the 'upper and lower fixed points' of a thermometer emerged. This paper is aimed at delineating the misconceptions students had on the two fixed points of a thermometer, how these misconceptions influenced students' use of proportional reasoning, and the reasons for their understandings.

### **Research Design**

A constructivist and interpretive (Bogdan & Biklen, 1992; Guba & Lincoln, 1987; Maykut & Morehouse, 1994; Meriam, 1988 ) case study was carried out with six grade 12 physics students from a co-educational senior secondary school in Nigeria. The purpose of the study was to understand the constructions that individual students and groups of students form in order to make sense of their difficulty with proportional reasoning within their social and cultural contexts. A hermeneutic dialectic process (Schwandt, 1994; Grundy, 1993; Guba & Lincoln, 1989) and an emergent approach was adopted for data collection and analyses through out the investigation. The hermeneutic dialectic process was used to engage each learner with some physics tasks and open-ended interviews were employed to elicit learners' initial emic constructions. Each participant was given the opportunity to compare and contrast their own emic constructions with some of the constructions which emerged from other participants in the hermeneutic dialectic circle in order to obtain their joint constructions on the issues which emerged. This design also afforded learners the opportunity to negotiate the differences in their individual constructions in order to arrive at a consensus.

### **Research Procedure**

The six students were selected serially using a maximum variation sampling method (Guba & Lincoln, 1989; Maykut & Morehouse, 1994). The students were actively engaged with various physics tasks

requiring proportional reasoning during which multiple research techniques were employed to elicit their claims, concerns, meanings and constructions of their problems with proportional reasoning. These physics tasks were adapted and in some cases modified from some past West African School Certificate (WASC) examination questions in physics requiring proportional reasoning and some proportional reasoning tasks used by other researchers in the field which were related to the students' physics syllabus. The techniques employed included observation, dialectical discourses, structured/unstructured interviews, questionnaire, dialogue journals, field notes, proportional reasoning tasks, video and audio tapings. Students' misconceptions about the upper and lower fixed points of thermometers emerged as one of the problems influencing their use of proportional reasoning in physics problem solving. Physical thermometers, diagrams and some of the techniques mentioned above were employed to understand the nature of the problem and to elicit students' constructions about the problem.

### **Data Analysis**

The data analysis process closely followed the data collection process and was an ongoing part of the research (Bogdan & Biklen 1992). The data and the analyses were constantly checked with individual participants. Data interpretations were based on the constructions with which each learner, group of learners and the researchers made sense of the various issues which emerged and the values and beliefs which shaped them. These interpretations were also linked to the immediate contexts within which the constructions were formed and to which they referred (Fieldman, 1995; Guba & Lincoln, 1989).

### **Outcomes**

Students' misconception of the 'upper and lower fixed points' of a thermometer became apparent when they attempted to solve the three thermometry tasks (See Appendix 1) in the given physics tasks. It would be worthwhile to note at this point that the students had all previously studied the concepts of 'thermometers' and 'the fixed points of thermometer' in their physics lessons. None of the six students were able to solve the three tasks using proportional reasoning. They believed that there were no other ways by which they could solve the thermometry tasks. Initially students felt that their inability to solve these tasks had to do with the nature of the tasks themselves.

#### *Student's Initial Reactions To The Tasks*

After trying without success to solve the tasks, the students claimed that the information provided in the given tasks was incomplete. The students complained that the temperature units provided in each of the three tasks were all the same (eg. mm or degrees) and could not understand why they were required to calculate the temperature in a different unit (degree Celsius). Students were not used to thermometers with 'mm' and ordinary 'degrees' as units. Students became confused by the tasks and their constructions are illustrated using the task below:

Task 1: A thermometer has its stem marked in millimetres instead of degree Celsius. The lower fixed point is 30 mm and the upper fixed point is 180 mm. Calculate the temperature in degree Celsius when the thermometer reads 45 mm.

Commenting on why they could not solve the thermometry tasks such as the one above, some students said:

Student A: What confused me was the mm. I've never seen a thermometer using mm. ....The thermometer was marked in mm and all of a sudden they just said find that out in degree Celsius. And I didn't know how to do that.

Student B: I don't see any relationship between the °C and the mm. When they give questions, like density now, it means mass/volume. But looking at this mm with degree I can't find any relationship and any formula that I know and I could not do it either.

Students believed that the tasks were incomplete. Their comments showed that they did not have an adequate understanding of the task and the task requirement. In order to complete the tasks they needed some prior basic knowledge of the 'upper and lower fixed points' of thermometers.

#### *Lack of Awareness of Task Requirements*

Further experiences, discussions and reflections on the three thermometry tasks revealed that the tasks relied on the assumption that students had a prior understanding of the concepts of the upper and lower fixed points. Students were also required to have a knowledge of the values of the upper and lower fixed points in degree Celsius and to link these knowledge with the information provided. However, they did not realise this until they were asked to reflect on and discuss the physics concepts, the tasks content and the task requirement:

Researcher: Why were you not able to understand on your own that you were going to need the equivalent of the values you were given in degree Celsius in order to solve the problem?

Student : When I saw it I thought it was like converting Centigrade to Fahrenheit or something like that. I didn't sense it would need requiring that I bring in the values of the upper and lower fixed points in degree Celsius.

Researcher: Why couldn't you relate that on your own?

Student : I thought perhaps they left out all the information about the question on the temperature in degree Celsius.

The students later realised that the tasks were also testing their knowledge of the values of the upper and lower fixed points in degree Celsius, and their ability to convert from any scale to the Celsius scale. However, all six students involved in the study got stuck when they tried to find the temperature values in degree Celsius. It became obvious at this stage that students were not sure of the actual values of the upper and lower fixed points of thermometers in degree Celsius. They were not sure if the values were fixed or whether it varied with different thermometers. As a result they were not sure of the values in degree Celsius which they needed to carry out the conversion from the mm scale to the Celsius scale. Hence there appeared to be some internal conflicts and confusions within all the students and these affected their reasoning. Student B's initial attempt at solving Task 1 above is shown below:

Task 1: lower fixed pt is 30mm, while the lower fixed pt in degree Celsius is 0

$$\begin{array}{ll} 30\text{mm} = 0^\circ & 1\text{mm} = 0/30 \\ 45\text{mm} = x & 45\text{mm} = 0/30 \times 45 \end{array}$$

Like the other students, Student B tried to solve the above problem based on his past practical experience and constructions on different thermometers. He had come across different types of thermometer with different range of values and this made it difficult for him to figure out the values of the lower and upper fixed points in degree Celsius. It became evident that he did not understand the meaning of the concept 'upper and lower fixed points of a thermometer'. This influenced his workings which is shown above. Student B provided some insight into what he had done:

When I read the lower fixed point was 30mm, like from what I have known from thermometers, the lowest degree in Celsius is 0. So I thought that if in 'mm', the lowest degree was 30, that means for the Celsius [scale] it will be 0. ... Why I was stuck here was that I was trying to use ratio and I found out that if 30mm is equal to 0°C then 1mm will be 0/30. ... Since my answer was infinity, anything I do will always end up as infinity and that did not look practical to me. In the sense that [a] thermometer has an end.

It was at this stage that their misunderstanding of the upper and lower fixed points of a thermometer became apparent. Hence all six students and one of the researchers (first author) later came together to understand the nature of the students misconception of the two fixed points.

#### *Students' Interpretations of the Upper and Lower Fixed Point of Thermometers.*

The activities and discourses with individual students indicated that the students were confusing the upper and the lower fixed points of a thermometer with the lowest and highest values that could be found on any thermometer scale. In order to understand students' own interpretations of the upper and the lower fixed points and enable them to reflect on their interpretations, they were all given thermometers with different range of values similar to the ones shown in Figures 1-4. Each student was asked to indicate the two fixed points on the thermometers and they all showed the lowest and highest values on their thermometers as their upper and lower fixed points. That is 0°C and 100 °C, 35°C and 43°C, -10°C and 110°C, and 15°C and 115°C.

The student with the thermometer similar to the one in Figure 1 appeared to have had the correct values. However, when the same student was given another thermometer similar to that shown in Figure 2, he said the values of the upper and lower fixed points were 35°C and 43°C respectively. This showed that the student did not understand the concept and was having a misconception like the other students. Students were of the opinion that these two values (even though they are referred to as fixed points) varied with different thermometers. They were confusing the upper and lower fixed points with the upper and lower limits of a thermometer scale and consequently had problems solving the three tasks using proportional reasoning.

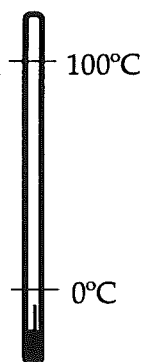


Fig.1

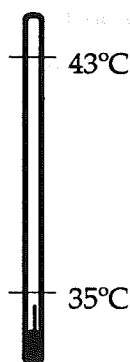


Fig. 2

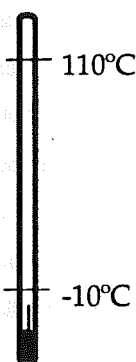


Fig. 3

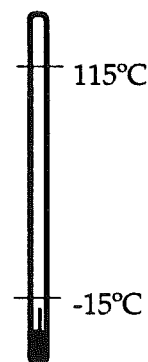


Fig. 4

When the students were asked to reflect on the meaning of the concept of the upper and lower fixed points and to explain what these meant to them, they realised the discrepancies between the values they had given and their definitions of the concept. Most of the students defined the lower fixed point as the “temperature of melting ice” and the upper fixed point as the “temperature of steam from boiling water”. They gave both values as  $0^{\circ}\text{C}$  and  $100^{\circ}\text{C}$  respectively. When the students were asked if the temperatures at which ice melts and water boils are fixed or varied, they claimed the temperatures are fixed. It was at this stage that they realised their misconception and understood that the values for the upper and lower fixed points of thermometers are fixed and not the same as the lowest and highest values on the different thermometer scales.

#### *The Influence of the Misconception on Students' Proportional Reasoning.*

The students needed to know the values of the two fixed points in the Celsius scale in order to solve the problems using proportional reasoning. Since students associated the fixed points with the lowest and highest values on a thermometer scale and reasoned about these in terms of different values for different thermometers, it did not occur to them that what they needed were the values  $0^{\circ}\text{C}$  (lower fixed point) and  $100^{\circ}\text{C}$  (upper fixed point). Before they were given the different thermometers for further investigation, some of the students said the lower fixed point was  $0^{\circ}\text{C}$  while some were not too sure about this value. Further probing showed that the students were not sure because they had seen some thermometers similar to the ones in Figures 3 & 4 which ranged from  $-10^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ ,  $-10$  to  $110^{\circ}\text{C}$ ,  $-15^{\circ}\text{C}$  to  $100^{\circ}\text{C}$ , and  $-15^{\circ}\text{C}$  to  $115^{\circ}\text{C}$ . As a result they believed that the lower fixed point could also be  $-10^{\circ}\text{C}$  and  $-15^{\circ}\text{C}$ . Others chose  $0^{\circ}\text{C}$  as the lower fixed point because they had only seen thermometers with scales beginning from  $0^{\circ}\text{C}$ . Hence some students associated the ‘30mm’ in the first task with  $0^{\circ}\text{C}$  and others could not associate it with any particular value.

However, none of the students were conclusive about the value for the lower fixed point. They particularly found it difficult to comprehend the value of the upper fixed point as  $100^{\circ}\text{C}$ . They figured that the value should be varied since they had seen and heard about thermometers with values ranging between  $-10^{\circ}\text{C}$  and  $220^{\circ}\text{C}$ ,  $0^{\circ}\text{C}$  and  $100^{\circ}\text{C}$ ,  $35^{\circ}\text{C}$  and  $43^{\circ}\text{C}$ , etc. Explaining why some did not have much problem with the value for the lower fixed point ( $0^{\circ}\text{C}$ ), they claimed that the thermometers they were used to seeing started from  $0^{\circ}\text{C}$  but had different “upper fixed points”. Students needed a knowledge of both values of the

upper and lower fixed points in degree Celsius as well as a good understanding of their meaning and relevance for them to be able to relate the information in the given tasks as shown in Figure 5.

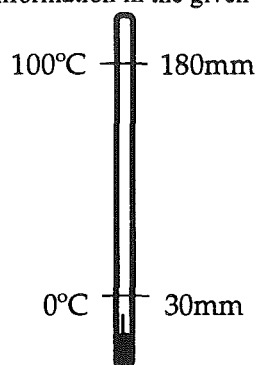


Fig. 5

A dialogue with one of the students illustrates how this misunderstanding influenced his proportional reasoning:

Researcher: What will 30mm correspond to in degree Celsius?

Student: That's 0°C.

Researcher: What will 180mm correspond to in degree Celsius?

Student: Hmm, I can't remember.

Researcher: Why did you choose 0°C as the lower fixed point?

Student: Hmm, from what I have known about the thermometers around, they are calibrated in 0°C, 1, 2, 3, to 100. ... they start from 0°C.

Researcher: Apart from seeing this from the thermometers, did you know that 0°C is the lower fixed point of a thermometer in degree Celsius?

Student: I knew in the sense that ... definitely it will start from zero. I have never seen something like -2, -2.5, or -3.5.

Researcher: If 0°C is the lower fixed point what is the upper fixed point?

Student: I don't think there will a definite upper fixed point. ... The thermometers I have seen are up to 45°C and some are up to 200°C. ... I have heard of [thermometers that are up to] maybe 2000°C and 5000°C.

Researcher: So what was your problem with the question?

Student: What confused me was that I have seen different types of thermometers. Since there are different types of thermometers, that put me in a fix in the sense that I did not know what type of thermometer they were talking about. May be the one used for measuring [the temperature of a] human body or the one used for measuring [the temperature of] a reaction.

What the students had seen, heard and read about different types of thermometers influenced their understanding of the upper and lower fixed points of a thermometer and subsequently, their ability to solve thermometry tasks using proportional reasoning.

#### *Students' Constructions of their Misconceptions*

Students' misconception was partly attributed to lack of understanding and questioning on the part of the students. They believed that if they were made to understand the meaning of the term or phrase 'upper

and lower fixed points' and encouraged to ask questions during physics lessons, they would not have had such misconceptions and this would have minimised their difficulty. The students believed that if their teachers drew their attention to the knowledge that the upper and lower fixed points were *fixed* irrespective of the different types of thermometers, that would have helped them in solving the tasks. Students said their knowledge about different types of thermometers from physics and chemistry interfered and confused them during problem solving.

The students also believed that their misconception was also due to the problem of language. Students tended to associate scientific terms or phrases with their everyday understanding of similar words or terms. As a result, students lost the scientific meaning of such terms like 'the upper and lower fixed points of a thermometer' when they learned the concept. Students felt that they should have been taught the linguistic meaning of the phrase 'upper and lower fixed points' during physics lessons and that the focus should not only be on the scientific aspects of the concepts in physics.

Students also associated their misconceptions with the way physics concepts especially the concept of the upper and lower fixed points are taught in the physics classroom and the way they are presented in physics textbooks. They claimed that they learned this concept in such a way that they could not appreciate its meaning and relevance. They were usually given the definitions, told the values and not made to understand why these values are fixed. The different contexts where these values could be relevant were not explored. Students claimed that no emphasis has been placed on the *fixed* nature of the values of the two fixed points. Students feared that the concept was not taught as an important aspect of physics yet it played such a vital role during problem solving. They also complained that the physics textbooks only casually mentioned such concepts or do not at all.

### Implications

The outcomes of the study indicate that students' misconceptions of the concept of the upper and lower fixed points of a thermometer influence their ability to solve physics thermometry problems using proportional reasoning. These misconceptions are associated with students' experiences and knowledge of different thermometers, the way the concept is taught in the classroom, lack of understanding and questioning on the part of students, and the alternative everyday meanings and interpretations students assign to scientific terms that are not well explained to them.

Proportional reasoning is essential for successful solving of thermometry tasks (which appears frequently in the West African School Certificate Examinations). However, an adequate understanding of the meaning and relevance of the concept of the upper and lower fixed points of a thermometer is required to enable students use proportional reasoning. But this concept is taught in the classroom and mentioned in both textbooks and physics curricula in a way that devoids it of its meaning and relevance. Most physics curricula briefly mention the need for students to be able to *define* the upper and the lower fixed points while some totally skip it. Subsequently, most textbooks provide only the definitions of the fixed points and the few which attempt to provide some explanation portray these fixed points as the 'lower and upper values' on a thermometer. Students are not given the opportunity to use and appreciate the meaning and relevance of

the fixed points. The concept is usually not treated as a main issue in the physics curricula and textbooks, and as a result it is not taught in-depth.

Another important implication of this study is that most physics students hold some confusion about the upper and lower fixed points that do not become obvious until they are faced with problem situations involving the concept. Most of the students are not even aware that they have misconceptions until they are made to reflect on the definitions, the meanings and the implications. Some students are able to state the right values of the fixed points in the Celsius scale in a particular context (which they may not really understand) and are not able to do so in different contexts. Statement of the right values does not depict an understanding of the concept of the upper and lower fixed points. Hence students' understanding and interpretations of the two fixed points need to be anticipated and accessed during instruction, learning, and problem solving in physics.

Most scientific terms students encounter in school do not exist in their everyday vocabulary. Although some scientific terms like 'upper and lower fixed points' may seem simple and straight forward and are assumed to be understood by students, they usually take on meanings that are different from those held by experts in the field. If potential students' misinterpretations of scientific words such as the 'upper and lower fixed points' are not anticipated and dealt with, students stand the risk of relating such words to their everyday understanding of 'lowest' and 'highest'. This leads to misconceptions and difficulties. Hence there is a need to devote some time to the learning and understanding of most scientific terms in order to ensure that students hold useful interpretations which are in line with those held by experts. Finally, there seem to be a need for a reconciliation of what students see everyday, what they read and what they are taught in physics classrooms so as to identify and deal with possible differences and discrepancies.

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### Appendix 1

1. A thermometer has its stem marked in millimetres instead of degree Celsius. The lower fixed point is 30 mm and the upper fixed point is 180 mm. Calculate the temperature in degree Celsius when the thermometer reads 45 mm.
2. A mercury-in-glass thermometer reads  $-20^{\circ}$  at the ice point and  $100^{\circ}$  at the steam point. Calculate the Celsius temperature corresponding to  $70^{\circ}$  on the thermometer.
3. The ice and steam points on mercury in glass thermometer are found to be 90.0 mm apart. What temperature is recorded in degree Celsius when the length of the mercury thread is 33.6 mm above the ice point mark?

# The State of Primary Science in Western Australia: A Survey Review

Kathleen Broderick and John Wallace  
*Science and Mathematics Education Centre*  
*Curtin University of Technology*

## Introduction

Prior to 1994, there was little activity in the promotion of primary science in Western Australian government schools since the development of the *Science Syllabus K-7* (Education Department, 1983) in 1983/4. There was evidence to suggest that many teachers were not teaching science well, if at all. There was concern about "the relatively low priority and small amount of time devoted to science education in primary schools, (approximately one hour each week) and the consequent generally low level of understanding displayed by primary students" (Education Department, 1994, p.3). In 1993 the Education Department of Western Australia tested Year 3 and 7 students statewide to determine the level of achievement in science. The *Monitoring Standards in Education(MSE) Report* (Education Department, 1994) discussed the achievements of students in five areas. The four conceptual areas and one process area were drawn from a *Profile of Science for Australian Schools*, the federal Labour government's attempt at a National Curriculum. The MSE Report highlighted a particular concern about the nature of science lessons: "Year 7 students reported a generally low frequency of science activity. The most common activity reported for Years 7 and 10 students was copying notes from the blackboard and completing worksheets." (Education Department, 1994, p.7) The results of this report prompted action from the Education Department of Western Australia resulting in the Science Project.

In 1995 and 1996 the Education Department directed considerable funding to primary science through the Science Project. The Project Targets were defined as follows:

- Provide all schools with access to exemplary curriculum materials.
- Establish an effective, whole school curriculum in primary schools.
- Establish science teaching methodology that is consistent with identified best practice.
- Provide access for teachers to update their knowledge of science and its role in society.
- Establish networks of curriculum leaders to provide ongoing support for teachers beyond the life of the project.

The Project has resulted in considerable activity in classrooms, schools and school districts (Venville, Wallace & Loudon, 1996). Much of the recent activity can be compared with that which took place during the period 1980-1985 when the *Science Syllabus K-7* (Education Department, 1983) was introduced and primary schools were assisted to develop whole school science programs. This earlier period of activity was described in *A Review of Primary Science in Western Australia 1980-1985* (Betjeman, 1985)—a report of a survey of schools' perceptions of the state of primary science at that time. In this report Betjeman (1985) also describes the various professional development and curriculum development initiatives of the time. The report is positive about the changes that took place in science at those times but is also realistic. "Primary science is still in the process of confirming its identity and direction in Western Australia." (Betjeman, 1985,

p.42). The aim of this paper is to report on schools' perceptions of the current state of primary science in Western Australian government schools and to compare these perceptions with those reported in the earlier survey by Betjeman (1985).

### Methodology

A postal questionnaire was developed to survey the state of science in Western Australian government primary schools. The survey can be described in four main sections. The first section dealt with the demographic information such as location and classification (not included in this paper). The second section was modelled as closely as possible on the Betjeman (1985) survey so that direct comparisons could be made. It consisted of seven questions requiring a yes or no response, a question on curriculum use in which respondents were asked to identify the type of science curriculum being used their school and a question about time spent on science at each year level. In the third section, respondents were asked a series of questions about awareness of current activity; participation in professional development; teaching strategies; monitoring tools and their uses; and, achievement of outcomes. The final section invited a general response and participants were invited to use an extended answer method to comment on any primary science issue. The survey was sent to 665 government schools (all schools with a primary population) addressed to the science coordinator, through the principal. Approximately 418 were returned representing a return rate of 63%.

### Results

#### *Awareness of Science Project*

In this question, respondents were asked about the level of awareness among the staff of aspects of the Science Project (project leaders, project plans and project content). The responses indicate that in most schools at least one person is aware of each of these aspects of the Project (see Figure 1). Of interest is the number of respondents who were unaware of the existence of Primary Teacher Leaders (9.4%), district Project plans (13.9%) or the content of the Science Project (18.5%). These figures represent a significant number of teachers who were not aware of the Science Project. Country schools are more likely to be aware of district plans and activities than metropolitan schools.

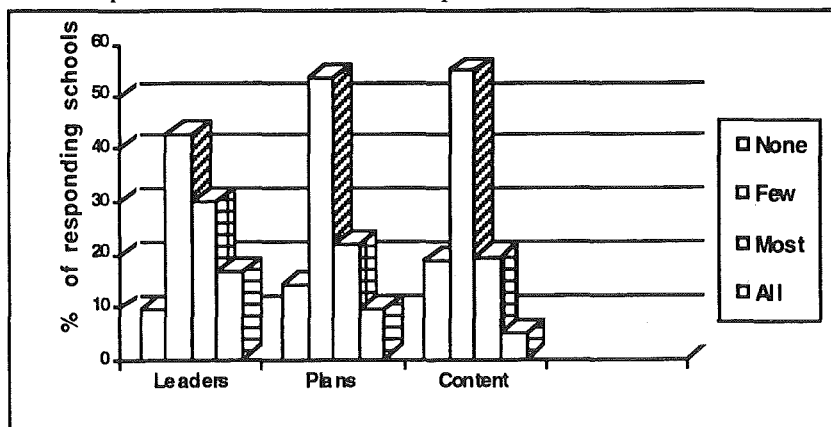


Figure 1. Awareness of the science project

### Participation in Professional Development

There was a high level of participation in professional development activities associated with the Project (see Figure 2). A third (30.7%) of respondents said that their whole staff had participated in professional development in science in 1995-96. This can be closely correlated with the number of schools who reported that they were using *Primary Investigations* (30.2%). It should also be noted that only one tenth (10.1%) of respondents said that no person from their school had participated in science professional development in 1995-96. Advice was sought from central office and/or district office staff by one or more people in 77.2% of schools. Country schools were more likely to have sought advice than city schools. Many schools (66.2%) reported that one or more of their staff actively involved their classes in science events in the last year. They may have participated in any one of a number of activities e.g. Science in schools week, District Science Challenges, Science Talent Search.

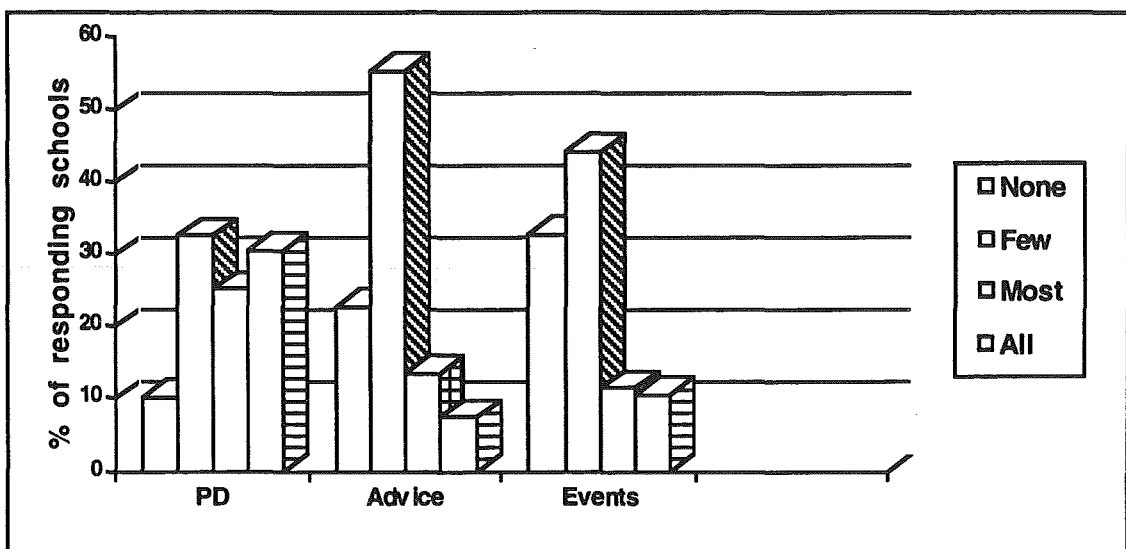


Figure 2. Participation in professional development activities

### Teaching Strategies

Figure 3 shows the responses to the questions regarding teaching strategies. A whole school, coordinated program is the method of organisation of primary science supported by Education Department policy. The results show that 32.4% of respondents indicated that all staff taught science within a whole school organised program. It is interesting that by definition, all staff would be involved in a whole school science program except perhaps support staff and specialist teachers. The 29% of respondents who indicated that most of their staff taught science in a whole school program may be considering these specialist roles in their answer. This could mean that as many as 61.4% of schools may have a whole school science program. In the "science in your school" section of the survey 68.1% of respondents reported that their school was implementing a whole-staff coordinated science program.

The idea of linking science concepts and skills cross curricula is to strengthen learning that takes place in science by following it up in other areas. For example measuring temperature is a skill which may be required in science but could be used in studies of Society and Environment. Many teachers link learning areas in this way. Responses show that only 2.2% of schools say that this linking does not occur. Integrating

science with other learning areas usually implies teaching in themes or around a central organiser and planning activities to develop understandings and skills across the learning areas. Results show that in many schools (53.7%) most or all teach science in this way.

Responses show that few teachers teach science in the morning. In most schools (87%) none or few teachers teach science in the morning. One response in the general comments section stated that one teacher was responsible for teaching all the science in the school and that it was timetabled in the morning for logistical reasons rather than any perceived educational benefit.

Cooperative learning strategies were used by most of the staff to teach science in 43.9% of the responding schools. Only 17.7% of schools indicated that all staff used explicit cooperative learning strategies. Compared to the 30.2% of respondents who said that all were using *Primary Investigations* at their school, this makes an interesting point. The program is based on explicit cooperative learning but apparently is not always being implemented in that way. In only 6.2% of schools were cooperative learning strategies not used in science at all.

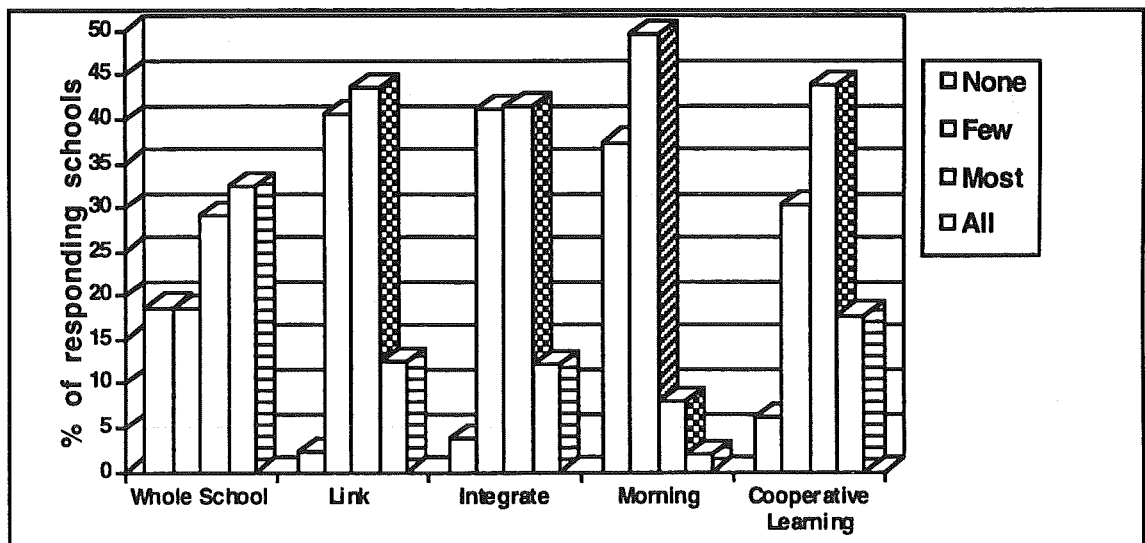


Figure 3. Teaching strategies

#### Time

The amount of time spent on the teaching and learning of science correlates directly with student achievement. There was a general trend that the amount of time increased directly with the age of the students. Students in Year 7 spent an average of 71 minutes on science each week as compared to Kindergarten students who averaged 49 minutes on science. There was a significant standard deviation at each year level indicating a considerable range in the amount of time spent on science.

In the general comments at the end of the survey two respondents chose to comment specifically on time. One respondent said "Whilst one hour is the average, more time is generated through extension to other areas such as language in particular." Language texts have changed significantly in the ten years since the preliminary report. New non fiction reading series often include science based texts so the comments are quite relevant. Another respondent said that it was difficult to average time spent on science over classes in a

large school (Class 5) and also mentioned integration as a factor that could account for more time but it is too difficult to isolate.

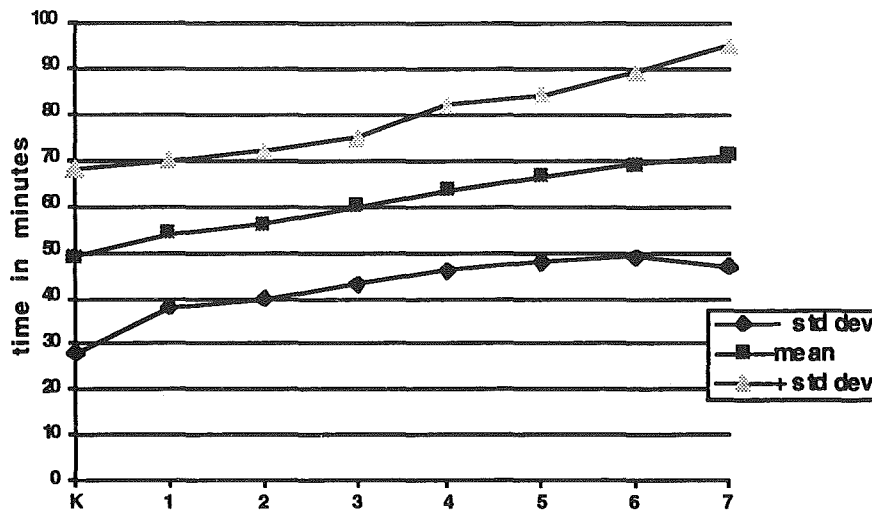


Figure 4. Time spent on science

#### Curriculum Use

Most schools reported using the Academy of Science program *Primary Investigations*. A little under one third (30.2%) of schools who responded said they were using *Primary Investigations* solely and a further 45.1% said they were using *Primary Investigations* and other science curriculum materials. Teacher selected topic, themes and activities accounted for 16.1% of schools and few schools (6.0%) were using a coordinated approach other than *Primary Investigations*. Of the few schools (1.7%) who indicated they used “other” curriculum materials, a wide range of curriculum materials were identified e.g. *Rigby Alive*, *Queensland Syllabus* and *Distance Education materials*.

#### Monitoring Tools and Outcomes

Monitoring student progress has become an increasingly important in Western Australian government schools. Monitoring in science presents difficulties in the collection of data on student skills and understandings. Data collected at a school level becomes part of the school’s Managing Information System (MIS). Question 23 was encoded as yes/no for each of the choices offered and so respondents could choose more than one alternative. Table 3 shows the monitoring tools used in schools and their perceived usefulness. Teacher assessment was by far the most common method of monitoring (90.4%). Teacher assessment can range from observation and checklist to teacher made tests so this figure indicates that the responsibility for the monitoring information is made at a classroom level but does not suggest the strategies used.

Tests are used by 60.9% of schools, either *Monitoring Standards in Education* or other types of tests to monitor student progress. A further 3% said they used the *University of New South Wales* test when they responded to the alternate choice on the survey. Many schools (42.4%) indicated that monitoring information came from teachers' reports (teacher judgments). The alternatives provided did not include *Student Outcome*

Statements as such, and of the 14.4% who chose to identify another alternative, 28% indicated that they used Student Outcome Statements as a monitoring tool.

**Table 4**

*Monitoring tools and their usefulness in guiding curriculum and pedagogical change and in making claims about student achievement of outcomes*

		Curriculum and pedagogical change	Student achievement of outcomes
Monitoring tool	% used	Question 24	Question 25
teacher assessment	90.4	2.14	2.2
MSE tests	39.8	2.43	2.52
other tests	21.1	2.5	2.56
MIS data from teacher reports	42.4	2.36	2.46
other	14.4	2.48	2.66

Note: usefulness was represented on a four point scale where: 1 = not useful, 2 = moderately useful, 3 = useful, 4 = very useful

Schools were asked to indicate how useful they found the monitoring tools they used (see Table 3). The information collected was found to be moderately useful in guiding change in most schools. It is interesting to note that 17.3% of schools indicated that the information collected through the various monitoring methods was not useful in guiding curriculum or pedagogical change in their school. The information collected through monitoring processes was found to be moderate to useful in making claims about student outcomes. Only 7% of schools found this information to be very useful while 16.1% suggested that the information collected was not useful in making claims about student outcomes.

#### *Improvement*

Most respondents (68.5%) felt that there had been improvement in science teaching and learning in their school compared to pre 1995. Of these 28.5% reported that there had been significant improvement. When given opportunity for general comment a few respondents (5) commented on the difficulty in locating monitoring information pre 1996. These schools are in rural and remote locations where transience of staff poses difficulties for the continuity of monitoring strategies and information. They felt unable to comment on the state of science in the school pre 1996 and could therefore not identify whether or not it had improved.

#### *General Comments*

The general comments section was available for extended response and 227 schools chose to add further comments in this section. The largest group of responses (31%) discussed the school planning process. Of these, most indicated that they had a well developed school planning process and most mentioned that science had been given priority status in 1995 or 1996. Others reported the difficulties and frustrations in implementing a whole school program.

"Our school reviewed science in '95 and decided the area needed attention. Science was included in the '96 school development plan as a focus area."

*Primary Investigations* was discussed by 22% of schools in the general response section. Most of the comments (36) were very positive and many suggested that the structure of the program assisted school organisation of science.

PI - whole school - has made a tremendous difference to teaching science. It has given us some direction; hands on approach is interesting. There are a few gaps in the program but teachers are supplementing the program with others.

Some schools (14) reported difficulties in implementing the program and mentioned particular problems such as catering for composite classes and the initial costs of establishing materials and purchasing the books. Other issues discussed included professional development, the role of science specialists and science in education support centres.

### Comparing the Studies

This section of the paper compares the findings from the Betjeman (1985) survey with the findings from the 1996 survey. In 1985 there were approximately 568 government schools with primary students. The survey was sent to every second school in every region of Western Australia, 87% were returned representing a sample size of 247. This survey was distributed in November 1994. The survey of science in 1996 was sent to 665 government schools and 418 (63%) were returned. This survey was distributed in July 1996.

#### Results

The section "science in your school" was retained in the 1996 survey as closely as possible to the original questions and format so that direct comparisons could be made between the surveys. Questions 3 - 11 of the 1996 Survey of Primary Science can be compared directly with the 1985 review (see Table 5)

**Table 5**

#### *Science in your school*

Question	% responding 'yes' to the question	
	1985	1996
3. grant/support	50.4	53.5
4. advisor/support	61	72.2
5. coordinator	60.6	88.2
6. policy	66	43.2
7. whole staff program	47.6	68.1
8. science equipment	96.9	94.2
9. equipment organisation	60.6	81.3



### *Grants*

Provision of a grant is compared directly with support from the Science Project. The results are very similar and it can be seen that approximately half the schools that responded benefited from grants in 1985 or support in 1996. In 1985, grants were awarded to schools who developed a written science policy and showed commitment to the development of science within their school. The grant was used for resource purchase and curriculum materials. In 1995, the Science Project did not provide schools with direct funding for the purpose of purchasing resources. Therefore no schools received grants in the period of 1995 and 1996. However many schools received support in the form of funding provided for professional development.

### *Advisor/ support*

In question 4, the comparison of a visit by an advisor (61%) in the 1985 study is compared to district office and central office support (72.2%) in 1996. In 1980-85 there were regional advisors in each metropolitan region and a central advisor. In 1995-96 there were School Development Officer's (SDO) in district offices of the clustered districts (regions) and a central project officer. Note that the 1995/96 district office staff were not funded by the central office project. The visit by an SDO would be equivalent to the visit by an advisory teacher. It is worth noting the similarities in these figures although there seems to be more activity in this area in 1995-96.

### *Science Coordinators*

There has been a marked increase (27.6%) in the number of schools with school coordinators in science. There are a few reasons that may account for this. Betjeman (1985) reported that "science coordinators have been responsible for the rapid improvement in primary science since 1980." Much of the focus of the Science Project in 1995/96 has been on the development of district leaders and networks of school based coordinators. During 1995, leaders were identified who in turn identified coordinators in schools. If science coordinators are important to the improvement of science within schools then the increase is a very positive one for primary science.

### *Science Policy*

A science policy is a clear indication of the way in which schools are addressing science education. A fall of 22.8% in the number of schools who have a written science policy may be accounted for in several ways. The advent of school development planning seems to have overtaken subject policy development in many schools and it is possible that schools do not have a written subject policy as such. The requirement of schools to have commenced a science plan in 1980-85 in order to receive grants may have caused schools to review their policy documentation. (Betjeman, 1985, p.26)

### *Whole staff program*

In both the 1985 and 1996 projects there were attempts made to involve the whole staff in primary schools. In 1985 it was thought that "if an appropriate organisation can be embedded in the school's operation then it is more likely to have longevity despite staff transfers." (Betjeman, 1985, p.34). So the aim was to work with whole school staffs through a coordinator. The increase of 20.5% in the number of schools

with whole school programs is significant as it means that decisions are made at a school level about program implementation and they are therefore more likely to have a longer life.

### *Science Equipment*

There seems to be little difference in the number of schools that have equipment accessible to staff. In 1985, 96.9% of respondents reported that they had science equipment accessible to all staff, compared to 94.2% in 1996.

### *Equipment Organisation*

The comparison between the 1985 question "Does your school use resource topic kits, in trays or boxes, as a way of organising science?" (60.6%) and the 1996 question "Is the science equipment in your school organised effectively?" (81.3%) is tenuous. The 1985 question was directly related to the methodology of the time and the 1996 question was an attempt to include other organisational methods. It was assumed that topic kits were an effective method of organising science equipment but that they were not necessarily the only way equipment could be organised.

### *Time*

One other direct comparison can be made between the 1985 and 1996 surveys on the question of time. The 1985 survey found that the time spent on science was only 3-4% of the total curriculum time available. The mean was between 40 and 60 minutes per week. From the data gathered by the 1996 survey the time spent on science was 4-6% of the total curriculum time available and the mean was between 48 and 71 minutes per week. Interestingly 44% of schools did either not respond or put a zero for K science.

In the *Review of Primary Science in Western Australia 1980-1985* Betjeman (1985) stated that a new system policy had been formulated and the recommended times were to be 60 minutes for junior grades, 90 minutes in the middle grades and 100 minutes in the senior grades. It is clear that while the average times have increased the majority of schools have not yet reached those recommended by the 1985 report.

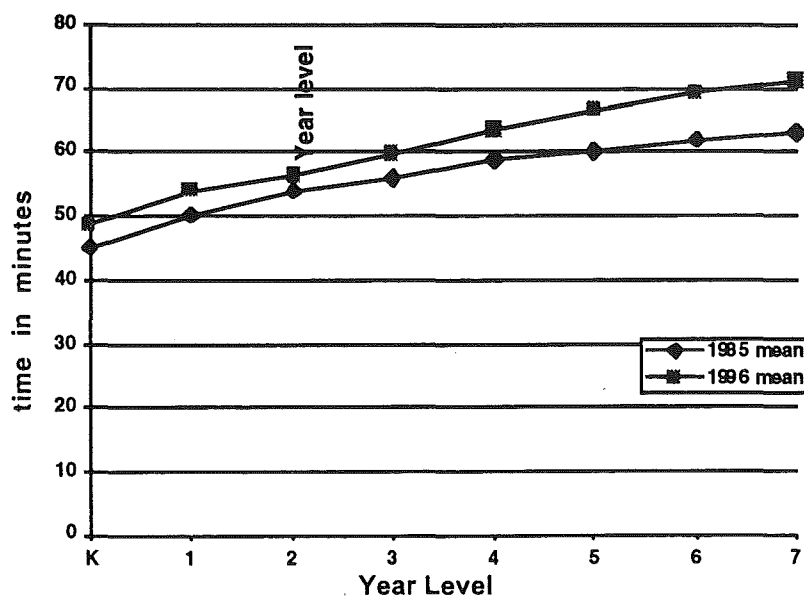


Figure 5. A comparison of the mean times spent on science 1985 to 1996

## Conclusions

This study examined school's perceptions of the state of science and the impact of the Science Project on science teaching in primary schools. A second aim of this study was to compare the perceived situation in primary science in 1996 with the situation in 1985. The results describe a generally positive state of primary science in Western Australian government schools. Teacher awareness of the Science Project is quite high. Most schools have sought advice on science teaching issues from district office or central office in 1995/96 and in most primary schools one or more teachers are aware of the Science Project. In about two thirds of schools all or most staff have participated in professional development activities in 1995/96 and nearly seventy percent of schools are implementing a whole school science program. Two thirds of the responding schools said they were using *Primary Investigations* either on its own or supplemented with other curriculum materials. Schools are monitoring science through a variety of tools and with mixed results. They did not necessarily find this information useful.

The comparison with the 1985 survey showed that there has been improvement in many areas. There has been a small increase in the amount of time spent on science by most teachers and this increase is evenly spread across the year levels. There has been a significant increase in the number of schools with identified science coordinators and the number of schools with a whole school science program. Two thirds of schools claim that there has been an improvement in the quality of science teaching and learning in their school compared to pre 1995. This is a significant figure because it represents the positive feeling about science that has been developed through activities undertaken during 1995 and 1996. While a project or program can create a positive attitude to initiate change it is the substantial work that is done in classrooms that will determine whether or not these changes are lasting ones. Many schools chose to comment on the positive feedback they have from their students who are now asking to be taught science.

The survey results indicate a positive change taking place in science as a result of the combination of two factors *Primary Investigations* and the Science Project. The activity facilitated by the Science Project has lead to common understandings of the needs of schools in science. Strategies have been developed and implemented to address these needs. One of the greatest needs was for a whole school science program and *Primary Investigations* has met this need for many schools. Primary science has undergone change since 1985 when it was "in the process of confirming its identity and direction in Western Australia" (Betjeman, 1985, p.42) to 1996 where science has an identity and is setting new directions as a result.

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# **The Effectiveness and Improvement of Faculty Culture**

Robert F Cavanagh  
*Forrestfield Senior High School*  
*Western Australia*

## **Rationale**

In 1992, Mitchell and Willower described culture as the way of life of a given collectivity (or organisation), and as a reflection of shared values, norms, symbols and traditions. When applied to a school, the culture will be manifest in the behaviour of the individual teacher, faculties and social groupings within the school (Getzels & Thelen, 1960). Accordingly, the prevailing culture is viewed as having a direct influence on the work of teachers in the classroom and provides the social context for school-wide activities including school development (Stoll & Fink, 1996; Whitaker, 1993). The success of the school in educating students and its capacity for restructuring and development in response to changing environmental pressures both appear a consequence of the culture.

The notion of school culture has evolved from the organisational management social systems theories and the research on school climate. The social systems representation of the school organisation acknowledged the existence of groupings of teachers bonded together by personal and social needs (Faber and Shearron, 1970, Hanson, 1979, Hoy & Miskel, 1987). It was considered that the interaction within a school's social system led to the development of a group climate and norms which, in interaction with personal and organisational needs, was influential on organisational behaviour (Getzels & Thelen, 1960). The notion of school climate was originally investigated by Halpin and Croft (1962), who identified six profiles of organisational climate related to perceptions of teacher and principal behaviour in elementary schools. Tagiuri (1968), conceptualised school climate as the total environmental quality resulting from a combination of physical and social factors including the ecology, milieu, social system and culture. While these developments provided interesting frameworks to view schools, it was not until the early 1980's that links between school environment and student learning were established. Anderson (1982) reviewed the accumulated research findings on school climate and emphasised the importance of cultural aspects of the school's climate on student learning. Culture was defined to be 'the social dimension concerned with belief systems, values, cognitive structures and meaning' (Anderson, 1982 p. 382). Anderson (1982), also indicated that the relationship between the ecology, milieu and social system dimensions of school climate and student learning was tenuous.

Sergiovanni (1993), advocated a shift in the conceptualisation of schools. He was critical of the application of traditional organisational theories in educational settings and proposed that schools should be conceptualised as communities and not organisations. The difference between the community and organisational conceptions of schools are summarised in the following table.

<b>Organisational Constructs</b>	<b>Community Constructs</b>
Formal organisation	Learning community
Organisational structure	School culture
Organisational objectives	Educational outcomes
Administrative processes	Cultural processes
Leadership	Cultural maintenance and transformation
School development	Cultural growth.

*Figure 1. Organisational and cultural constructs*

The community conception of schools requires school culture to be considered as the culture of a learning community and not simply as one aspect of the school's climate. It is the culture of the school which provides bonding and cohesion amongst teachers and enables them to work collectively towards improving the educational outcomes of their students. An effective school culture is supportive of the educative mission of schooling and it is proposed that in studying school culture, the focus should be upon aspects of the culture which are conducive to improvements in student learning. Research into school effectiveness and improvement has identified characteristics of the school culture which are influential on improvements in educational outcomes (Sammons, Thomas and Mortimer, 1995; Stoll and Fink, 1996; Stoll and Mortimer, 1995). This paper discusses school culture from a school effectiveness and improvement perspective.

### **Background**

Cavanagh and Dellar (1996) investigated the culture within Western Australian secondary schools. The investigation initially utilised a conceptual framework comprising eight cultural processes which the literature indicated were related to school effectiveness. These processes or 'cultural elements' included teacher efficacy, teachers as learners, collegiality, mutual empowerment, collaboration, shared visions, school-wide planning, and transformational leadership. The conceptual framework was applied in a mixed method investigation of school and faculty cultures which included quantitative and qualitative techniques. The School Cultural Elements Questionnaire (SCEQ) (Cavanagh & Dellar, 1996), was developed from the eight element framework to measure the culture of schools and faculties. The instrument contained eight scales with 64 items to measure prevailing culture and another 64 to measure the preferred culture. Other features included half the items being written in a negative form, a cyclical pattern of distributing the items within each scale and an 'easy scoring' matrix to allow respondents to score their own data.

Following trialing and refinement, the SCEQ was administered in eight schools to 422 teachers. The data from the initial quantitative investigation were subjected to factor analysis during which the original eight element conceptual framework and SCEQ scales were re-examined. This process resulted in a revised conceptual framework comprising six cultural elements and modified seven item instrument scales with improved reliability and construct validity. The quantitative investigation was supplemented by an interview programme in two schools to provide additional information on aspects of school culture which could not be

quantified. These included the influence of internal and external contextual factors on the maintenance and change of the prevailing culture.

The overall empirical findings of the study were then incorporated in the development of a model of school culture (Cavanagh, 1996). The School Improvement Model of School Culture (Figure 2) provides a theoretical representation of school culture which can be utilised in understanding and applying the empirical data. The model has six elements which were operationally defined as follows:

**Teacher efficacy** concerns the belief of teachers in the importance of the social institution of education and the need for school growth which is grounded on pedagogical principles.

An **emphasis on learning** produces a learning community in which there is a commitment to professional growth and improved outcomes for students.

**Collegiality** empowers teachers to exercise professional judgements through the development of supportive inter-personal relationships.

**Collaboration** is interaction between teachers in which information is shared on school operational matters including the instructional programme.

**Shared planning** is a collective process whereby a common vision of the school is actualised by logical planning.

**Transformational leaders** share power and facilitate a school development process that engages the human potential and commitment of teachers.

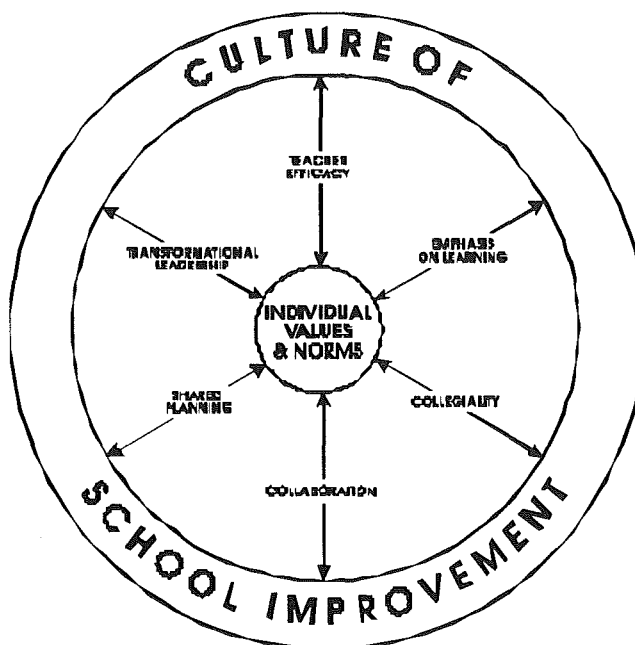


Figure 2. The School Improvement Model of School Culture

These six elements are the vehicles by which the values and norms of individual teachers are shared, ameliorated and consolidated to produce the collective values and norms which constitute the culture. The extent of their presence in a school is characteristic of the culture of the school and when all six are well developed, the school has a culture conducive to the improvement of student learning. The structure of the

model also provides a framework for presenting SCEQ data. The six radial components of the model can be used as axes for plotting data to produce a radial graph which represents the culture of a school.

### Faculty Based Culture

The processes which have formed and maintain school culture are also present in subject area faculties and the SCEQ can be used to measure the level of the six cultural elements within a faculty and profile its culture. SCEQ data provides teachers with information about their own culture for use in staff development programmes. The theoretical grounding of the instrument in school effectiveness ensures that this information is of consequence to the learning of students in the faculty and consistent with the principles of school improvement. Re-administration of the instrument provides longitudinal data to measure the extent of cultural change in the faculty and to evaluate faculty improvement initiatives.

### Examples of Faculty Culture

Figure 3 presents SCEQ data on the culture of two faculties in a large local senior high school, Scottview SHS.

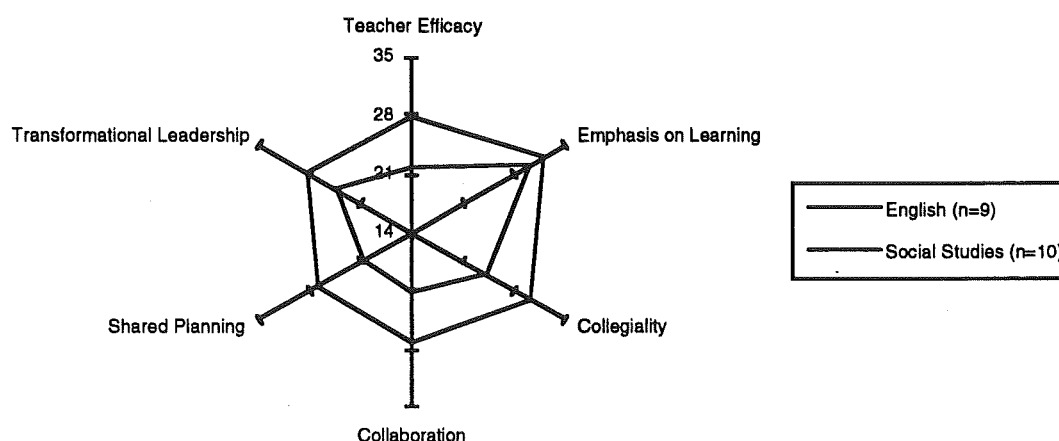


Figure 3. Faculty cultures

The radial graph presents the means scores for the six SCEQ scales. The range of each scale has been set between 14 and the maximum possible score of 35 to make the variations in data more obvious. Single Anova analysis of variance indicated that differences of 2 or more are statistically significant at the 0.05 level. Scores between 14 and 21 result from an average questionnaire response of 'uncertain' or 'disagree', those between 21 and 28 are from average 'uncertain' or 'agree' responses and those above 28 are from average 'agree' or 'strongly agree' responses.

Apart from the 'emphasis on learning' cultural element, the cultures of the English and Social Studies faculties were significantly different. The culture of the English faculty was discussed with the heads of department and they described the faculty as being composed of strong individuals who were often divided over issues and did not work together in a cooperative manner. This is reflected in the low scores for

'collegiality' and 'collaboration'. The lack of cohesion within this faculty also influenced the participation of teachers in school-wide programmes. The individualism in the faculty resulted in its members not being involved in decisions about the future of the school, not participating in 'shared planning'. The low score for 'teacher efficacy' is indicative of these teachers being uncertain about the importance of educating children. The relatively higher score for the 'emphasis of learning' scale suggests that although they may have doubts about the importance of the social institution of education, within their own faculty, student learning and their professional growth were valued. The 'transformational leadership' score relates to their perceptions of school leadership which they perceived as being supportive of teachers and the growth of school programmes. In contrast, the Social Studies faculty was a cohesive team with positive attitudes towards their profession and the learning of students. These teachers worked cooperatively within the faculty and were not isolated from colleagues in other faculties.

Figure 4 presents data which illustrates cultural change and growth within a faculty.

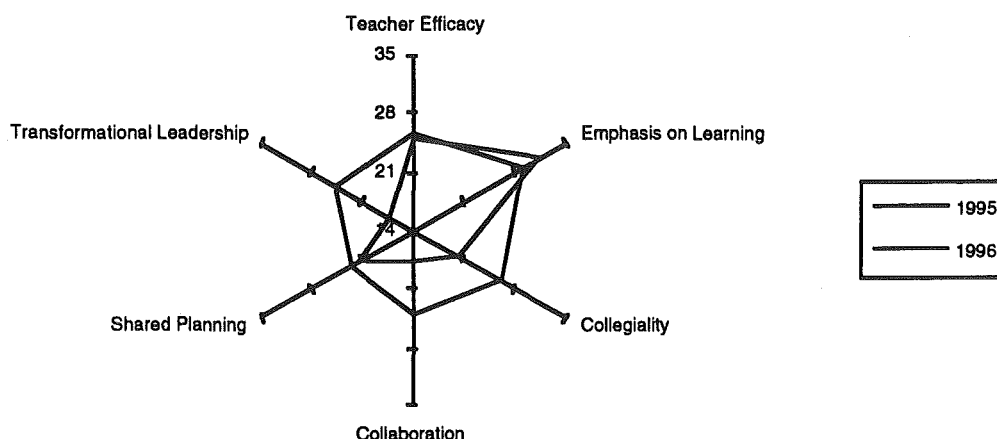


Figure 4. Faculty cultural change

The data were obtained over a 12 month period and corroborated by interviewing teachers. In 1995, the Landview SHS Social Studies faculty was described as being disunited and divided, one interviewee stated that 'collegiality was a nightmare'. Following major staff changes from 1995 to 1996, the faculty developed a new culture which is reflected in the large increases in SCEQ mean scores for the 'collegiality', 'collaboration' and 'transformational leadership' scales. The faculty was described by interviewees as having undergone an 'almost complete about turn'. Interviewees commented on 'increased collaboration, shared planning and collegiality'; 'program writing is done in pairs'; and 'we are working together as a department'.

The previously discussed examples of faculty culture were specifically selected to exemplify the differences between faculties and the phenomenon of cultural change. In general, SCEQ faculty data from six senior high schools has revealed that within each school, there was a diversity of faculty cultures. It also showed in-consistencies in faculty culture for specific subject areas across schools. For example, Science faculties were not all the same. Another finding concerned the stability of faculty cultures. The major change



in the culture of the Landview SHS Social Studies faculty was not typical, most faculties experienced only minor changes during the period of investigation.

### Summary

The School Improvement Model of School Culture was developed in consideration of contemporary conceptions of schools and the cultural elements which influence their effectiveness in educating students. These theoretical propositions were tested by collecting and analysing quantitative and qualitative data in local senior high schools. The School Cultural Elements Questionnaire provides a reliable and valid means of informing teachers of their faculty and school cultures. Utilisation of a questionnaire for this purpose solicits potentially sensitive information in an objective and non-judgemental manner.

Faculty and school improvement needs to focus on the values and norms of teachers and the culture of their school and faculties. Improvement of the school and the growth of its culture require that teachers understand the nature of their culture and the mechanisms by which it develops, is maintained and changes. The School Improvement Model of School Culture and the SCEQ can be utilised in professional and school development programmes to develop this understanding.

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# Mapping the Development of Conceptual Understandings in Primary Science: Some Initial Findings From Three Year 7 Classes

Christine Coulstock and Mark W. Hackling  
*Department of Science Education*  
*Edith Cowan University*

## Abstract

This paper describes the types of teacher-whole class interactions that occurred in three Year 7 classrooms in Western Australia. The researcher provided lesson outlines for the teachers which suggested activities, demonstrations and focus questions, and details of concepts to be developed. Although the lessons were not prescriptive the outlines specified the types of activities that were expected and these included whole class discussions. The quality and nature of these whole class discussions varied between classes. This paper reports the types of interaction that occurred, the participation by class members, the ways teachers developed and elaborated on understandings and the conceptual understandings that were developed by the students.

## Introduction

Primary science is often perceived as being poorly taught with many primary teachers lacking confidence and competence in teaching science (Yates & Goodrum, 1990). Teachers may lack content knowledge, particularly in the physical sciences, which may either discourage them from teaching science (Yates & Goodrum, 1990) or may result in restricted or inaccurate content being taught (Carlsen, 1992). Discussions are an important part of science education, but, if the teacher lacks knowledge and confidence, they may be limited and may not develop scientific understandings in children (Roth, Anderson & Smith, 1987). Students often have alternative frameworks of which teachers may be unaware, and which many curriculum packages do not address.

Constructivist psychology indicates that new knowledge is constructed by individuals (Driver, 1989; Wheatley, 1991) and, as it is affected by their current knowledge and beliefs, may result in non scientific understandings being developed (Driver, 1989; Driver & Oldham, 1986). Learners need to be active participants in their learning (Driver, 1989; Driver & Oldham, 1986; Wells, 1989), developing new understandings through social interactions (Driver, Asoko, Leach, Mortimer & Scott, 1994; Solomon, 1993) and activity based investigations.

### *The Role of Discussion in the Construction of Meaning*

Teaching strategies have been designed which are based on constructivism and take into consideration the learner's understandings (eg. Driver & Oldham, 1986; Neale, Smith & Johnson, 1990). These strategies include elicitation of students' held ideas, including probing for deeper understanding; material centred cooperative group work; and group and whole class discussions (Driver & Oldham, 1986; Neale, Smith & Johnson, 1990; Roth, Anderson & Smith, 1987). Whole class discussions need to include open and closed questioning, although closed questions are considered unlikely to develop understanding,

and teacher directed discussion where the teacher leads students to correct understandings with links being made to concepts previously covered (Driver, 1989; Gunstone, 1995; Neale et al., 1990; Roth et al., 1987).

The level of teacher knowledge may have an effect on the type and quality of discussion. Carlsen (1992) suggests that teachers lacking scientific knowledge may limit questioning by students, not give clear evaluations of students' answers, and their explanations may lack clarity although they may dominate classroom talk. Teachers with a better understanding of the concepts under discussion may offer explanations which are not at a suitable level for the learners (Ausubel, 1968; Barnes, 1976).

### **Problem and Significance**

Research indicates that to teach science effectively teachers should use constructivist teaching strategies which include activity work, talk within groups and whole-class discussions. Whole-class discussions in primary science classrooms may be limited by the teacher's lack of knowledge and confidence and may lack the type of interactions necessary for developing scientific understandings.

### **Purpose and Research Questions**

The purpose of this study was to examine the nature of whole-class discussions that occurred in three primary classrooms and map the discussions against the changing conceptions of the children in these classes.

The research questions, therefore, were:

- (1) What strategies are used by the teachers to enhance discussions?
- (2) What understandings are developed by the students and how do these relate to the content, type and quality of the class discussions?

### **Method**

This study examined interactions in primary science classrooms during a five lesson unit of work on the topic of electricity. All teacher-class, teacher-group and teacher-individual interactions in three upper primary classrooms were audio recorded, together with audio and video recording of all interactions and activities of one small group in each class. The researcher remained in the classroom as a non-participant observer during all lessons.

The study was conducted in two Year 7 classes and a Year 6/7 class from schools in semi-rural environments close to Perth, Western Australia. The three teachers, Mr Avery, Ms Brown and Mr Clark (pseudonyms), were experienced and had previously taught electricity as a science topic in Year 7. It was apparent during the course of the lessons that only Mr Avery had a sound scientific knowledge, with the other teachers demonstrating some lack of knowledge. The teachers had quite different teaching styles.

Teachers were each supplied with lesson outlines to cover the unit which were not prescriptive but included background information, activities, demonstrations and focus questions. The lessons, as conducted by the teachers, usually consisted of an introduction which included task directions, materials-centred activity work, whole-class discussions and sometimes a review of the lesson.

### *Data Analysis*

All audio tapes were transcribed by the researcher with long periods of speech by any one person divided to show change of content, eg. from control mechanisms to concept discussions. This was then transferred to a data-base and coded according to defined criteria which allowed the researcher to select needed data.

### **Results**

This section reports the way teachers developed conceptual understandings during whole class interactions with the term 'discussion' being used to describe those periods when the teacher and students were reviewing previous work or treating new work in a whole-class setting. Initially, an overview of the teachers' and children's behaviours during discussions is presented, and this is followed with data regarding students' test results from the three classes.

#### *Types of Interactions During Whole Class Discussion Times*

The three teachers had very different styles of discussion. Mr Avery was a friendly teacher, called by a nickname by his students. He conducted animated but quiet discussions and any control mechanisms that he used tended to be incidental and not distract from the flow of discussion. He used practical demonstrations and available media to explain ideas and used analogies effectively. Students usually came to the front of the class for demonstrations where they could easily see what was happening. When questioning students during discussions he used more open questions than the other teachers, requiring students to justify and explain their answers. His students asked non-procedural questions and demonstrated interest in the topic by offering information other than that requested. They were also willing to argue their point of view with Mr Avery. Science equipment was always packed away before the main discussion time, and students were asked to turn and face the teacher. Students were generally attentive during discussions.

Ms Brown was more distanced from the students and conducted discussions that lacked animation and interest. Her control methods tended to interrupt the flow of the discussion. She used few practical demonstrations and, when student models were displayed it was to look at construction and not to develop understanding of concepts being discussed. Students were seated at their desks for all demonstrations and may have found it difficult to see. She used no analogies. She only used open questions prior to activities when students were predicting what might happen, and most discussion was conducted using closed questions. Her students only asked procedural questions and gave limited factual answers with no extra information. They were rarely called upon to justify their answers. Science equipment was always on the desk during discussions and although students were sometimes asked to face the teacher they did not remain in that position. Students were often distracted by the equipment during discussions.

Mr Carter was friendly towards students and had nicknames for most of them. His discussions were animated and fast moving and, although his control methods interrupted the flow of discussion, they were generally less intrusive than Ms Brown's. He used practical demonstrations and student models to help explain concepts, but used them less frequently than Mr Avery. Students moved to see some demonstrations with others held at the front of a seated class. He used analogies effectively. He used more questioning than

Ms Brown although less than Mr Avery, with effective use of open questions. Students were willing to ask questions other than procedural questions, and occasionally questioned points made by the teacher. As in Ms Brown's class, the science equipment was left on the desks during discussions and students, although not always facing Mr Clark, were generally more involved in the discussion.

#### *Development of Conceptual Understandings*

One understanding to be developed was the concept of an electric circuit as a set of components joined together in specific ways and at specific places to allow the flow of electric current. During the first lesson the activities and discussions were centred round this concept and there were opportunities to review this in subsequent lessons, particularly in the second lesson where there were opportunities to compare the newly constructed circuits with those produced in the first lesson, and to examine the connection points in a globe holder. Each class was supplied with a wall display diagram which showed a simple circuit and illustrated the path by which electric current flowed through the globe. This was used by Mr Avery but not by Ms Brown and Mr Clark.

During the first lesson Mr Avery specifically discussed the connecting points during three separate whole-class discussions of circuits, working and non-working. He demonstrated the flow of current through a complete circuit on one of the diagrams. He also strongly evaluated student comments on the flow of current and repeated student answers. At the beginning of the next lesson he used the simple circuit diagram to demonstrate the flow of electric current through a circuit. The connections were mentioned incidentally near the beginning of the third lesson and later in the lesson it was agreed the circuit constructed was the same as that in the first lesson. He then demonstrated the globe holder and explained how it worked. There was no further specific discussion of the connection points in other lessons, although the poster was frequently used to demonstrate circuits.

Ms Brown made no specific mention of connection points in the whole-class discussions during the first lesson, when students were deciding whether circuits drawn on the blackboard would work, although some students did include battery connections in their explanations of why two circuits would not work. At the end of the lesson, when four more circuits were drawn on the blackboard, Ms Brown described the circuits mentioning connection points to the battery but ignoring the connecting points on the globe.

During the review at the beginning of the second lesson the connections were discussed although the student explanation was ambiguous and Ms Brown only mentioned the battery connections when responding to the student's answer:

Student:        Connect one to the positive and one to the negative and then connect the other end to both sides of the battery.

There was no explanation of the connections in globe holders and no discussion as to whether the circuit made in this lesson was similar to that previously made. There was no further specific discussion on connection points.

Mr Clark had three major whole class discussions during the first lesson. During each of these Mr Clark mentioned the connecting points in the circuit but no emphasis was placed on them, and also indicated them on blackboard drawings or models. On one occasion a knowledgeable student described the connecting

points in a circuit in a way which was positively evaluated by Mr Clark who then described and demonstrated the circuit using a model:

Student:        Having a wire to the bottom of the globe and then the other the silver part or the other bit of globe to the top of the battery

During this lesson Mr Clark also described the current flow through a globe holder. In the second lesson it was agreed that the circuit constructed was the same as that previously constructed and in the third lesson, during the initial review, a student described the battery connections in a circuit.

The mean scores for the pretests and posttests for the whole electricity topic show an improvement in understandings in all classes (Figure 1) with Mr Avery’s class showing the greatest improvement in understanding, Mr Clark’s class the next greatest and Ms Brown’s class showed the least improvement.

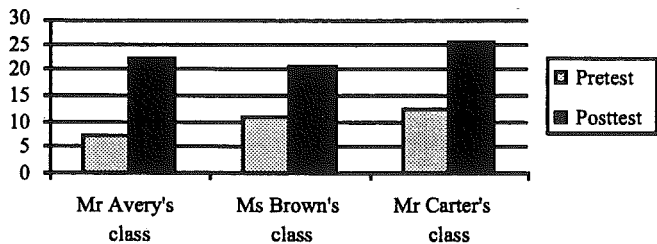


Figure 1. Mean scores of science pretests and posttests (Maximum possible score 59)

The mean scores for Question 7 which probed student understandings of the connection of wires, globe and battery into a complete circuit again show an improvement in all classes from pretests to posttests with Mr Avery’s and Mr Clark’s class demonstrating a substantial improvement in scores and students from Ms Brown’s class showing a limited improvement (Figure 2).

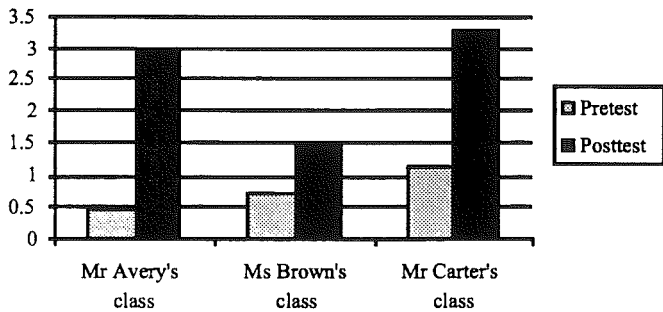


Figure 2. Mean scores on question 7 in science pretests and posttests (Maximum possible score 7)

Table 2 shows the changes in student conceptions of circuits between the pretests and posttests. In the posttest the number of students in Mr Avery’s class correctly identifying working circuits in Question 7 increased from 16% to 72%; in Ms Brown’s class the increase was from 15% to 28% and Mr Clark’s class the increase was from 20% to 63%.

**Table 1***Changes in student conceptions of complete, working circuits between pretests and posttests*

	Mr Avery's class (n = 25)	Ms Brown's class (n = 32)	Mr Clark's class (n = 30)
Total students retaining or changing to a scientific conception	18	9	19
Total students retaining or changing to an alternative conception	6	22	11
Total students who retained or changed to no response or informal response	1	1	0

### Discussion

Driver and Oldham (1986) and Neale et al. (1990) suggest that teachers need to elicit student understandings so that unscientific conceptions can be addressed during teaching. During discussions all teachers had the opportunity to recognise understandings students held and ensure they were investigated and discussed. Mr Avery probed students' conceptions of circuits and ensured their ideas were tested and discussed. Ms Brown and Mr Clark used a show of hands to decide whether circuits were working, but did not elicit students explanations of why the circuits were working or not. Roth et al. (1987) recognised the importance of open questions and the need to include directed discussion to focus students towards correct understandings. Mr Avery's and Mr Clark both used student answers to develop scientific understandings and evaluated or tested student ideas. Open questions asked by Ms Brown before circuits were tested were never addressed fully after the investigation, with no evaluation of student ideas. Roth et al. (1987) also recognised the need for closed questions as part of the discussion but suggested that an emphasis on only closed questions resulted in less successful outcomes. Ms Brown's limited use of open questions and emphasis on closed questions resulted in little understanding being developed by students. In Mr Avery's and Mr Clark's classes students had opportunities to not only offer thoughtful answers to questions but also to be able to verbalise their ideas by asking questions and disputing points, giving the teachers a deeper insight into student understandings and the students an opportunity to consolidate their ideas (Roth et al., 1987). The limited answers and participation in Ms Brown's class never allowed students, in a whole-class situation, to generate ideas or Ms Brown to recognise differing understandings. Ms Brown was less knowledgeable about electricity than Mr Avery and, as Carlsen (1992) suggested, teachers who have limited background knowledge tend to limit class discussions and consequently student learning.

Links need to be made between activities and student understandings (Driver, 1989; Gunstone, 1995; Neale et al., 1990; Roth et al., 1987) and concepts should be reviewed to ensure they are accepted by students (Roth et al., 1987). Mr Avery and Mr Clark spent time reviewing concepts and this allowed concepts that had previously been treated to be linked with new knowledge. Ms Brown rarely made links between concepts or lessons.

Only one area of conceptual understanding in the electricity topic has been discussed here, but analysis of another conceptual area, where the content and quality of the discussion in Ms Brown's and Mr Clark's class was better than that of Mr Avery's, and students in Ms Brown's and Mr Clark's classes performed better in the test than Mr Avery's students, reinforced the view that the quality and content of whole-class discussion has a powerful influence on the understandings developed by the students.

### Conclusion

As a large number of variables impinge on student learning in science classrooms, no direct causal relationship between the type, quality and amount of class discussion and student learning can be inferred. However, the type, quality and amount of whole-class discussion in the classes observed were quite different and these differences are associated with markedly different conceptual development by the children. These data are consistent with social constructivist explanations of the crucial role that can be played by discussion in the construction of meaning.

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# Primary Technology: Teachers Concerns and Challenges

Judith Cousins  
Science Education Department  
Edith Cowan University

## Introduction

The presentation of the Technology and Enterprise Student Outcome Statements established technology as a learning area in its own right, with its own special content and processes. However, no firm guidelines have been developed to provide teachers with assistance on teaching strategies, topics to be developed, or assessment procedures to be used, in the implementation of this new learning area. This paper will present a summary of recent results gained from surveys, questionnaires and interviews, showing the concerns pre-service and practicing teachers have expressed related to the teaching of Technology and Enterprise lessons in their classrooms. The ideas from four exemplary teachers will be explored.

## The Survey

The purpose of the survey was to discover teacher's initial concerns when teaching a technology lesson and was designed to be as simple as possible. The survey form was a single piece of paper with eight concerns listed. Respondents were required to rank these concerns in order of importance from 1 being the most important to 8 being least important. The instructions stated:

*When about to implement a technology activity in your classroom which of the following factors/issues are the most important?"*

The eight factors which were listed were: resources, evaluation, safety, support, cost, time, likely difficulties and personal skills. These factors were derived from several sources. Some were gained by the researcher in informal discussions with teachers and Principals and others from literature published in this area, Treagust, Kinnear and Rennie (1991); Aubusson and Webb (1992); Hoban and Hoban (1992); Eggleston (1992); Clayfield and Hyatt (1993); Anning (1994).

The factors in the survey were randomly listed and the survey administered with little introduction beyond saying the researcher was trying to find out the factors which would influence teachers implementing technology programmes in their classrooms. There was no explanation of why the factors had been chosen, what they meant or opportunity for the respondents to elaborate on the rankings. Four groups of teachers and pre-service teachers were selected by convenience. A total of 169 surveys was completed.

Group 1 consisted of 25 teachers attending a primary science weekend conference. They had chosen a workshop titled "Teaching Technology" which indicated they were interested in this topic. They completed the survey prior to commencement of the workshop. Group 2 consisted of 12 teachers attending a school-based workshop. This was an after-school session at an Independent Girls school where the school coordinator of technology was trying to initiate some interest in this area. At this time the teachers were "acting in a support role to the coordinator, without taking a leading or proactive role in their classrooms."

Group 3 consisted of 12 teachers attending a school- based workshop related to the science package 'Primary investigations'. Group 4 consisted of 124 Third Year pre-service teachers. This group had completed all core units of their course and were preparing for their ten week teaching practice. Four of these surveys were incomplete and deleted from the data.

**Table 1**

*Mean rankings given by four groups of practicing and pre-service teachers*

Item	Group1 N=25	Group 2 N=12	Group 3 N=12	Group 4 N=120
Resources	1.80	1.75	2.00	1.68
Time	3.52	3.66	2.08	4.65
Skills	4.48	4.75	3.58	4.90
Cost	4.72	3.66	3.58	6.12
Difficulties	5.00	5.50	6.50	5.55
Safety	5.08	4.25	6.50	3.78
Support	5.64	6.25	7.00	5.02
Evaluation	5.76	6.16	4.50	4.26

The results from Table 1 show that resources is the factor of prime concern to all groups of teachers. This can be interpreted in several ways as resources may mean equipment, consumable materials, written curriculum materials, or all three. It can also be defined as human resources. Time was the second priority for practicing teachers, which appears to indicate they believe that the planning and preparation of technology lessons may be time consuming. The cost factor is given reasonable priority by the practising teachers, always in the top four. Safety is high on pre-service teachers priorities, which may be due to a perceived lack of confidence in managing classes with all children engaged in active learning. The low ranking of evaluation by the practising teachers is of concern to the researcher as it may be interpreted as teachers not feeling the need to address evaluation at this stage of implementation of the learning area.

### **The Questionnaire**

The questionnaire was devised to gain insights into teacher background, aspects of teaching technology, teachers' familiarity with the Technology and Enterprise Student Outcome Statements and some ideas on the integration of technology and other subjects. There was an opportunity for teachers to make additional comments. As the teachers completed the questionnaire in their own time there was no time limit set. The questionnaire used a mixture of response types, both closed and open-ended items.

The questionnaire was produced following analysis of the surveys. The aim was to focus on the survey responses and to obtain a more detailed picture of the issues and factors teachers are concerned with in implementing this new learning area.

The questionnaire was given to 40 teachers. Thirty of these teachers were studying part time working towards completion of their Bachelor of Education degree, while still teaching full time. They were enrolled in either a science education unit or a mathematics education unit and the questionnaire was given out at the end of a lecture and collected the following week. The other ten teachers were from the primary division of an Independent Girls school and they were given the questionnaire at the conclusion of a one hour professional development session on "Teaching Technology". The questionnaires were completed in their own time and posted to the researcher. The response rate for the first group was 90% and for the second group, 80%.

Results from the questionnaire have been analysed under four sections. teacher background; teaching technology; student outcome statements; and integration of technology with other learning areas.

#### *Section 1: Teacher Background*

The experience of the responding teachers is presented in Table 2.

**Table 2**

*The teaching experience of the 34 responding teachers*

Number of years teaching	Number of teachers
1-5	7
6-10	11
11-15	10
16-20	6

The above Table indicates the teachers were very experienced, with 80% having a minimum of six years of classroom experience.

The Year Level the teachers were currently teaching is indicated in Table 3.

**Table 3**

*Year Level teachers are currently teaching*

Year Level	Number of teachers
Pre Primary	7
Junior Primary (Years 1-3)	11
Middle and Upper Primary	11
Support (different classes)	1
Relief (moving between schools)	4

It can be seen that there was a good spread of responses across the Year levels.

## Section 2. Teaching Technology.

The purpose of this section was to try to ascertain at what stage these teachers were in implementing technology within their classrooms. The first question asked teachers to choose which of four levels they thought described themselves. The results are in Table 4. Two teachers did not respond, but both wrote:

"I am not sure what technology means".

**Table 4**

### *Teacher's levels of technology teaching experience*

Response choice	Number of teachers
Just a beginner	18
Have made a start but need further guidance	9
Have done some activities reasonably successfully	2
Feel confident I know where I am going	3

These data clearly show that at this time a number of teachers are still at the beginning of implementing technology (53%), while another 30% consider they need further guidance. Only 3 (9%) teachers indicated that they felt confident in this learning area, with 2 teachers (6%) feeling that they were reasonably successful. These results were not surprising because the Technology and Enterprise learning area was only designated as such twelve months before the questionnaire was administered and many schools do not appear to be attempting any formal implementation as yet.

The second question in this section asked: What would motivate you to teach more technology? The responses covered a range of areas which could be categorised under five headings shown in Table 5.

**Table 5**

### *Motivation required to teach technology*

Motivational source	Number of teachers
Resources	17
More knowledge about what technology is	10
Professional development	5
Curriculum materials	3
Time	3

Consistent with the findings from the survey, it is immediately obvious that teachers are finding the provision of resources for technology tasks one of the major difficulties to be overcome in the classroom situation. The responses indicated that 'resources' can mean materials as well as ideas.

Other questions in this section related to the technology being taught, sources of ideas for technology lessons, the documentation used in the planning process, the main difficulties being experienced, the best technology each teacher considered they had done and aspects of assessment. The responses varied but can be summarised as follows:

**Technology being taught:** 'design, make, appraise' activities; computing; building with Lego; using calculators; and exploring mechanical items.

**Ideas for technology lessons:** other teachers; own ideas, professional development courses; and resource books.

**Documentation used in planning:** daily work pad; programming; 'Primary Investigations'; and Lego resource cards.

**Main difficulties being experienced:** having time to do extended activities; providing enough materials; knowing how to plan appropriately; finding ideas.

**Best technology taught:** making boats from junk; using Lego Technics; building kites; and making spaghetti bridges.

*Assessing Technology.* Sixteen teachers responded to this item, with only 7 giving a positive response. Methods of assessment included: evaluation of the final product; observation of the children as they worked; listening to children's discussions; use of a checklist, and interviewing children.

Problems associated with assessment were mentioned, such as, time to teach and assess, time to mark final products and the difficulty in making subjective judgements.

### *Section 3. The Technology and Enterprise Student Outcome Statements*

The purpose of this section was to determine teachers' familiarity with the Technology and Enterprise Student Outcome Statements. Four levels of response were provided, as shown on Table 6.

**Table 6**

*Teacher's responses to familiarity with the Technology and Enterprise Student Outcome Statements*

Response	Number of teachers
Haven't read it	15
Have skimmed it	16
Have read it thoroughly	3
Have a good understanding of it	0

Table 6 shows that of the 34 teachers in the sample, not one considered he/she had a good understanding of this document and only three had read it thoroughly. 44% had not read it and 45% had only skimmed it. This material was distributed to schools in early 1995, twelve months before the questionnaire was administered, so it appears, from this sample, that little organised discussion has yet occurred and individual schools or teachers are working with the document in some isolation.

#### Section 4. Technology and Integration

This section tried to find out if teachers were seeing Technology and Enterprise as a separate subject or whether they expected to integrate it with other learning areas. Thirty two teachers responded to this item, with three teachers stating they would teach it separately and twenty six that they would integrate it. A question relating to assessing technology if it was taught in an integrated manner was ignored by 9 teachers. Other responses indicated a lack of confidence in this area, examples included:

*"Not sure", "You tell me" and "Good question!"*.

#### Interviews

Four exemplary primary technology teachers were interviewed to gain insights into their practices when implementing Technology and Enterprise lessons. The interviews contained eighteen structured questions and other non-scripted questions, based on the responses of the interviewee. These interviews produced an extensive amount of data which can only be summarised in this paper.

The teaching experience of these four teachers ranged from eight to thirty years. They were currently teaching Year 1, Year 4, Year 6 and Year 7/8. They were all enthusiastic, and indicated they felt confident and competent to teach Technology and Enterprise, and were willing to assist others to gain greater understanding and expertise in this learning area. They were all well conversant with the Technology and Enterprise Student Outcome Statements.

These exemplary teachers were asked what problems they saw in teaching this learning area, so a comparison could be made with responses from the surveys and questionnaires.

These four teachers gave a range of responses to this question on perceived problems or concerns. Two teachers commented on the lack of direction for teachers as to where technology fits into the school curriculum and that many teachers do not understand the philosophy behind technology education. They stated that there was no syllabus and that although there were plenty of 'one-off ideas' available there was nothing that presents teachers with a coherent programme. One teacher mentioned 'teacher apathy' as a problem, with some teachers not wanting anymore change nor wanting to try anything different. Three of these four teachers highlighted the lack of resources and the fact that little money was being set aside for this learning area. It should be noted that the schools where these teachers were working had all allocated some money for Technology and Enterprise activities.

The question of safety was raised but all four teachers considered that technology tasks just required sensible planning and supervision. As one commented, "Technology doesn't introduce any extra safety aspects that you wouldn't already cover in your classroom."

The aspect of resourcing for technology education was discussed and all four teachers saw the provision of resources as essential for technology tasks. Depending on the topic being undertaken the type of resources varied but these teachers mentioned the importance of tools and simple equipment. Items such as glue guns, hammers, nails, and clamps were seen as necessary for construction activities.

The area of assessment was addressed, with each teacher having thoughtful ideas and suggestions on what and how this should be carried out. The importance of 'skilling up' children so they could design, build

and evaluate was highlighted. The process the children went through during the completion of a technology task was seen as equally important to the final product and a range of assessment procedures, such as group assessment, peer assessment, use of checklists and observations were all seen as methods of assessing children's progress in this learning area. All four teachers conceded that this was a difficult aspect of teaching technology and that they felt they needed to further consider their methods and strategies.

These teachers all taught technology in an integrated way. Although they often began a topic as a technology task there were always 'spin-offs' into other learning areas, and this was seen as natural and positive.

These four teachers have established practices and styles suited to their individual skills and teaching contexts. They are leading by example and the interviews provided useful information on how exemplary practitioners are viewing the Technology and Enterprise learning area.

### Conclusion

This paper has reviewed a study to gauge the concerns of teachers when implementing the Technology and Enterprise learning area. The results show that some teachers have little understanding or familiarity with the Technology and Enterprise Student Outcome Statements, are uncertain how to include technology activities successfully within their curriculum, and see the provision of resources as a necessary requirement for classroom implementation of technology tasks. Some teachers show concern about safety aspects and few indicated any confidence in assessing this learning area. These concerns must be addressed if Technology and Enterprise is to be implemented in primary schools in a well considered and cohesive way. At present there are pockets of exemplary teaching of primary technology and the challenge is to develop these 'lighthouses' so all teachers can gain and build from these experiences and hence all children have opportunities to grow and develop in this significant area of learning.

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1. The first part of the paper is devoted to the study of the properties of the function  $f(x)$  defined by the equation

$$f(x) = \int_0^x \frac{1}{1+t^2} dt$$

for  $x \in \mathbb{R}$ . It is shown that  $f(x)$  is an odd function and that it satisfies the inequality

$$|f(x)| \leq \frac{\pi}{2} \quad \text{for all } x \in \mathbb{R}.$$

2. In the second part, we consider the function  $g(x)$  defined by the equation

$$g(x) = \int_0^x \frac{t}{1+t^2} dt$$

for  $x \in \mathbb{R}$ . It is shown that  $g(x)$  is an even function and that it satisfies the inequality

$$|g(x)| \leq \frac{\pi}{4} \quad \text{for all } x \in \mathbb{R}.$$

3. Finally, we study the function  $h(x)$  defined by the equation

$$h(x) = \int_0^x \frac{t^2}{1+t^2} dt$$

for  $x \in \mathbb{R}$ . It is shown that  $h(x)$  is an odd function and that it satisfies the inequality

$$|h(x)| \leq \frac{\pi}{4} \quad \text{for all } x \in \mathbb{R}.$$

# Implementation of a Year 10 Bioethics Unit Based on a Constructivist Epistemology

Vaile Dawson  
*Science and Mathematics Education Centre  
Curtin University*

## Introduction

As this century draws to a close, our school students face a rapidly changing and uncertain future. The active encouragement of our students to think critically about ethical issues will enable them to make well-informed political, moral and social decisions about their future and the future of others. I believe that school students need to be equipped with appropriate decision-making skills if they are to contribute to public debate about the ethics of problematic issues such as the arms race, population growth, food and health resource allocation, environmental degradation and control of information technology (Frazer & Kornhauser, 1986; Rubba & Harkness, 1993).

This paper describes the implementation of a Year 10 bioethics unit at an independent girls school in Perth, Western Australia. Bioethics is the study of ethical issues and decision-making associated with the use of living organisms and medicine. Rather than defining a correct decision, it is about the *process* of decision-making, balancing different benefits, risks and duties (Macer, 1994). Bioethics education is about helping students to develop, articulate and evaluate critically their own bioethical values. It aims to make students aware of the divergence of opinion and multiplicity of values that exist in a pluralistic society. Bioethics education also allows students to develop decision-making skills in a climate of respect and tolerance (Reich, 1995). Bioethics education is *not* about imposition of the teachers values and it is *not* about indoctrination of one particular set of values.

There are a range of science topics that can be used to illustrate the role of bioethics in science. The area selected in this study was that of human organ and tissue transplantation. This topic raises a number of ethical issues and thus provides a rich source of dilemmas with which students can discuss, debate and reflect on their own ethical values (Kries, 1992).

When I first taught the unit, I trialled a number of the available resource materials with the main aim of conveying factual information about human organ and tissue transplantation. However, it soon became apparent that there were many ethical, religious and legal aspects that could not be ignored. Indeed, the students reacted very strongly to these issues. They insisted continually on discussing and attempting to clarify these problems. As a result of this response, the development and implementation of strategies for teaching the bioethics unit were undertaken from a constructivist perspective on learning.

An evaluation of the teaching strategies developed and utilised in this unit has been reported elsewhere (Dawson, 1994, in press). In brief, during the development of the bioethics unit, I elected to implement a range of teaching strategies that would maximise opportunities for discussion and debate while, at the same time, provide information and a stimulating learning environment. The most effective strategies were those that were student-centred and co-operative (e.g., role-plays, debates, oral presentations,

interviews). That is, the students were engaged actively and explicitly in constructing their own understandings.

Constructivism is a theory about knowledge which recognises that each individual constructs his or her own personal meanings based on his or her prior experiences (von Glasersfeld, 1989). That is, knowledge is not an external 'out there' fact waiting to be discovered or transmitted from the teacher to the student. Rather, 'knowledge is constructed in the mind of the learner' (Bodner, 1986).

A constructivist epistemology acknowledges also that learning is a social activity in which students interact and develop their own meanings through discourse (Driver, 1990; Tobin, 1993). Through discussion with peers, students can clarify their understandings and build on each other's ideas. This perspective does not imply that the teacher should be passive or superfluous. Rather, the role of the teacher is to guide and support students as well as provide a stimulating environment where students will actively learn.

A constructivist perspective seemed to provide a compelling pedagogical framework to enable students to construct their own bioethical values about transplantation. Importantly, the teacher should not impose on students his or her own values, but help students to become critically aware of ethical issues on the basis of their own values and those generally accepted by our society (Skamp, 1986, Mertens & Hendrix, 1990).

### **Research Methodology**

In my role as a teacher-researcher engaged in action research (Kemmis and McTaggart, 1988, p.5), data were generated to evaluate the effectiveness of my constructivist pedagogy. The following research question formed the basis of an ongoing generation and analysis of data which occurred within an interpretive case study framework (Merriam, 1988):

To what extent were the students empowered to explore their own beliefs and values? That is, did they (a) share control with their teacher, (b) exercise a critical voice, and (c) engage in negotiations with their peers?

The research methodology undertaken in this study was based on a qualitative case study approach (Merriam, 1988). It entailed a detailed examination and evaluation of a specific issue, that is, the efficacy of a constructivist epistemology for teaching bioethics to secondary school students. In this study, the data were interpreted by myself in the role of 'teacher-researcher'. That is, as a teacher, I was actively engaged in research within my own classroom.

The Bioethics unit was part of a compulsory Year 10 course entitled 'Women and technology'. The time allocation for the unit was 10 x 50 minute lessons spread over a single 10-week school term. Data were collected from three classes (termed A, B and C) each containing around 10 students. The names of all students have been changed to protect their identity. Sources of data include questionnaires, student interviews, videotape and audiotape recordings of lessons, informal discussions with students and classroom observations recorded in a personal journal (Holly, 1992). The comparison of multiple sources of data (triangulation) served to increase the reliability (i.e., the degree to which the data can be replicated under

certain conditions) of this study (Merriam, 1988). The validity (i.e., the degree to which the data fits reality) was enhanced by the use of rich descriptions and a consideration of disconfirming evidence.

#### *Constructivist Learning Environment Survey*

Students' perceptions of their learning environment were determined using several scales of a questionnaire entitled 'Constructivist Learning Environment Survey (CLES) for Science Education' (Taylor, Dawson & Fraser, 1995; Taylor, Fraser & Fisher, in press).

The CLES questionnaire was administered to all students at the conclusion of the bioethics unit. The purpose of the questionnaire was to determine the extent to which the classroom environment was constructivist. The survey asks students to respond to items related to: (1) the *relevance* of the topic of transplantation to themselves and the world around them; (2) the extent to which students were empowered to express a *critical voice* about the nature and quality of teaching strategies (3); the extent to which students *shared control* in the management of their classroom environment (4); and the extent to which students had opportunities to make sense of their ideas through *negotiation* with their *peers*.

The CLES questionnaire had 35 items (7 for each of the four scales mentioned above) and 7 items related to students' attitude toward the learning activities and classroom environment. Each item has a 5-point Likert-type frequency response scale which comprises the categories: *almost always* (5 points), *often* (4), *sometimes* (3), *seldom* (2) and *almost never* (1). Therefore, the maximum possible mean score of each 7-item scale was 35 (i.e., 7x5) and the minimum score was 7 (i.e., 7x1). The students' responses were analysed statistically using a computer program.

### **A Comparison of Two Classroom Environments**

Below, I describe my experiences with two (out of the three) Year 10 classes, designated Class B (a total of 9 students) and Class C (a total of 10 students). I have chosen to compare these two classes because, although I attempted to create a similar classroom environment in both, students in Class C responded favourably to a constructivist pedagogy, while the responses of the students in Class B were more varied.

#### *Development of a Constructivist Learning Environment*

In developing a constructivist learning environment, I acknowledged the importance of students' prior knowledge and values by listening to and accepting students' views on transplantation. I endeavoured to ensure that the students and I interacted on a relatively equal footing rather than a 'powerful teacher' and 'powerless pupils'. Students were encouraged to make decisions on, and to modify the types of learning activities in which they participated. During the unit, students also had many opportunities to engage in verbal negotiation with peers. That is, students were encouraged to discuss, debate and reflect on their existing and developing understandings and values through discussion with myself and their peers.

*Class C.* During the first lesson with Class C, I explained to students the rationale of the bioethics unit. That is, that the unit was concerned with human organ and tissue transplantation but that, unlike a conventional science class, they would not be required only to listen to factual information and that there was to be no formal summative assessment which required them to memorise 'reams' of facts. The main

emphasis would be on identifying and discussing ethical issues which arise in human organ and tissue transplantation. I explained that I did not want them to adopt a particular ethical stance. Rather, I wanted them to think critically about their own views.

Also, I informed the students that I would be collecting data about this unit to use in a research project as part of my Masters Degree. I sought their cooperation in this venture and assured them that any information obtained would be treated in a confidential way. I informed students that they would be helping me evaluate some teaching strategies and that I was investigating whether an 'open' style of teaching was an effective way for students to learn about bioethics. The students were very curious as to what I was studying and why I would want to study. They asked questions about what would be done with the data and who would see it. I answered their questions honestly and frankly. I stated that, "as a teacher, it is sometimes difficult to know whether a teaching strategy is effective or not and that I would appreciate their views on any aspect of the unit".

When reflecting on the lessons with this class, my perception was that the students worked cohesively and seemed to enjoy the topic, the teaching strategies and the opportunity to debate issues with each other. They seemed to be genuinely interested and perceived the topic to be personally relevant to them. For example, during the second lesson, Jemma informed the class that her uncle had died two years ago and that her mother had needed to make a decision about donating his organs.

*Class B* . As for Class C, I explained to Class B the purpose of the bioethics unit and my intention to collect data for a research project. The students also asked many questions about the purpose of the research and how any information would be used. Again, I assured students that the results obtained from questionnaires, interviews and my own observations would ensure that their identities remained anonymous.

Class B contained four students who, as the unit progressed, displayed an increasingly negative attitude to the teaching strategies and a concomitant increase in disruptive behaviour. The negative attitude of these four students was coupled with a personality conflict between themselves and another student in the class. The demeanour of these students had a retrograde effect on the classroom environment. I was reluctant to quash these four students in the early stages as I wanted them to take responsibility for their learning and behaviour. I hoped that self-discipline or peer-disapproval would modify their behaviour. I had explained to the students that they had control over what happened in the classroom and I believe the four students wanted to test the limits of acceptable behaviour. The behaviour of these students tended to improve when lessons were more structured and focused. They appeared to feel safer and more comfortable when the goals of the lesson were straightforward and explicit, that is, when the classroom environment was closer to their ideal of a 'normal' teacher centred environment.

#### *Constructivist Learning Environment Survey Results*

The students' perceptions of the learning environment for each of the CLES scales are displayed in Figure 1. The scales of *critical voice*, *shared control* and *student negotiation* are discussed below.

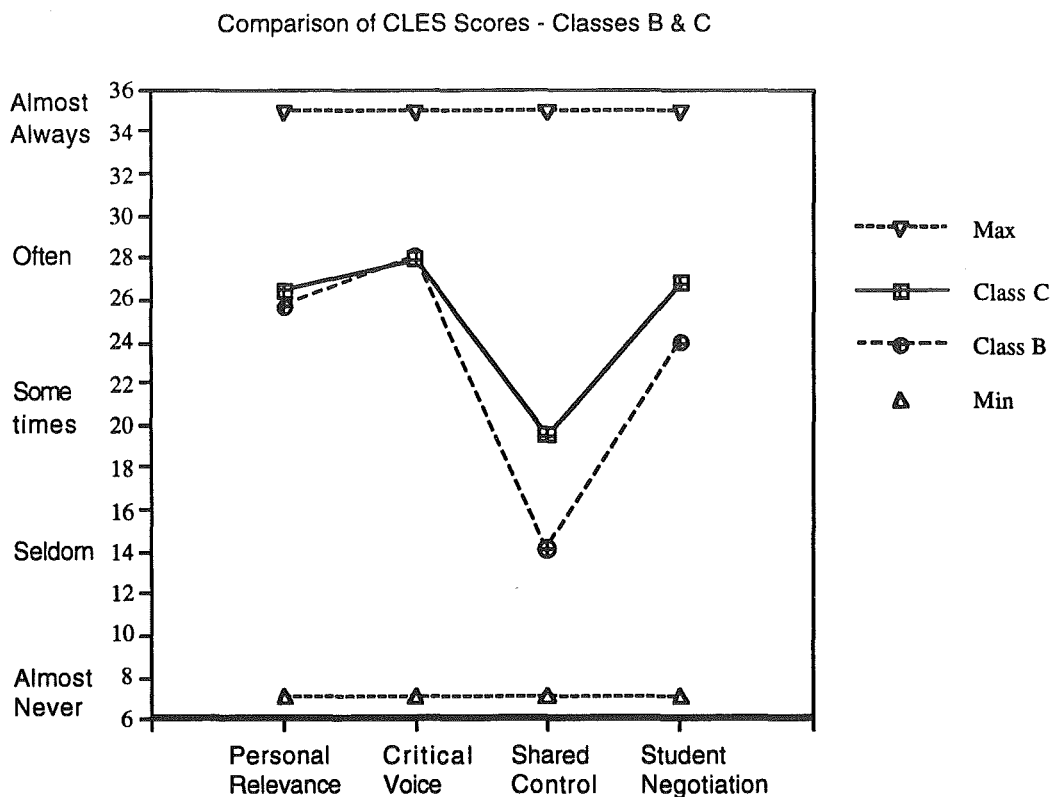


Figure 1. A comparison of the CLES scale scores in Class B and Class C.

*Critical Voice*. Students in both classes were encouraged to voice their criticisms and to question the appropriateness of the teaching strategies. In view of my observations of Class B (i.e., a less favourable environment) and Class C (i.e., a more favourable environment), I had expected a marked difference in the critical voice scales of each class. Yet, from the CLES data it seems that both Class B and Class C 'often' had the opportunity to express a critical voice.

What is not evident from these CLES results is the negative way that students in Class B expressed their critical voice. Some of the students in this class were very vocal about the manner in which teaching strategies were used. For example, when the students had been using a personal journal for three weeks, I asked them if they thought the journal was useful in helping them to clarify their thoughts about bioethical issues. The responses of most students were overwhelmingly negative. Although the comments of some students were quite frank and their attitudes 'bolshy', I was pleased that they felt secure enough to question and reject a seemingly inappropriate teaching strategy. After seeking a response from every student, I acquiesced and discontinued the journal. The students did have a critical voice although, unlike Class C, their opinions were often voiced as complaints rather than constructive comments.

After the students in Class C had been using the personal journal for three weeks I asked them about their views on its effectiveness in enabling them to reflect on their bioethical values. Four students said that the journal was a waste of time if it was not going to be marked, although one student pointed out that if it was to be marked then she might not be so honest. Lauren said she would like me to read her journal.

Another student had lost hers. The remaining four students stated that they liked the journal and found it to be helpful in sorting out their ideas and thoughts. The students said they would continue with it only if I requested. We agreed that we should have a vote and, subsequently, we discontinued the journal. Although there was a general negative response to the effectiveness of the personal journal, the students in this class tended to be apologetic about its failure rather than confrontational. That is, they expressed their critical voice in a positive way.

*Shared Control.* I felt that students were given the opportunity to share control with me to a larger degree than is normally the case in their science lessons. However, the students were not involved in planning, preparing and selecting the teaching strategies which were used in the unit. This was due to the constraints of the second part of this study, namely an evaluation of the usefulness of the teaching strategies in enabling students to clarify, reflect critically on, and modify, their own ethical values. However, as the unit progressed, I actively encouraged students to modify the manner in which teaching strategies were implemented.

For example, when students designed a questionnaire about transplantation, they negotiated the length of the questionnaire, size of working groups, and period of time for completion. Thus, students chose to work under conditions which better suited them individually, rather than under conditions which suited the majority of the class or the teacher.

The CLES results indicate that Class C students perceived that they 'sometimes' shared control with me while Class B students perceived that they 'seldom' shared with me control of the classroom. However, my perception is that both classes were offered similar opportunities to share control of their learning activities. Perhaps the more favourable attitude of Class C students gave them the impression that they had a greater share of control although I offered them the same degree of control as Class B students.

The differences between students' perception of the degree of shared control is especially evident when examining individual students. A student in Class B scored only 7 for shared control (the minimum score possible). Perhaps her negative attitude to the topic and the learning activities led to a feeling of powerlessness over her learning environment. Nevertheless, she scored 32 for a critical voice, so she did not feel constrained about voicing her displeasure. In contrast, a second student (from Class C) scored 25 for shared control and 33 for critical voice. Thus, within the classes there existed a wide range of experiences.

*Negotiation with Peers.* The CLES data indicate that the opportunity for student negotiation occurred 'often' in Class C in comparison to 'sometimes' in Class B. This result agrees with my observations that the students in Class C were receptive to the comments of their peers, whereas students in Class B were relatively less willing to listen to and respect the views of others. Although, students in Class B voiced their opinions during discussions, they did not seem to listen to, or respect the views of their peers sufficiently. They tended to talk *at* each other rather than *with* each other.

In contrast, as the unit progressed, students in Class C became more willing to share their private thoughts once they realised that their views would be listened to in an empathetic manner. For example, when discussing the format for designing a questionnaire to elicit the views of others on transplantation, Christine, a quiet student, informed the class that she had asked her Form Tutor about organ transplantation

and had written down his comments in her personal journal. She was pleased that he had agreed with organ donation and had recorded his consent on his driver's licence. At the end of the lesson she stayed behind to show me her personal journal. Christine's comments prompted Patricia to read from her personal journal about her mother's and father's thoughts regarding transplantation. These tentative disclosures and their non-critical acceptance by myself and other students further enhanced the positive atmosphere of the classroom. The acceptance of students' comments by their peers does not imply that the students' ethical values were similar to each other. Indeed, when students carried out activities where they needed to reach a consensus regarding ethical dilemmas, they spent a considerable amount of time attempting to reach an agreement within their groups.

### Discussion

The results of this study indicate that there was considerable variation in the degree to which students benefited from a constructivist learning environment. While most students participated with enthusiasm in all learning activities, some did not. A few students appeared to be unaccustomed to and uncomfortable with the notion that they could be active participants in their own learning.

I believe that the negative attitude displayed by four of the students in Class B stemmed partly from their unease with my new style of teaching. It seems that the suddenness of providing these students with the power to make choices and decisions and have responsibility over the implementation of teaching strategies was stressful for them and they reacted by behaving in a negative and confrontational manner. In hindsight, I have frequently considered whether I could have dealt with this class in a different way. Prior to conducting this study, I would not have allowed students to behave in such a negative way and I would have made it clear that offhand and negative comments were inappropriate. It seems likely that my role as a teacher-researcher placed further stress on these students as it added to their sense of insecurity. I believe they felt that they were being judged or tested in some way and they didn't know how to respond.

The short length of the unit (ten lessons in total) meant that I needed to implement change from the first lesson. If I had taught these students over a longer period of time I may have been able to adjust the rate of change to suit their needs and thus avoid some of the conflicts that arose between these students and myself. At times, their behaviour caused me to seriously question whether a constructivist pedagogy was appropriate. However, my perception is that despite the disagreeable behaviour of this small proportion of students, the majority of students welcomed the opportunity to share control with me, exercise a critical voice and negotiate with their peers. Most of the students were highly motivated and demonstrated enthusiasm for the topic of transplantation and their own ethical values. They participated in all activities with vigour, offered constructive criticism about the teaching strategies, and seemed to enjoy the freedom and shared control which they experienced in the classroom.

Whenever a teacher attempts to adopt a new teaching pedagogy there are likely to be factors which affect its implementation and success. Before I commenced this study, I was aware that students have certain expectations concerning themselves as learners, the role of the teacher, and what constitutes an appropriate classroom environment. For many students (and teachers), an ideal classroom environment is one where the



teacher seems to *transmit* knowledge, usually as immutable facts (especially in science), and the student seems to *absorb* this knowledge passively. The teacher manages the students so that interruptions to this process are minimised. Given that the classroom environment that I was attempting to create required the students to reevaluate and significantly modify their well-established roles, it was possible that some of the students may not have viewed a constructivist environment in a positive manner. There was a tension between my desire to enable students to construct their own meaning through dialogue and the students' expectations that the role of the teacher was to provide information. Nevertheless, I have gained invaluable insights into the potential for change towards a more ethical and equitable classroom learning environment.

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# **The Atomic Model in Science Teaching: Learning Difficulties or Teachers' Problems?**

Helmut Fischler  
*Free University of Berlin, Germany*

## **Abstract**

In a grade 9 physics class a teacher introduced an atomic model to the students that was oriented at modern aspects of physics and dispenses with subsidiary planetary orbits. In a test, most of the students described the atom in terms of the Bohr model. This result caused an analysis of the teaching process on the one hand and of the teacher's conceptions of teaching and learning on the other. The results of the investigation support the statement that many learning difficulties students have, when confronted with a modern atomic model, are caused by the teachers' problematic conceptions of learning and teaching and by their inadequate decision making in the course of the teaching process.

## **Teachers' Thinking: Theoretical background**

In many research projects on teachers' thinking the aspect of subject related factors plays a secondary role (Bromme & Brophy 1986; Clark & Peterson 1986; Tobin et al. 1994). But there are some reasons to suppose that both the subject-related instructional possibilities for designing a lesson and the specific learning factors have an influence on the effective orientations of the teacher's acting in a teaching situation. The conditions of learning physics, for example, make demands on the teacher that cannot be compared with those made in other teaching subjects. Therefore it is necessary to relate the general principles and results of the research field 'Teachers' Thinking' to the more content specific problems within a school subject.

Most of the research projects working with science teachers are restricted to the determination of the teachers' conceptions of teaching, assuming a close connection between these conceptions and teachers' decision making. At least for novices this hypothesis has been repeatedly shown to be incorrect (Fischler 1994; Brickhouse & Bodner 1992). A deep gulf between intention and action is a normal characteristic for them. It is not often possible for them to realize their instructional orientations, in principle they have great difficulties to teach according to their conceptions (Artiles et al. 1994). But even experienced teachers often abandon their intentions under the pressure of constraints that emerge in every day work (Lyons & Freitag 1994; Hewson et al. 1994). Because of this discrepancy between intention and action, research activities have to integrate teachers' decision making while teaching into the research design.

In several investigations it has been proved to be beneficial in confronting the teachers with problematic situations shown on videotape and asking them for statements and proposals for possible solutions. In the case study to be described here, the teacher conducted lesson is the starting point for the statements about his conceptions that have been affecting his actions. In most of the investigations concept maps are used to figure out the structure of teachers' conceptions. Some researchers point out that Kelly's repertory grids (Kelly 1955) are a more appropriate tool to get information about the developmental process that leads to the identified conceptions (Pope & Keen 1981; Morine-Dersheimer et al. 1992). Repertory grids

support a constructivist view which is regarded as helpful not only for the investigation of students' conceptions, but also of teachers' conceptions, therefore it is being used for this research project.

### **Instruction and Students' Knowledge**

The grade 9 students described in this paper have been observed and questioned since grade 7: Observations during lessons, questionnaires, and interviews in groups are expected to provide information about the development of students' conceptions concerning the particulate nature of matter. The following teaching sequences were recorded and questionnaires were administered:

#### *Chemistry Topic: Development of Atomic Models.*

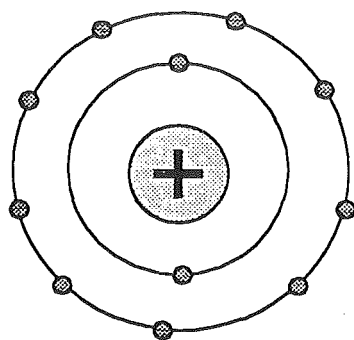
At the beginning of the first lesson a female student reports on the historical development of the atom models. At the end of this presentation the teacher asks whether he should dictate a summary. The students accept this offer thankfully. In the last 20 minutes of the lesson the teacher covers the Dalton model. In the second lesson the teacher continues the dictation. For half an hour he describes the Bohr model in detail. An illustration shows the electrons as thick dots in drawn orbits. The teacher explains: 'Orbits of electrons that have the same distance from the nucleus are called shells.' In the third lesson names and properties i.e. mass and charge of the particles in the nucleus and in the shell are listed systematically. Finally, in the last of the four lessons the structure of several different types of atoms are described in diagrams of the Bohr model.

#### *Physics Topic: Electric Current in Liquids and Metals; Electrons and Ions.*

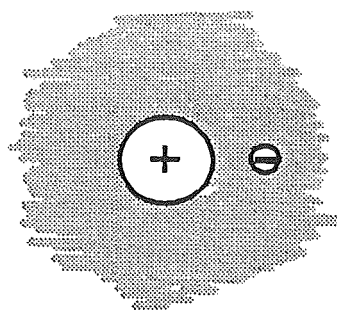
The aim of these four lessons is the explanation of conductivity by means of the electron model. First the conductivity of electrolytes is explained: Negatively and positively charged ions move to the electrodes. With the help of the Edison Effect it is brought out in the next two lessons that the moving charged particles are negative and known as electrons. In the last lesson of this sequence the electron conduction is described in detailed illustrations: It shows a positive nucleus of large mass in an environment that is shaded without boundary, in which the electrons are located and the movement of the electrons is not brought into question (Figure 1).

#### *Class Test After the Chemistry and Physics Lessons*

"Describe the atom model talked about in the physics lessons, possibly with a drawing", is a task in the class test after the lessons in chemistry and physics. Most of the students drew and described the Bohr model as it was drawn during chemistry instruction. Electrons were drawn as particles in orbits with the nucleus in the centre. Some students kept in mind that the first complete 'shell' contains two electrons and the second 'shell' eight electrons. In some mixed forms the drawing of the physics lessons is presented while the verbal description mentions the orbits in which the electrons move.



Atomic model in chemistry lessons



Atomic model in physics lessons

Figure 1.

### Teacher W.: Conceptions of Teaching and Learning

Teacher W. has taught physics in the same class since the beginning of grade 8. He had taught the four physics lessons on electrical conductivity and formulated the class test. In the initial part of the interview he was first questioned about the instructional principles that have been decisive in his teaching, first in reference to the four lessons, then to his teaching overall. The second part of the interview focussed on the construction of the repertory grid. In a further interview teacher W. had made statements on the presented analysis of the repertory grid. Finally, in a third interview, he was asked to comment on the summary made by the researcher.

### The Particulate Nature of Matter and the Atomic Model

The interview with the teacher begins with the question with what intentions he has started the four lessons. After having listed some topics and ideas that for him have been in the content related centre of the lessons (electrical conduction in electrolytes and metals, surplus of electrons, Rutherford's atomic model) the teacher (T.), at the very beginning of the interview, describes a goal that is obviously of great importance for him:

T.: 'The intention was that the students somehow learn the model structure of conduction, that it is not possible to look into it, only indirectly. That one creates patterns of explanation that have the character of a model. That is not to say that there are small spheres that move here and there, but we can imagine it so or so ...'

Two sentences later the interviewer wants to know more exactly what the object is that students should form a model about:

T.: 'Yes, conduction processes. Of course, this later on simplifies the reflection of the electrical resistance, when it is clear to the students how the charged particles move in the conductor.'

In this statement the teacher does not talk about a model. This would be more the case with a formulation like: '...when it is clear to the students which idea one has of how the charged particles move.' Not only in the dialogue with the interviewer who as an expert knows what the teacher talks about, but also

in the lesson, when he gives explanations to students who have even to learn what a model is, the teacher uses the short form that replaces the careful description stressing the model character by a realistic phrase:

- T.: 'Therefore, what does the atom look like now?' (T. draws an illustration)
- 'This is, we have a positive nucleus and around this - which colour should I choose now, I pick blue, around this a negative shell in which electrons are.'

Maybe it is the physicists' slang that prefers short descriptions, but perhaps it is the opinion that it is not always necessary to speak of models, almost never necessary where topics of students' learning are concerned. The possible interpretation of the teacher's statement will again appear later on.

In the lessons the teacher had stressed neither the particulate nature of the charged particles nor the model characteristics. The interviewer (I) draws the teacher's attention to this discrepancy between the stated intention and the actual teaching of the lessons. His reaction clearly shows a pattern of arguments that can be found quite often with teachers:

- I: 'The Edison Effect could be explained also by means of a continuum of charges. How do you justify to the students that there are electrons?'
- T.: 'For the students the particulate nature of matter is quite clear. The teacher had taught this subject last year.'

The teacher's idea that a topic already taught is remembered by the students even one and a half year later, is a commonly held belief. Here, there is also the fact that the teacher underestimates the problems that the students have with the conception of the particulate nature of matter. Also on this point the teacher is in accord with most of his colleagues: They do not consider it to be possible what the results of numerous investigations verify, namely, that on the way to learning the concept of particles the students stop at various intermediate concepts. These intermediate concepts are interwoven with ideas about particles that have properties like matter has, for instance colour and temperature.

Because the interviewer is not convinced of this long-term learning effect, he asks once more:

- I.: 'Do you think the students have understood that this is a model generated by us?'
- T.: 'This is a long-term concern. The goal of the single lesson is the electrons' movement. This is the immediate goal. The other is the long-term goal, an objective that can be considered only over a long-term.'

This statement can be heard quite often. General intentions that are not directly related to concrete subjects seldom are the focus of teachers' thinking. The reference to the long-term character of the goal sounds like an attempt to put off an inconvenient theme. The experiences, so far, do not exactly encourage him to a more logical position.

In a short part of the interview it is the judgement about what kind of learning processes are to be assumed behind the students' discussion on the Edison Effect:

- T.: 'This I have noticed quite often when we have discussions. They consider it as an amusing diversion. They prefer to calculate with a formula rather than to participate in such a broad discussion. I have already observed this in grade 8 when we also worked on the particle model.'

It is the teacher's experience that the students do not appreciate such discussions, at least they do not accept their seriousness. The observation in the chemistry lesson mentioned above where the students, let off the task to actively work on the discursive development of various atomic models, very delightedly accepted the teacher's offer to dictate in detail, and this observation confirms the physics teacher's judgement: The students have a conception of physics and chemistry teaching which fits the learning of facts and writing them down more than the thinking and talking about the phenomena presented.

Unusual for an experienced teacher is the idea that overestimates students' ability to abstract:

I.: 'In the chemistry lessons the Bohr model was definitely presented to the students. In the physics class test the students fall back to a considerable extent to the drawings of the chemistry lessons. No student described the drawing presented by you, that is a nucleus surrounded by an electron cloud.'

T.: 'Actually, I am a little amazed. The students have held a little to the concrete form.'

It is not surprising that the students do not recall the physics teacher's drawing at all, but that the teacher assumes that the students would draw a model different from Bohr's (nucleus, electrons in orbits). In the second interview the teacher justifies his astonishment. The Bohr model would contain much more information than the model drawn by him (nucleus and area for electrons). He had rather assumed that the students would remember the rather 'simpler' model and be able to repeat it. Obviously the teacher considers the influence of concrete pictures that are oriented at mechanical models as being lower than it really is according to all research results concerning the topic 'atomic models'.

### Summary

The statements in the interviews and the judgements given for the repertory grid draw a net of interrelations between teaching principles, expectations and judgements. They refer to the teacher's general conceptions of teaching and learning in physics lessons as well as to his opinions about the treatment of the topic 'particle structure' in the classroom.

It is remarkable that an instructional principle that is provided with high priority undergoes such decisive restrictions. There is a gap between intention and action that, above all, is caused by the discrepancy between the desired and the experienced reality of teaching. In the initial statements and with accentuation teacher W. speaks about the *Emphasis on model structure* as the most important instructional intention, at the very least, for the four physics lessons in which the electron model for electrical current was marked on. However, the teaching conditions outline narrow limits for the realization of this intention and activate the doubts that the teacher had anyway.

The most important factors within this conflict between different goals are content specific on the one hand and have general aspects which are independent from special situations or topics on the other hand. Listing them and commenting on them provides a summary of the teacher related problems on the way to teaching the atomic model. It is obvious that students' deficient learning results are partly caused by the teacher.

## Content Specific Aspects

### *Missing Appropriateness in Teacher's Speech - or: Hidden Realism?*

Even Copernicans say: 'The sun rises in the East', knowing very well that the earth turns toward the sun. But as it is with this example, so it is also in the field of thinking in models, where a verbal inaccuracy makes those students more unsure who have their problems with the understanding of the physical view.

Physicists and physics teachers often convey the impression that they merge model and reality not only in descriptions but also in their thinking, at least when an explicit reflection on aspects of the philosophy of science is not required. The reason for this is probably the attitude of teachers and researchers in physics towards a more realistic view. The emphasis on the model structure of physical descriptions in physics teaching would then be a process of adjusting to instructional principles that do not necessarily correspond to the teacher's conceptions about the philosophy of science.

### *The Teacher's Experience with Students' Attitudes Towards Models in Physics*

'Students want to know how it really is,' the teacher states. That means the students are not always able to understand that the existing knowledge does not allow a description except a model oriented one, if no inadmissible conclusions have to be drawn. The careful inferences in physics surely have to be practiced; in any case, for students it is by no means a matter of course. The stronger interest in 'how it is' and not in 'how one has to imagine it' probably is connected with the students' aversion to the discussion about interpretations and models in the classroom. Therefore they are not willing to follow the teacher into a discussion about these kinds of questions within the philosophy of science.

### *Underestimating the Efficiency of Illustrative Models*

For the physicist an illustration is only a visualizing intermediate step and a current support on the way to a deeper understanding of a content. For the student it quickly becomes the final description because he or she does not have success in managing the following abstraction. Expecting a foreseen failure in this work of abstraction teachers often - so to speak as an anticipation with resignation - carry out a restriction on a visualized level of description and how it happened to the students of this case study in the chemistry lessons. The problems that teachers get for the long term, with such short-term assistance for learning, are generally underestimated.

### *The Teacher's Ambivalent Attitude Towards the Instructional Principle 'Particle Structure'*

The preference for this instructional guideline that becomes apparent in the first words of the interview obviously conflicts with the reserved judgement in the course of the conversation and in the repertory grid. In the teacher's opinion the students have a lack of interest in the discussion about this important principle. Therefore, it gets properties that, in the teacher's perspective, suppress motivation and hinder learning. It is not realized as a guiding line for the teacher's decision making against his own pedagogical conviction.

## General aspects: Teaching and Learning in Physics Lessons

### *Long-term Goals in Individual Lessons*

Probably, it is the fate of many of the goals formulated in general introductions that they are highly accentuated as being important for physics education but come into the background in the daily teaching process in which concrete topics and tasks dominate. The slow development of an appropriate understanding of models' function and scope presumably belongs to these goals, although there exist many contexts that are suitable for such discussions.

### *Teachers' Conceptions of Students' Physics Learning*

Novices particularly have conceptions that consider learning as single events and therefore do not think much of repetition and practice. Experienced teachers have gathered many examples that physics learning is much more difficult and that often enough regresses come about. Yet it can be observed that even experienced teachers do not always actualize all of the learning problems as they appear in empirical investigations. Often many of the students do not have the possibility to ask or the time to work on what is presented. The teacher's intention to progress in treating the topic leads to a situation in which individual students' answers are too quickly regarded as a result of physics learning even though the knowledge is poor. Therefore, often feedback to the majority of the students does not occur.

In this case study the teacher has not passed over students' learning problems thoughtlessly but he surely was too confident that his explanations would fundamentally and permanently change students' existing conceptions about the particle structure of matter and atoms.

### *About the Dilemma in Physics Teaching: Demands on Physics Learning and Students' Readiness to Learn*

The teacher's categorization of the instructional principle '*Heeding students' understanding of the used terms*', shows two competing criteria the teacher cannot bring together. As an element in the repertory grid this principle is regarded as essential for teaching which promotes physics understanding, but at the same time as unsuitable for the realization of good physics teaching. The instructional intention '*Emphasis on the model structure*' has come out of this evaluation as well. This can be an indication of the teacher's failure in working up the content related instructional aspects of this topic.

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# **The Application of Constructivist Learning Strategies to the Redesign of the Lower Secondary Science Curriculum**

Bob Fitzpatrick  
*Science Department*  
*Armadale Senior High School*

## **Introduction**

What convinces a stable well organised group of science teachers in a government high school to throw away the existing Unit Curriculum structure for the Year 8 course and experiment with not only a new course structure but also a new teaching/learning philosophy? How easily do teachers accept and use the constructivist learning model? How has the change in course structure enabled teachers to take risks and develop their pedagogical skills. These are some of the questions that I have asked myself many times since the decision by the Science Department staff at Armadale Senior High School to change the Year 8 course. I hope that in this reflective history of what has happened at our school some of these questions might be answered.

## **Why Did We Change?**

We recognised need for change in the way we were teaching and what we were teaching at a breakfast meeting held in mid 1994. We decided as a department that firstly the science that we were teaching had to be made more exciting and more competitive with the stimulation that students received from such sources as home entertainment technology. Whether or not we achieved this aim the changes that resulted from these thoughts led to the introduction of more investigative activities within the Unit Curriculum courses, an inclusion of these as part of the assessment structure, and a consequent down-grading of formal testing. During 1995 we often commented to one another on the success of these investigative activities in terms of the student enjoyment and the opportunities which arose for teaching scientific skills.

When I moved to Armadale Senior High School in 1994 I had been teaching for 17 years. In my 'previous life' in England I had been a Head of Science and had been involved in the writing of the Schools Council *Exploring Science* series and the rewrite of the *Nuffield 11-13* series. After six years of assimilating what I thought was the Western Australian way to teach science I was ready for a change.

At the beginning of 1995 I was still unhappy with some of the material that we were teaching. In particular I felt that the non-academic year 10 students were becoming increasingly alienated by what I thought was a watered-down version of a preparation for potential T.E.E. students. After discussions with the Head of Department and other teachers I was encouraged to apply to the *Science Teachers Leaders Course* so that I could do something useful instead of just whingeing". After years of stagnation the course blew away the cobwebs and very quickly convinced me of the benefits of adopting a constructivist philosophy. It seemed to me to fit with the ideas of Kuhn and Popper that I had read many years ago, and made such good

sense that it should be used immediately to improve the way young people are educated. I could see many ways to make use of constructivist learning strategies in my own classroom and indeed began to trial some.

I also felt that all the time and money invested in putting me through the *Science Teachers Leaders Course* would be wasted unless I in someway transferred some of my own development to the teachers at Armadale. In any case if I wanted to change what I was teaching and the way I taught then I could not do that in isolation.

Just as we began to make some tentative plans for minor changes on the basis of some trials of some of the constructivist strategies midway through 1995, we were struck by the dazzle of *Primary Investigations* coming over the horizon. We realised that more than half our Year 8 intake in 1996 would be coming to us having experienced this new science course. As a staff we were not even sure what *Primary Investigations* was, but we did know that we could no longer carry on with our existing science program without taking external changes into account. Indeed we asked ourselves how new Year 8 students would view what we were then serving up as science compared to what we had heard was a 'purpose built' investigative science course.

Finally two other Teacher Leaders began to influence my views in relation to implementing some meaningful change that would utilise our recently gained knowledge as well as benefit both the teachers and students at our respective schools. The three of us decided to form a cooperation pact to share whatever we produced in our schools, with a specific focus on the Year 8 curriculum. It just so happened that the two other teachers were Jeff Medcalf from Albany Senior High School and Chris Watts then at Hedland Senior High School, so we could not have been much more widely separated.

### **How Did We Implement Change**

The decision to attack the Year 8 curriculum was an obvious choice. There was less risk in tampering with what the new intake would be doing and whatever damage we did could be repaired in later years. We were concerned about students losing interest in science during Year 8 so there was a hope that the course that we came up with would maintain their enthusiasm. By working on the Year 8 curriculum we could form a network with Albany and Hedland Senior High Schools, and thereby share the preparation of work schemes between the three schools.

The next step was to find out more about *Primary Investigations* so that we could better prepare for the transition of primary students into high school science. The Armadale District Staff Development Officer, Scott Harris, arranged for our entire Science Department to attend a *Primary Investigations* professional development session at Challis Primary School. All of the secondary teachers were impressed by the thought that had gone into the preparation of the materials that made up the course. The kind of activities that we had begun to dabble with were strung together into a learning progression that was being applied by non-science teachers. The way that simple equipment was used to produce challenging problems which involved imaginative thinking in the search for a solution began to make us all think about what was possible. A couple of the Armadale teachers were particularly taken by the 5 E model for the structure of the learning progression in *Primary Investigations*, and its influence arose later in the story.

Another benefit of the morning spent at Challis was the chance for specialist secondary science teachers to talk with primary teachers who happen to be teaching some science. Our view of the purpose of a science education was altered after hearing how primary teachers felt that science was offering an across the board development of skills such as group cooperation, organisation, recording, and problem solving. Every primary teacher already using the package stressed the magic ingredient of enjoyment, questions about motivation were no longer relevant.

We were all ‘fired up’ by what we had seen at Challis although we knew that we needed a program with a greater degree of flexibility for the individual teachers while maintaining or taking further the investigative flavour. The next step was to design a program for term 4 of 1995 for the writing of some themes or topics and the professional development that I felt was needed to enable us to achieve our aims. These aims or outcomes were:

- The students should be enthusiastic about Science after a year of High School Science.
- The transition from Primary Science to High School Science should be smooth.
- The learning involved in the Year 8 course should act as basis for further courses in Science.
- The activities and strategies involved in the course should be student centred and based on constructivist principles in order to promote an effective learning environment.
- The content of the course should be relevant and allow access to all students. It should be their science or at least seem to be so.

Table 1 shows the program which the Science Department worked through during the last term of 1995. This program formed part of a submission for contract payment from the Education Department of Western Australia which encouraged the group by the official recognition that what we wanted to do was worthwhile.

**Table 1**  
*Program of curriculum development activities*

Time	Target
Week 1	Constructivist science teaching. Divide into working groups to prepare topic descriptions.
Week 2	Comparing the topic descriptions with the Outcome Statements and drawing up a list of possible outcomes for each topic.
Week 3	Prepare a more detailed description of the content and begin to plan activities.
Week 4	Workshop on possible strategies e.g. P.O.E., concept maps, problem solving, experimental design, anomalous events, etc.
Week 5	Complete planning and preparation of activities, and review topic description.
Week 6	Review possible assessment strategies and plan assessment items. Strategies could include: portfolios, quizzes, concept maps, investigative activities, etc.
Week 7	Whole group editing session.
Week 8	Finish each topic to the following plan: <ul style="list-style-type: none"><li>• Topic description</li><li>• Possible outcomes</li><li>• General overview - including: rationale, content, activities, and learning strategies.</li><li>• Assessment items.</li></ul>

Topic Titles:     What’s cooking  
                      Small world  
                      Where there’s smoke………!

The first meeting was scheduled for a one and a half hour session after school, which in my own mind I had divided up into a half an hour for talking about the constructivist learning model and one hour for organisational matters. In fact nearly the whole meeting was taken up with the discussion of constructivism and the organisational issues concerned with writing teams were squeezed into the last ten minutes. The writing program was constructed as a blend of the activity of writing and 'formal' professional development due to my wish to share my experiences and knowledge from the Science Teachers Leader program with my colleagues. The relevance of the professional development components of the program became obvious as the teachers began to write and attempt to put together a course based upon constructivist principles.

### The Structure of the Topics

The writing teams were given complete freedom in terms of the structure of the topics that they were writing. The group that I was involved with chose to emulate the story led theme idea that is employed in the Curriculum Corporation books such as *What Happens When You....* During our first meeting before school one morning we began by brainstorming the concepts which could be connected with the title *Where There's Smoke.....* and then used these ideas to construct a flow diagram of how these ideas might be put together into a course. Part of the rationale behind our thinking was that the learning program should be negotiated with the students once they were drawn into the topic through the initial activity. For example when I taught this topic I began with the potassium permanganate and glycerol demonstration, which led to a discussion about how easily fires can start, and then on to the students own experiences with fire. We knew when we first thought of this topic that Armadale children would often encounter bushfires in their semi-rural environment, providing them with a variety of rich experiences. I asked them to write about an adventure with fire which could be fact or fiction and then we discussed what they could study in order to know more about fire. We then constructed our own flow diagram for the topic.

The next stage in writing the *Where There's Smoke.....* topic was the listing of possible outcomes, based on the draft S.O.S. and listing the possible activities through which the outcomes might be achieved. Then it was down to the 'nuts and bolts' of finding resources for the topic, writing worksheets for activities, trying out activities (especially for safety) and planning assessment strategies so that we met the target outlined in the Week 8 box of the writing program.

The other groups worked differently. In particular the pair writing *What's Cooking?* decided to organise the learning progression for the topic around the 5 E version of the constructivist learning model from *Primary Investigations*. The 5 Es stand for engagement, exploration, explanation, elaboration and evaluation. The students were *engaged* by being posed the problem of winning a competition to produce the best toffee at a local show by adapting what they already know about toffee making. They then had to *explore* through predicting, trialing, testing and modifying their champion recipe working in a scientific way to achieve the best result. This best result was assessed by the student's parents for toffee made at home by the student. The *explanation* took the form of library research on questions that the previous phases had generated, and at a level determined by the abilities of the students. *Elaboration* took the form of the preparation of an oral presentation demonstrating solutions to the problems faced, new knowledge gained,

and any conclusions arising from their work. The *evaluation* came from the oral presentation which was assessed by their peers, the parental assessment of their product and other assessments that the teacher required in order to decide the students level of understanding or achievement.

We felt that these two topics, together with *Small World* showed a wide variety in format but the use of a 'jigsaw' structure for a classification topic from the Albany writing group widened our horizons further. From large home groups the students were divided into expert groups of four to research one of the major plant groups such as algae, ferns, angiosperms and so on. Each expert group had to provide a cloze exercise, an unlabelled diagram, four questions for a quiz or test, and another activity to use with their home group. Our school librarians were so impressed with the way that the students worked that the whole activity has been shown around by the school Stepping Out coordinator as an example of good practice. The students then went back to the lab. to work through their activities with their home groups and I was redundant! Or rather I was able to work with some individuals because the groups did not want me interfering with their teaching. I was astounded by the speed with which the students could become independent learners, the only negative aspect being the very difficult fact based questions that they produced.

### **Freedom Through Structural Change**

Apart from the writing of new topics to suit a constructivist approach to learning, a vital ingredient of the success that we have had has been due to the change in structure of the year 8 course.

Firstly there was no time limit. We agreed from the start that a teacher or class could choose to achieve the outcomes for year 8 by working through just one of the topics if they wished. This means that there can be no time limit and that the teacher has the freedom to follow a particular interest or the development of a concept until they see fit to end the topic.

Secondly there was a free choice with the type of assessment that teachers could use. Some teachers still wished to use formal testing for some of the topics, whereas others used the full range of portfolios, oral presentations, informal discussions, observations, display work, model building, and open-ended investigations. In order to achieve this liberation in assessment we discussed the need for confidence in teachers professional judgements of the level of achievement of students rather than having a formal system of comparability based on numbers. This was particularly important as we were trying to move to a system of combining the assessment with the teaching progression.

Lastly the administration at Armadale helped by removing the unit numbers and titles from the reporting system and replacing them with 'Science semester 1', 'Science semester 2'. A small but significant change.

### **Summary**

By adopting a constructivist learning model and freeing the teacher from the constraints of time lines and set assessment structures, we have changed the science curriculum at Armadale Senior High School.

These changes allowed teachers to experiment with new pedagogical techniques, learning strategies and assessment strategies in a low risk environment. The three major pedagogical skills, negotiating, group work and thinking on your feet (Hand and Vance, 1995) have all been explored by all the teachers involved in the new year 8 course. Although there have been many teething problems not one teacher has declared that they would rather teach the unit curriculum. The further development of the topics and articulation of the course as a whole is providing an avenue for additional professional development in an active and concrete way. We are also convinced that what we are doing is better for the students and after all that is the bottom line.

#### **Acknowledgment**

I would like to thank and pay tribute to the teachers of the Armadale Senior High School Science Department for the dedication and energy they demonstrated in writing and teaching the new year 8 science course.

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# Development of an Interactive Multimedia Package Designed to Improve Students' Understanding of Chemical Equations

Patrick Garnett<sup>1</sup>, Mark Hackling<sup>2</sup> and Ron Oliver<sup>1</sup>

<sup>1</sup>*Faculty of Science, Technology and Engineering*

<sup>2</sup>*Faculty of Education*

*Edith Cowan University, Perth, WA.*

## Abstract

Research indicates that students often fail to develop acceptable levels of understanding of chemical phenomena. Chemical equations and their interpretation is one aspect of chemistry where levels of understanding are limited and students often hold inappropriate alternative conceptions. One factor which contributes to student difficulties is the presentation of chemical equations at three levels: the macroscopic, the submicroscopic or particulate, and the symbolic. This paper describes the development of interactive multimedia materials designed to improve students' understanding of chemical equations. The materials include three modules dealing with molecular equations, ionic equations, and interpreting equations. The molecular and ionic equations modules include demonstration videos, particulate simulations, and instruction, with feedback, on writing balanced equations. The module on interpreting equations develops students' skills in interpreting equations by providing them with exercises which require them to work with equations at a particulate level.

## Introduction

### *Alternative Conceptions Research*

Research (Garnett, Garnett & Hackling, 1995; Nakhleh, 1992) indicates that it is very difficult for beginning chemistry students to develop adequate conceptions of the unobservable entities (atoms and molecules) and events involved in chemical reactions. The inability of students to visualise the submicroscopic particulate nature of matter and the processes involved in physical and chemical change represents a major barrier to students developing a scientifically valid understanding of many chemistry concepts. As a result, beginning students commonly exhibit a wide range of alternative conceptions concerning the molecular basis of chemical reactions and this subsequently affects their ability to write balanced equations, interpret the symbolic representations used in equations and solve problems based on equations. These alternative conceptions, as well as being an important concern in their own right, are also important in that they limit students' ability to interpret subsequent phases of instruction, particularly in a hierarchical subject like chemistry.

Several studies have investigated students' understanding of chemical equations and the processes they represent (eg. Garnett, Hackling & Vogiatzakis & Wallace, 1992; Ben-Zvi, Ceylon & Silberstein, 1987; Yarroch, 1985). Some of the alternative conceptions evident from these studies are listed in Table 1.



Table 1

*Students' alternative conceptions: Balancing and interpreting chemical equations*

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1. Subscripts in formulas are numbers used in balancing equations (and do not represent atomic groupings).
  2. Equation coefficients are numbers used to mechanically balance equations (and do not represent the relative numbers of species reacting or being produced in chemical reactions).
  3. Chemical equations do not represent chemical reactions at a particulate level.
  4. Chemical equations do not represent dynamic processes in which molecules/particles react with one another to produce new molecules/particles by rearrangement of the atom.
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Yarroch (1985), in a study of Year 12 American students, found that about half the students who were able to balance chemical equations were unable to draw a reasonable diagrammatic representation of the equation at a particulate or molecular level. Students often drew representations which, while consistent with the total number of atomic particles involved, were inconsistent with the formulas of the substances involved and the coefficients in the equation. Yarroch concluded that many students had inadequate conceptions regarding the meaning of formula subscripts and equation coefficients. Students often regarded these as numbers distinguished by their location in an equation, and used to balance the numbers of atoms on both sides of the equation, but had little understanding of their chemical significance.

Ben-Zvi, Eylon and Silberstein (1987) found that substantial numbers of Israeli students also held inappropriate conceptions about both structural and interactive aspects of chemical reactions. Students commonly represented the molecular compound  $\text{Cl}_2\text{O}$  as two fragments,  $\text{Cl}_2$  and  $\text{O}$ ; and failed to distinguish between  $\text{N}_2\text{O}_2$  and  $\text{N}_2 + \text{O}_2$  when considering possible products of a reaction between  $\text{N}_2$  and  $\text{O}_2$ . Student difficulties with the interactive nature of chemical reactions are illustrated by the reaction between  $\text{N}_2$  and  $\text{O}_2$ ; some students thought  $\text{N}_2\text{O}_5$  could not be formed because of the need for three additional  $\text{O}$  atoms; others thought  $\text{NO}$  could not be formed because the mass of the products would be less than that of the reactants.

Garnett et al. (1992) investigated some Year 10 Australian students' abilities to balance chemical equations and apply an understanding of equations to 'simple' stoichiometry problems. As reported by Yarroch (1985) students were often unable to draw diagrammatic representations of equations and many students showed a lack of understanding of the different use of subscripts in formulas and coefficients in chemical equations.

In this study students also had considerable difficulty when asked to formulate an equation which described the reaction represented by 'before reaction' and 'after reaction' diagrams. Some students merely added up the number of species of each type in the 'before' and 'after' boxes with no recognition that one of the species was present in excess or of the need to simplify the coefficients in the equation. As well, many students disregarded the different meanings of formula subscripts and equation coefficients.

It seems apparent that many students lack a conceptual understanding of the submicroscopic particulate nature of matter and the changes represented by chemical equations. In addition, Andersson (1986) and Ben-Zvi et al (1987) identified students who held a 'static' rather than 'dynamic' understanding of chemical reactions. Such students failed to visualise chemical reactions as dynamic processes in which particles/molecules react to produce new particles/molecules by rearrangement of the atoms through breaking bonds and forming new bonds.

Clearly, many students' ability to balance and understand chemical equations is limited by their lack of understanding of the submicroscopic particulate nature of matter and their inability to visualise the dynamic nature of chemical reactions. This inability to visualise reactions probably also limits students' success in solving stoichiometric calculations, particularly where these are of a non-routine nature.

The difficulties students experience because of the abstract, unobservable, particulate basis of chemistry was previously described within the Piagetian epistemological framework (Herron, 1978) and several authors (Garnett, Tobin & Swingler, 1985; Gabel & Sherwood, 1980; Herron, 1978) advocated the use of concrete models to help students better understand the nature of matter. Modern multimedia technology has considerable potential to provide students with simulations of the submicroscopic/particulate nature of matter in its various states and the processes underlying physical and chemical change.

#### *Chemistry at the macroscopic, submicroscopic and symbolic levels*

Johnstone(1991) has proposed that chemistry is taught at three levels. The macroscopic level is sensory and deals with tangible and visible phenomena (eg. salt dissolving in water). The submicroscopic level provides explanations at a particulate level (eg. disruption of the ionic lattice and ions, surrounded by water molecules, moving into solution). The symbolic level represents processes in terms of formulas and equations (eg.  $\text{NaCl(s)} + \text{H}_2\text{O(l)} \rightarrow \text{Na}^+(\text{aq}) + \text{Cl}^-(\text{aq})$ ). Johnstone believes that insufficient attention is given to understanding chemistry at the submicroscopic level and has pointed out the difficulty for students when teachers move quickly between these different levels. Perhaps it would be useful to students to point out these different ways of knowing chemistry, and to clearly identify for students which level of thinking is being used at any particular time. From the research evidence available at this stage, it appears that students have most difficulty in dealing with the submicroscopic which is, of course, outside their experience and can only be made accessible to students through the use of models, analogies or computer graphics.

#### *Computer based instructional materials*

Major difficulties for students of chemistry are the abstract, unobservable particulate basis of chemistry and the manner in which practising chemists and chemical educators move between the macroscopic, submicroscopic and symbolic representations of chemical substances and processes. These difficulties represent significant problems for chemistry educators but modern audiovisual technologies including the use of computer graphics provide exciting opportunities to present students with acceptable concrete representations of the particulate basis of chemical structure and behaviour.

Several studies (Hameed, Hackling & Garnett, 1993; Zietsman & Hewson, 1986) have indicated that it is possible to develop computer based instructional materials based on a conceptual change pedagogy

which facilitate improved student understanding. This instruction is most likely to be successful when it provides visual concrete representations of unobservable processes and events, and causes students to reflect on their present conceptions.

Interactive multimedia describes an instructional technology with a number of critical attributes (Jonassen, 1988). In particular this medium includes opportunities for high levels of student engagement, the use of multiple media forms to represent information, and contextual feedback in response to student input. In addition IMM technologies are able to provide learning environments which are self-paced, able to cater for individual differences among students, learner centred, flexible in terms of time and place of delivery, and potentially offer a collaborative learning environment.

Interactive multimedia materials are eminently suited to the simulation of chemical processes using dynamic graphical representations of molecular interactions.

Tasker, Chia, Bucat and Sleet (1996) have reported recently on the VisChem Project which has developed molecular animations of a range of chemical processes aimed at improving students' understanding of the submicroscopic/molecular basis of these processes.

### **Description of the Project**

This project developed an across-platform interactive multimedia package designed to help beginning students to understand the particulate basis of chemical reactions, their symbolic representation as chemical equations and to apply this understanding when balancing equations and solving simple problems based on equations.

The materials were designed to expose students to the three levels of chemical knowledge described previously, ie. the macroscopic, submicroscopic and symbolic levels, and provide an understanding of the particulate basis of chemical reactions. As well it was intended that the program provide opportunities for students to learn and practise the steps associated with balancing chemical equations. Finally the program aimed to develop students' skills in interpreting chemical equations at a quantitative level including an understanding of the concept of limiting reagent.

The project has developed three discrete modules that introduce students to chemical equations and develop skills in balancing equations and their interpretation. The materials are designed for use in lecture, tutorial or self-instructional modes. Two modules deal separately with 'molecular' and 'ionic' equations. A third module provides students with practice in the interpretation of equations.

Modules 1 and 2 both include instruction relating to eight chemical reactions. For each of these eight reactions students can:

1. View a video demonstration transformed into computer images. These images were intended to show students the actual appearance of a reaction when it occurs in real life. The purpose of this macroscopic view was to provide a link between the real world and the submicroscopic/particulate models chemists use to interpret chemical reactions;
2. View a simulation of the reaction at a particulate level; these animations use dynamic graphics that illustrate the behaviour of atoms and molecules and the transformations they undergo in chemical

reactions. The animations were designed to represent, at a particulate level, the processes that occur during chemical reactions using information that is available about these processes. In some examples where these processes are very complex, the process animations were simplified;

3. Write a balanced chemical equation. Equations are used to represent chemical reactions at a symbolic level. Students are provided with a particular approach to the balancing of equations which enables them to scaffold their knowledge. In this interactive program students are provided with a word equation and are asked to enter the formulas of each of the substances involved. Feedback is provided in relation to the chemical formulas written and also on the coefficients used to balance the equations. An option allows students to enter the physical states of all the substances involved.

Practice sets of twenty additional reactions are provided with both these modules to give students further practice in writing balanced chemical equations.

In Module 3 students develop their understanding of what chemical equations represent and their skills in interpreting equations. They are asked to interpret equations by drawing "before" and "after" diagrams to represent what occurs in a chemical reaction; do simple calculations to develop an understanding of the meaning of coefficients in chemical equations; and write equations to represent reactions illustrated by "before" and "after" diagrams. The concept of limiting reagent is introduced in some sections of this module.

### **Features of the IMM Materials**

#### *Use of Illustrations and Dynamic Graphics*

The program was designed to make extensive use of video illustrations and animations using dynamic graphics. Levin (1981) has described the advantages of using these images in learning materials. From a cognitive perspective, graphics have been found to help learners focus their attention on explanative information and to aid them in organising information into useful mental models (Mayer, 1989).

#### *Learner Interactivity and Engagement*

The program was planned with a number of opportunities for learner interactivity and engagement. Planning of the interactions was guided by constructivist principles that place high levels of importance on learner activity in any instructional setting (Reeves, 1993). Constructivist epistemologies value learner-centred activities that facilitate personal involvement in creating and framing knowledge construction through students' cognitive activities (Lebow, 1993; Reeves, 1993). In multimedia environments, interactivity that leads to high levels of cognitive engagement appears to be an important aspect in achieving this.

#### *Feedback*

Feedback routines were carefully planned to encourage reflection among learners and to anticipate learning difficulties based on learner responses. A decision was taken to include oral feedback in certain parts of the program in place of conventional textual feedback. Cognitive load theory (Sweller, 1988)

reasons that when viewing computer feedback in several forms, for example, animations and textual descriptions, the tasks create split attention with the learner attending to two discrete information sources. The theory argues that one of the sources can be neglected and the learning becomes inefficient and ineffective. The use of oral and visual feedback can reduce the split attention and lead to enhance learning outcomes.

### *Interface Design*

In most CBL packages learner control is a key element of the instructional design and high levels of learner control are usually considered a positive attribute associated with increased learner motivation and achievement gains. The user interface for this program provided for higher rather than reduced levels of learner control. We planned to exert some instructional influence over naive users through implementation strategies that included a level of instructor support and scaffolding. The program content was organised in an hierarchical fashion which reflected a recommended instructional sequence but which placed little constraint on users' instructional choices. An aspect of the implementation of this project will be to investigate and explore implementation strategies that can be linked to high levels of learner achievement.

### **Conclusion**

This IMM package was designed to improve students' understanding of the particulate/molecular basis of chemical reactions, and their ability to interpret chemical equations and solve problems based on equations. The provision of concrete representations of unobservable entities and processes, and the use of an interactive approach with associated feedback should facilitate students' achievement of scientifically acceptable conceptions of chemical equations and their application.

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# **Anyone Can Teach Science: An Old Argument Revisited**

David R Geelan

*National Key Centre for School Science and Mathematics  
Curtin University of Technology*

## **Abstract**

Discussion between those who believe that, with some curricular support, any good teacher can teach science and those who believe that it requires a specialist has been prolonged, sometimes heated and usually inconclusive. This paper reflectively explores interpretive results from a study in which the author team-taught with a group of five non-specialist science teachers who were teaching science to Year 7 and 8 students for the first time. The results of the study will probably not settle the argument, however they may reconstruct it in more productive ways. The research also offers intriguing possibilities for ways to support non-specialist teachers in teaching science.

## **Introduction**

When teachers, teacher educators and the general public talk about just what qualifications are needed for teaching science, and what characterises good science teachers, subject knowledge is always one important facet. Certainly we hear anecdotes of teachers who 'knew their stuff but couldn't teach', but much more disapprobation is reserved for teachers who 'didn't even know what they were talking about - I knew more than them'. In this discussion I want to explore just what it is about knowledge of science that is important to the activity of teaching science, in the context of my experience as a team teacher with a number of non-specialist science teachers. While Shulman's (1986) distinction between pedagogical knowledge, content knowledge and pedagogical content knowledge is one interesting approach to this question, I have chosen to construct the argument slightly differently for the case of science, because I believe that in science education what counts as both content knowledge and pedagogical content knowledge has recently undergone, and is still undergoing, a significant shift.

There are a large number of recent studies (a few examples include Atwood & Atwood, 1996; Ginns & Watters, 1995; McDevitt et. al., 1995; Shugart & Hounshell, 1995) in which the scientific knowledge and understandings of preservice and serving teachers have been examined - and usually found wanting.

Atwood & Atwood (1996) found that only one of forty-nine preservice primary teachers possessed what they defined as a scientific conception of what causes the seasons on each of their two tests, and that it was a different student on each occasion. They used two different instruments, a paper-and-pencil test and an explanation with models activity, to test the knowledge of the teacher education students, and suggested that the level of alternative conceptions held by these students would create serious difficulties for their own primary school students when this subject was taught, since not one of the 49 answered the question with a scientific conception for both tests. Shugart & Hounshell (1995) discovered a negative correlation between subject matter knowledge and being recruited or retained as a teacher - that is to say, those with greater degrees of subject matter knowledge tended to either not become teachers or to leave teaching for other professions.



The study of McDevitt et. al. (1995) is a little different, in that it seeks to compare the subject matter knowledge and understandings of preservice primary teachers in a model teacher education program with those in standard programs. McDevitt et. al. develop quite sophisticated instruments for measuring the richness and flexibility of students' constructs relating to the science ideas, rather than simply measuring their ability to recite scientific facts. They found that teachers in the model program did develop more thorough scientific understandings than their colleagues in standard teacher education programs.

### **Narratives of Classroom Experience**

The following brief 'impressionistic tales' (Van Maanen, 1988) describe some of my experiences in working as a team teacher and science support person in five middle school classrooms in the northern suburbs of Perth. This teaching was conducted as part of a research project in the school, and I was present in the classrooms as a volunteer. My purpose for being present was to make rich observations of the life in classrooms, from a perspective balanced between that of a teacher and a university researcher. The teachers had agreed to let me into their classrooms to conduct my research because they perceived that my active role as a team teacher and collaborative planner would bring extra experience and expertise in the area of science, where they did not feel confident. In other words, I provided 520 hours of my time as a teacher and consultant to the school, and they provided a research site for me. Of the five teachers, three had been secondary school teachers with specialisations in areas other than science, including mathematics, English and Languages Other Than English. The other two were experienced primary school teachers.

I have changed all the teachers' names to protect their identities, and the characters presented in the following tales are composites bearing characteristics of more than one of the teachers. The tales do, I believe, capture something real about what happened in the classrooms, however they should not be taken as direct transcripts of actual incidents - they are my impressions, filtered through my own experience and knowledge, and constructed for my own purposes.

In acknowledging this, it is important that I disclose something of myself, in order that you, the reader, can make a judgement about the quality and usefulness of these impressions and ideas for your own purposes. I am a science teacher with four years experience in secondary school science classrooms in Victoria and New South Wales. I worked as a science lecturer and teacher educator in Papua New Guinea for two years, before coming to Perth in 1995. I have accumulated Bachelor of Education (Chemistry) and Master of Education degrees and am working toward my Ph.D. in science education. I felt that it was important to offer more to the school than I took away in my research, because I have an ethical commitment to caring for the participants (teachers and students). None of these professional facts define me, however: I'm also a Christian, but I am first and most and always a husband to Sue and a father to Cassie and Alex.

It should be noted that these tales go somewhat outside the notion of impressionistic tales described by Van Maanen (1988), in that as well as attempting to be rich portrayals of the surfaces of classroom events, they contain depictions of my own reflections and thoughts, as both the narrator of the tale and a character within it. These musings should also be considered as an integral part of the fictionalised tale, rather than a 'Gods-eye-view' commentary upon it.

### *The Water Atom*

"It's like the water atom", James is saying. He writes on the whiteboard 'H<sub>2</sub>O'. "It has one hydrogen molecule and two oxygen molecules to make up a water atom." I'm sitting at the back of the room, the 'designated scientist' for the purposes of this Year 8 class, but James has the floor, he's the teacher. Should I correct him? And to what extent? Neither of us wants the students to take misinformation away from the lesson, but I don't want to undermine his authority either.

The rain on the tin roof of the classroom gusts louder for a moment, and a squall blows it against the windows. The classroom is a drowsy island of warmth and over-used air, cut off from its surroundings by curtains of rain. I'd been struggling to stay awake in my chair at the back - our team-teaching is more often a two-handed performance from the front of the room, but today James wanted to take the lead, and I was pleased to let him.

"Two hydrogens and one oxygen", I say, sitting up straighter, "the number relates to the letter it's after, not the letter it's before." At this stage, I choose not to correct the atoms/molecules terminology, or the use of subscripts - time enough for those ideas later.

This time, James accepts the correction and moves on - he's secure enough in his own area of expertise as a SOSE teacher that he's happy to be occasionally corrected in science. On other occasions, though, he's 'spat the dummy' and said "OK - you teach it!" That might be fine this year, but next year I won't be here to correct James, and he'll still be teaching science. With what kind of scientific information and understandings will his students leave Year 8?

### *True Facts*

"Science is a way of finding out true facts about the world around us," says Christine one bright spring morning, "isn't it Mr Geelan?" I have all sorts of misgivings about this as a statement of the purpose of science - both from the perspective of philosophy of science and from concerns with social justice, equity and awareness of the value of other cultures. If it were me, I'd prefer to say something a little more equivocal, like 'science is a way of constructing ideas about the world that are useful for human purposes', and then go on to recognise the validity of some non-Western and non-mainstream perspectives on the world.

As thirty-one faces turn toward me (no, actually about twenty-two - the rest are having whispered conversations about Melrose Place or adding a new layer of graffiti to their folders), I wonder - are these misgivings appropriate for sharing with this class, right now? I'm really not sure. Is studying the nature of science a legitimate part of Year 8 school science, or is it better to continue in the same old objectivist vein, then challenge it when the students are older and have more tolerance for ambiguity?

The school has as two important facets of its mission statement the integration of curriculum across learning areas and inclusivity of gender and culture. The student body is very heterogenous - in Christine's class we have students from Bulgaria, China, Vietnam and Italy, and two Aboriginal students. There are even some female students! If we are to include the traditions and cultures of all these students, rather than just masculine Western culture, and if we are to integrate science meaningfully with other

learning areas, showing its appropriate role in a mature understanding of the human world, then I think we DO have to address questions of the nature of science at Year 8.

Of course, I don't think all of this as Christine and the class await a response to her statement - these issues have been part of my thinking for a long time, and I really don't have a firm conclusion. What should I say?

### Science Teaching and the Nature of Science

Many teachers and students, including James and Christine, would say that the problem with their knowledge of science - the deficit - is in the area of 'knowing scientific facts'. This kind of deficit is fairly readily remedied: there are CD-ROMs for that these days! James could go and check the composition of water, or ask a student to do it, and the slight misunderstanding would be cleared up.

Is it really that simple, though? Poincare said 'A scientist must organize. One makes a science with facts in the same way that one makes a house with stones; but an accumulation of facts is no more a science than a pile of stones is a house.' This points at the idea that science is not simply a connection of unrelated facts, but an orderly, interconnected structure of understandings. Even if James and his students can recite the facts that 'a water molecule has the symbol H<sub>2</sub>O and contains two hydrogen atoms and one oxygen atom', if they do not have a rich web of connected understanding of the concepts of atoms, molecules and chemical bonding (at a level of detail appropriate for Year 8 students), and perhaps of the influence of microscopic structure on macroscopic properties, can they be said to know the relevant science?

This is one of the problems encountered when non-specialist teachers teach science - they may use as a teaching referent the notion of 'science as facts', rather than the notion of 'science as a network of understandings'. If teachers conceive of science as an unstructured collection of facts, they are likely to teach students similarly, perpetuating the misunderstanding. The point then, is that rather than a simple deficit of scientific facts - facts are easy to come by - one of the problems for non-specialist science teachers may be a naive or impoverished notion of the nature of science.

Christine's situation, however, is slightly more difficult. Although it is again concerned with the nature of science, and with a limited understanding of that idea, it is more difficult, because it falls in a more controversial area. Many scientists and philosophers of science would accept and affirm Christine's statement that science finds true facts about the world - others would not. Constructivist perspectives on epistemology and the nature of science are becoming increasingly influential in the field of science education, and constructivist science educators and philosophers would suggest a view of science more like the one I describe in the tale - science is a way of constructing ideas about the world that are useful for human purposes. What is perhaps required of Christine in her role as a science educator is a quite sophisticated understanding of these epistemological arguments about the truth value of scientific information and ideas, and beyond that, a knowledge of the developmental stages of her students against which to test the appropriateness of particular ideas for them, and beyond that a level of pedagogical content knowledge (Shulman, 1986) that will tell her what strategies are most effective in teaching those sophisticated

understandings to students. In the tale I, a professional science educator with a science degree and considerable experience in science education, was not sure of the appropriate approach. How then can a teacher like Christine - excellent without doubt - be expected to make these judgements in the classroom with very limited knowledge of science and no education in the nature of science?

### Conclusion

Based on my classroom experiences in the course of this study, it can be very difficult indeed for teachers without a good knowledge of science to be effective science teachers. Rather than a lack of knowledge of specific scientific facts, or even of processes and skills, the key problem is usually that such teachers lack a rich, flexible and viable understanding of science and the nature of science from within which to try to formatively understand the developing scientific understandings of their students. This means that they are unable to fulfil the challenging roles - as supporters and facilitators of students' learning - demanded of them by current developments in education. For this reason I would suggest that the teaching of science, particularly in the secondary school, by teachers without a background in science is generally not as effective as it could and should be.

One question requires further research: is it possible for prospective science teachers to be supported and encouraged in developing this type of rich understanding of science through relatively short professional development courses, incorporating aspects of the history and philosophy of science, as well as thorough and reflective study in a few science 'content' areas? The research of McDevitt et. al. (1995) suggests that this may be possible. Or is only very prolonged and significant study of science such as an undergraduate degree sufficient for this purpose? (And conversely, does a science degree always lead to such an understanding?) An answer to this compound question offers significant potential for affecting the future direction of science teacher education.

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# **Prior Knowledge, Prior Conceptions, Prior Constructs: What Do Constructivists Really Mean, And Are They Practising What They Preach?**

David R Geelan  
*National Key Centre for School Science and Mathematics  
Curtin University of Technology*

## **Abstract**

Papers and presentations within the broad constructivist/conceptual change axis within science education usually include some commitment to the idea that learning must build on students' existing mental structures. In practice, however, for some this translates as 'previously learned school facts', for others as 'misconceptions' to be swept away, while still others develop complex instruments and strategies for exploring students' sense-making schemes. From a perspective informed by both Kelly's 'personal construct psychology' and Glasersfeld's 'radical constructivism' I suggest that it is simply impossible for a teacher to meaningfully construe a student's construction processes, and that such efforts are misguided. Instead of attempting to discover what students know and then build on those foundations, I suggest that the teaching/learning/research process must be re-imagined as 'collaborative social learning' if constructivism is to be meaningful in science education.

## **Introduction**

Constructivist perspectives on teaching and learning (as opposed to, or at least derived from, constructivist epistemological perspectives) generally affirm two general principles:

1. Knowledge is actively constructed by learners, rather than transmitted by teachers.
2. Such knowledge is constructed on the 'foundations' of students' existing knowledge, not on a 'blank slate'.

This discussion is concerned with the second of these principles - I wish to explore what is meant by 'existing knowledge', and the wide variety of near-synonyms used within the various tribes of constructivism (Geelan, in press). Such terms include the 'prior conceptions', 'misconceptions' and 'alternative conceptions' of the conceptual change paradigm (Posner et al., 1982) and Vygotsky's (1978) 'spontaneous knowledge'.

I want to suggest that, while these perspectives have been valuable in taking the discussion in science education beyond behaviourist and transmissivist models which minimise the role and importance of the learner in learning, they are ultimately both philosophically untenable and educationally unfruitful. Rather than expending energy and time on attempting to understand students' understandings from the 'outside', I suggest that we're all in life, and school, together. As I have said elsewhere:

If constructivism is to mean anything, it must mean that the theorist is irrevocably involved in life, in social interaction, in learning - in the very things the theory purports to explain. This being so, there is no meta-theoretical perspective, no 'outside' from which to understand the activities of teaching, learning and research. They must be understood from 'inside' through social relationships which define both the mode and the content of our discourse. (Geelan, in press).

### Prior What?

This issue has been raised again for me recently as I worked as a tutor for external postgraduate students in a science education course. One of the assignments for a curriculum unit asked students to develop a unit of study for their secondary school science students, using constructivist perspectives on teaching and learning. In an alarming number of these assignments I read sentences like "in order to determine the existing knowledge of the students, I had them do a paper-and-pencil test". In other words, for these teachers, 'existing knowledge' meant 'already memorised school facts', and to build on existing knowledge meant to add to this collection of school science facts. This may be due to limited conceptions of the nature of science and school science (Geelan, 1996), or to a poor understanding of constructivist perspectives, however it is a very common 'misconception' (to turn the terminology of the field in on itself) of new converts to constructivism.

Certainly the idea that 'prior knowledge' means that selection of 'school facts' already written on the blank slate is not the view of the authors of seminal works in the field. Posner, Strike, Hewson and Gertzog (1982) speak of 'interpretive frameworks', Piaget (1972) of 'schemes', Kelly (1955) of 'construct systems' and Glasersfeld (1989) of 'conceptual structures'. By these they mean complex, inter-related, well elaborated networks of constructs and understandings which serve an adaptive function by allowing learners to explain their past experiences and predict their future experiences. Piaget (1972) introduces the terms 'assimilation' - placing new experiences within the existing sense-making schemes - and 'accommodation' - adapting the schemes themselves to explain anomalous experiences - and describes their dynamic interplay in learning.

Constructivist perspectives on teaching and learning have posited the existence of students' sense-making schemes and suggested that it is educationally necessary for teachers to take them into account in teaching, usually including some attempt to measure the students' existing conceptions. There remains the difficult question - assuming that it is desirable for teachers to somehow measure the existing knowledge or prior conceptions of their students, is it possible for them to do so? (This leaves aside the equally difficult questions of whether it is possible for a single teacher to understand richly the sense-making schemes of 30 students, and of what kinds of tests or instruments might allow such teacher understanding to be developed within the limited time available.)

### Construing Others' Constructs

George Kelly's (1955) 'personal construct psychology' is one important theoretical plank of personal constructivist perspectives on teaching and learning. The 'fundamental postulate' of personal construct theory is that "A person's processes are psychologically channelized by the way in which he anticipates events" (quoted in Bannister & Fransella, 1971). This postulate is supported and elaborated in a series of eleven corollaries. Taken together, the formal content of personal construct theory suggests that human beings develop complex, hierarchical, dynamic systems of constructs, based on the replication of

experiences, with which to anticipate future experience. This corresponds closely to other personal constructivist perspectives such as those of Piaget (1972).

The corollary which is of most interest in the present discussion is the 'sociality corollary', which states: "To the extent that one person construes the construction processes of another he may play a role in a social process involving the other person" (Bannister & Fransella, 1971). This reminds us that, from a constructivist perspective, we have no *direct* access to the construct system of another - when we attempt to understand their understandings, we are ourselves involved in a construction process, one of construing their constructions. Steier (1995) refers to constructivist perspectives which ignore this idea as 'naive constructivism' - the belief that it is possible for us as teachers or researchers to stand back and objectively observe others enmeshed in the processes of construction. Instead, Steier claims, we must recognise that we are ourselves enmeshed, that "the idea that 'worlds are constructed' applies to US as well" (1995, p 13).

If we combine personal construct psychology's 'sociality corollary' with radical constructivism's (Glaserfeld, 1989) assertion that knowledge performs only an adaptive function, and tells us nothing about ontological reality, we come up against problems in deciding what status to assign to our knowledge of our students' knowledge. Glaserfeld has addressed this question directly - he states:

...introducing the notion of social interaction raises a problem for constructivists. If what a cognizing subject knows cannot be anything but what that subject has constructed, it is clear that, from the constructivist perspective, the others with whom the subject may interact socially cannot be posited as an ontological given (1989, p 126).

Glaserfeld goes on to develop a constructivist perspective on social interaction, however this never carries us any closer to a direct understanding of another's constructs - we must always construe them, based in our own experiential reality, and often on flimsy evidence. (People may lie, or be unable to clearly communicate their own constructions; cultural differences may lead us to misconstrue the signals of another.)

Does this scepticism about the possibility of understanding another's understandings in any final way lead to despair about the possibility of teaching in ways that take student's existing schemes into account? By no means! Rather than retreating from constructivism into perspectives which take the learner's sense-making schemes less seriously, we need to advance into perspectives which take students', teachers' and researchers' collective construction processes more seriously.

### Reflexivity

Frederick Steier (1995) discusses the idea of 'reflexivity' from a perspective that he characterises as 'ecological constructionism'. Here he describes unreflective constructivism and constructionism:

...there have been many who have adopted a constructionist label to what is still defined by objectivist enquiry. Here we find those who take, as an object of study, other persons' constructions of reality as something to be understood in an objective manner, somehow apart from the researchers' own tools and methods. (Steier, 1995, p 70)

Steier emphasises that it is impossible to gain direct and unfiltered access to the construction processes of another - as suggested in the preceding section from both a personal construct psychology and a



radical constructivist perspective, we are always one level of construction away. Rather than finding this daunting or worrying, however, Steier celebrates the circularity and reflexivity of constructionist research and teaching by calling those with whom he is involved in research 'reciprocators', rather than 'subjects' or 'informants', in order to emphasise the collaborative nature of such work. He notes that answers to interview or test questions are given *to someone* - the answerer construes the person and expectations of the questioner, and answers appropriately. Thus, the person of the teacher or researcher cannot disappear from the research - if the research report does not identify the researcher, then something essential about the data is lost. Similarly, when a teacher attempts to construe the construction processes (or prior conceptions, or sense-making schemes) of a student, the student is construing the teacher right back, and the answers received will reflect this. The student's construct system is not inert - by analogy with quantum mechanics, observing it changes it. This further distances the possibility of teachers usefully measuring and describing students' existing knowledge.

### Collaborative Social Learning

What is the solution to this apparent conundrum? We can only abandon our 'objective' pose on the side of the pool of life, take off our suits and ties and jump in - we were always immersed in life anyway; our pose of dryness was a con!

Regarding the merging that occurs between the various social activities and interactions of research, teaching and learning if a concern for reflexivity is taken seriously, Steier says:

Thus we must recognise that...we, as researcher, act as teachers. In addition...our reciprocators act as teachers... Understanding this might, in turn, allow us to learn what we already know, or to be surprised. Constructionist research programs that take issues of reflexivity seriously necessarily become programs of collaborative learning. (Steier, 1995, p. 84)

What form might such 'collaborative social learning' take in the classroom? Jardine and Clandinin's (1987) conception of 'teaching as story-telling' holds out some entrancing possibilities:

The meaning, sense and significance of features of the child's curriculum emerge out of the child's sense of the on-going narrative of the classroom, a shared narrative between teacher and child... The meaning emerges out of the living context of the class, the living history of the class. Teaching as story-telling is not a matter of the teacher inventing a story ... as if the teacher is able to understand alone what this can mean and can decide how it might become topical in a class. (Jardine & Clandinin, 1987, p 477)

In this image we see an organic, emergent, dialogical process of mutual meaning-construction and rich interaction replacing a monological tale, told by the teacher alone. Students and teacher together explore the world and create an on-going narrative, an on-going living tale of 'life in our class'. In Jardine and Clandinin's image of teaching and learning, there is no question of the teacher stepping back and 'objectively' looking at the students, measuring their prior conceptions and tailoring teaching to them. Instead, I am led to return to the term 'organic' to describe the process of instant, moment-by-moment evocation and response and feedback that characterises this type of teaching. Rather than abstracting students' knowledge-making

schemes from the contexts that give them meaning, the teacher seeks to interact with, understand intuitively and respond appropriately to the students on a human level.

### Conclusion

Attempting to measure and understand another's construction processes in any final, objective sense is, in my opinion, neither philosophically tenable (particularly if our constructivism incorporates a concern for reflexivity) nor educationally fruitful. My suggestion, then, is that teaching, learning and research in education instead be re-imagined as 'collaborative social learning', in which students, teachers and researchers recognise in one another other human beings with whom they can play, live and learn. In the process, the learners teach and the teachers learn, and new knowledge is generated through rich social interactions.

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# Progression in Learning How to Work Scientifically

Mark Hackling<sup>1</sup>, Patrick Garnett<sup>1</sup>, and Robert Fairbrother<sup>2</sup>

<sup>1</sup>Edith Cowan University, Perth; <sup>2</sup>King's College, University of London

## Abstract

Trailing of the *Working Scientifically* strand of student outcome statements in Western Australia has focussed on developing strategies for implementing and evaluating open investigation work in primary and secondary school science so that data could be collected to clarify and validate the progression described in the student outcome statements. Out of this work has emerged the view that progression in learning can be facilitated by matching the degree of openness and complexity of investigation tasks to the experience and skills of the student, providing scaffolding to support student decision making, and by using teacher formative assessment and student self-assessment set within the developmental framework of the student outcome statements.

## Introduction

The National Science Statement (Australian Education Council, 1994a) and the Key Competencies Report (Mayer, 1992) have placed a high priority on the development of investigation and problem-solving skills in Australian schools. The student outcome statements of the *Working Scientifically* strand of the National Profile (Australian Education Council, 1994b) describe progression in learning of science investigation skills through eight levels. Several authors have argued that scientific problem-solving skills can be developed through inquiry oriented or investigation style laboratory work that gives students opportunities to practise the skills of problem analysis, planning experiments, collecting, organising and interpreting results (Roth & Roychoudhury, 1993; Tamir & Lunetta, 1981; Tamir, 1989; Woolnough, 1991; Woolnough & Allsop, 1985). There is a need to increase the opportunities within the secondary science curriculum for students to work on open investigation tasks so that they can develop science investigation and problem solving skills (Hackling & Garnett, 1995; Staer, Goodrum & Hackling, 1995). We need to help students make the transition from passive followers of recipe style laboratory worksheets to become autonomous decision makers on problem solving investigation tasks. This paper describes the nature of open investigations and outlines some approaches to facilitating students' progression in learning science investigation skills. The recommendations made in this paper are based on the experiences of trialing the *Working Scientifically* strand in Western Australian schools in 1995 and 1996.

## What is an Investigation?

Investigations are activities in which students take the initiative in finding answers to problems (Jones, Simon, Fairbrother, Watson & Black, 1992). The problems require some kind of investigation in order to generate information which will give answers. Garnett, Garnett and Hackling (1995) describe a science investigation as "a scientific problem which requires the student to plan a course of action, carry out the activity and collect the necessary data, organise and interpret the data, and reach a conclusion which is

communicated in some form" (p. 27). The planning component and the problem solving nature of the task distinguish investigations from other types of laboratory work.

Many would now argue that the student needs to be involved in selecting the problem or variables to be investigated, and the problem should be embedded in a context that is familiar to the student for the learning experience to be meaningful and represent authentic science (Woolnough, 1994). Student choice enhances ownership, motivation and persistence in the face of difficulties.

It is convenient to identify different phases in investigations such as a beginning or planning phase, a doing phase, and a concluding phase. The *Working Scientifically* strand in the Western Australian science curriculum (Education Department of Western Australia, 1994) contains four sub-strands; Planning investigations, Conducting investigations, Processing data, and Evaluating findings. In practice these phases may not take place in the strict order of, say, Planning - Conducting - Processing - Evaluating because half way through Conducting it may be realised that some more planning is needed and therefore a more recursive model (see Figure 1) may more accurately represent the investigation process.

A model of science investigation processes

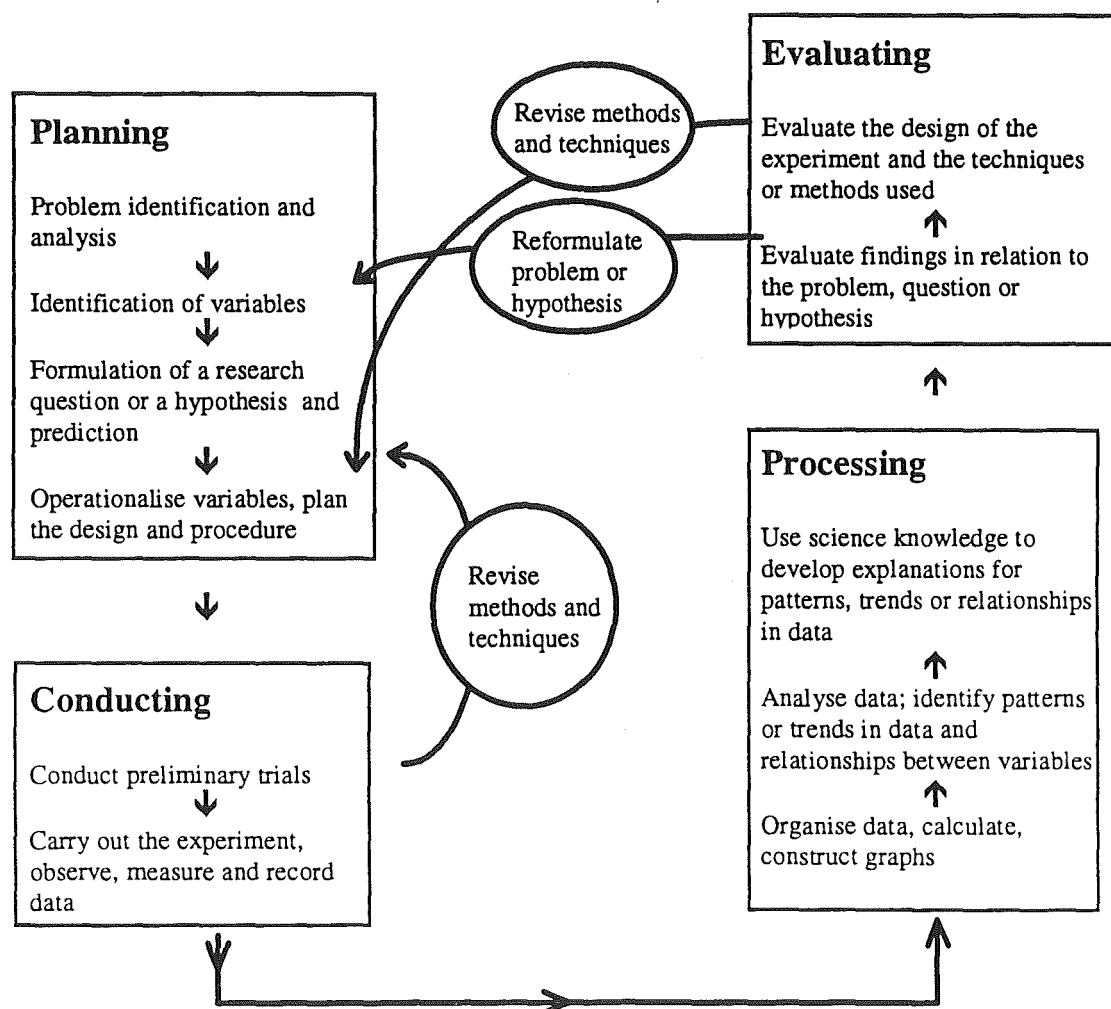


Figure 1. A model of science investigation processes (Hackling & Fairbrother, 1996)

## Facilitating Progression in Learning How to Work Scientifically

Progression in learning to work scientifically involves changes to the roles of the teacher and students, and changes to the nature of the investigation tasks. Some aspects of progression are outlined in Figure 2.

From	To
<b>The Teacher</b>	
Directing activities	Allowing autonomous working
<b>The Students</b>	
Following instructions	Being an autonomous decision maker
Being uncritical	Using creativity, judgement and critical thinking
Using simple procedures	Devising and using complete procedures and techniques
<b>The Investigation</b>	
Informal exploration	Systematic investigation
Simple information	Complex information
Everyday context	Scientific context (derived from the science being taught.)
Qualitative data	Qualitative and quantitative data
Discrete variables and data	Continuous variables and data

*Figure 2. Some aspects of progression in working scientifically*

It is argued that progression will be facilitated by:

- Matching the openness and complexity of the tasks to the experience and skills of the student.
- Providing appropriate scaffolding to support student decision-making.
- Student self-assessment and teacher formative assessment linked to outcome statements.

### Matching the Openness and Complexity of the Tasks to the Experience and Skills of the Student

There are a number of significant task and context variables that influence the difficulty of the investigation. The extent to which the problem statement specifies and operationalises the variables determines the openness of the task. Openness can be increased for more experienced students. The nature of the variables and data (discrete – continuous, qualitative – quantitative), the procedural complexity, and the sophistication of the conceptual context also have to be matched to the readiness of the learners. The uncertain leading edge of students progress must be viewed through a 'window' that includes those things the students have learned and in which they have confidence, those competencies with which students are currently grappling, and the things that are yet to be encountered. The difference between what the student can do independently and autonomously, and that which can be accomplished given the support of peers and the teacher has been described as the zone of proximal development or ZPD (Vygotsky, 1978). The openness and complexity of tasks need to be matched with the student's window of progress so that the task is slightly in front of the leading edge of developing competence and is therefore challenging without being daunting. This will allow students to work within their ZPD and given appropriate scaffolding they should make good progress.

Providing Appropriate Scaffolding to Support Student Decision-making

To support students as they move from dependence on recipe-style worksheets towards being autonomous decision-makers they need scaffolding (Vygotsky, 1978) to structure their work. Our experience has been that planning and report sheets that list a sequence of questions (e.g. What are you going to investigate? What do you think will happen? Why will that happen? What are you going to do? What will you need? How will you make it a fair test? etc.) are very effective in structuring a sequence of decision-making steps for the students (Hackling, 1995). Planning the design of the experiment and planning for control of variables are complex tasks which may require additional scaffolding for inexperienced students. This can be provided in the form of a variables table (see Figure 3) and teacher modelling of its use.

Research question: How does the amount of light affect the growth of seedlings?

<p>What I will keep the same</p> <p><i>type of seeds</i> <i>type of soil</i> <i>amount of water</i> <i>amount of fertiliser</i> <i>size of container</i> <i>planting depth of seeds</i></p> <p>Controlled variables</p>	<p>What I will change</p> <p><i>the amount of light:</i> <i>dark</i> <i>partial shade</i> <i>full sun</i></p> <p>Independent variable</p>	<p>What I will measure</p> <p><i>the height of the seedling</i></p> <p>Dependent variable</p>
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Figure 3. An example of a variables table (Hackling & Fairbrother, 1996)

Inexperienced students may need teacher intervention to help them work through a problematic aspect of their investigation. The use of open questions to scaffold students' analysis and resolution of the problem can be quite powerful where the teacher structures the students' thinking through the problem rather than providing a ready-made solution. The learning of these complex craft skills of science can be facilitated by the teacher adopting teaching strategies consistent with a cognitive apprenticeship model of instruction (Garnett & Hackling, 1996), such as modelling, scaffolding, coaching, providing opportunities for students to explain, discuss and compare ideas and strategies, and the fading of support as competence develops (Hennessy, 1993).

Student Self-assessment and Teacher Formative Assessment Linked to Outcome Statements

To facilitate progression students need to know the assessment criteria, what they are doing well, what they are doing poorly, and what they need to do better or differently to make progress (Black, 1993; Torrance, 1993). A profile of learning outcome statements that describe progression in learning can provide a framework for student self-evaluation and teacher formative evaluation. Such evaluations can locate the student on the profile and help identify what must be done for progress to be made. Discussions between teacher and student about the student's performance in relation to the profile can help clarify the assessment

criteria, what has been learned, and what must be learned next. Current assessment practices which are largely normative, summative and often atomistic and decontextualised will need to change significantly to being criterion or standards referenced, more formative, holistic and authentic if assessment is to make a greater contribution to student learning. Such significant changes to teaching practices will need to be supported with opportunities for teacher professional development.

### Conclusions

The secondary science curriculum has to this point in time offered few opportunities for students to develop science investigation skills and become autonomous decision-makers on problem-solving investigation laboratory tasks. There is a need to increase the number of open investigation tasks in which students can plan and conduct their own investigations, analyse the data, and evaluate their own work. Teachers will need to plan carefully the sequence of investigation tasks that will match the skills and experience of their students, provide appropriate scaffolding to support students' developing investigation competencies, and use more student self-evaluation and teacher formative evaluation within a learning outcomes statements framework to facilitate progression in students' learning.

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# **Student Difficulties in Differentiating Heat and Temperature**

Allan Harrison  
*Science and Mathematics Education Centre  
Curtin University of Technology*

## **Introduction**

The diverse intuitive views of the world that children bring to physics instruction is well documented in the science education literature (Driver et al., 1985, 1994; McDermott, 1993; Osborne & Freyberg, 1985) and an extensive body of theoretical and classroom research has been devoted to developing conceptual change teaching models that address these views (Duit et al., 1992; Hewson, 1981, 1982; Posner et al., 1982). Despite many successful students completing physics courses with some of their intuitive conceptions intact (Yager, 1991), progress in synthesising an effective model of conceptual change learning has been relatively slow. It was thought that discrepant event teaching would stimulate children to relinquish their ideas in favour of scientists' science; however, many students assimilate the 'new' science alongside their intuitive views, rote learn the science concepts for just the duration of the topic, or make little effort to reconcile obvious differences. Recent alternative perspectives on learning argue that conceptual change is often an incremental process (Duschl & Gitomer, 1991) that may be driven by a range of hot, irrational, social and motivational forces as well as cold, rational factors. Solomon (1987) claims that significant social factors influence classroom learning and knowledge construction, and social negotiation and group work are important ingredients in conceptual change.

## **Method and Summary of the Research**

This research investigated five Year 11 physics students' conceptual development during an eight week study of heat and temperature at a new independent school. A qualitative case study was framed to describe the learning processes that favoured a change from intuitive student conceptions to the scientific view of heat and temperature. The author taught the class and was assisted in the teaching and research by a discussant and a colleague who provided theoretical and critical support. The class used the heat and temperature module in the *Physics by Inquiry* (Physics Education Group, 1988) curriculum materials which substantially satisfied the Secondary Education Authority's (1994) syllabus. The learning environment was restructured to allow the students to proceed at their own pace and to socially negotiate the learning outcomes in small group and whole class discussions. Converting the teacher-centred classroom into a student-centred one required the teacher to reconceptualise his role.

Three of the five students significantly restructured their conceptual understanding of heat and temperature in a scientific way. One unsuccessful student lacked the requisite cognitive ability and personal study skills, and another able but unsuccessful student lacked the necessary social skills for success in group work and independent learning. Four students progressively adopted scientifically precise language and the

consistent verbal and written use of scientific terminology by three of the students supported the belief that they understood the concepts they described. Two students also reformed their thinking about science.

Analysis of pre-tests, initial discussions and early work showed that each student commenced each unit of study with naive, undifferentiated conceptions lacking a number of key concepts. Four students viewed heat and temperature as equivalent entities and this prevented them from solving simple everyday problems. During the initial discussions and activities, students developed an operational definition for temperature, and added the concepts of thermal interaction and thermal equilibrium to their conceptual framework. These ideas became anchoring conceptions that helped each student separate heat and temperature. Student investigation results provided information for use in concept substitution (Grayson, 1994) which led to the students to further differentiate heat from temperature and stimulated them to reconstruct their conceptual frameworks in a coherent way. As the course progressed, the three successful students consistently identified misuse of the concepts of heat and temperature by themselves and the two less successful students.

Thermal interactions were treated using proportional reasoning based upon the concept of heat capacities and temperature differences. Three students developed their own version of the standard heat calculations and in the final test, two quite different methods were used with equal success. Similarly, a series of concept maps showed that for each student, the number of concepts held increased with time; the detail and sophistication of the connections increased with time, and conceptual hierarchies emerged as the course drew to a close.

### Theoretical Framework

Constructivist perspectives of knowledge development explain that rather than adopting the teacher's knowledge, students construct their own science conceptions. Students bring intuitive alternative conceptions to the classroom and they generate *synthetic models* as they try to make sense of their ideas and the teacher's instruction. Because alternative conceptions are firmly grounded in the student's everyday experiences, they are highly resistant to change (Osborne & Freyberg, 1985) and a range of conceptual change learning models have been framed which explain the tenacity of student conceptions (Carey, 1986; 1991). These authors argue that science learning consists of a mix of: knowledge accretion; assimilation, conceptual capture or weak knowledge restructuring; and accommodation, conceptual exchange or strong (radical) knowledge restructuring. Duschl and Gitomer (1991) claim that students continuously accrete knowledge so that over time their conceptions may gradually change from intuitive to scientific.

Concept substitution (Grayson, 1994) seemed an appropriate way to reform students' conceptions of heat and temperature because it involves probing each student's ideas to identify the scientifically acceptable aspects of the student's conception(s). Once the correct aspects of the student's understanding are identified and supported, scientifically correct terms and processes are substituted for the incorrect items. In this way, the students' correct ideas act as anchoring conceptions for the substituted ideas. This research also utilised the key elements of Ausubel's *meaningful learning* theory (Novak, 1984).

It was believed that Ausubel's theory of meaningful learning was particularly useful for interpreting changes in student conceptions that occur during constructivist learning episodes. "The central idea in Ausubel's theory is that of *meaningful learning*, which he defines as 'nonarbitrary, substantive, nonverbatim incorporation of new knowledge into cognitive structure'" (Novak, 1984, p. 608). Nonarbitrary incorporation of new knowledge means that the new knowledge is related to prior knowledge and that the learner makes conscious, deliberate efforts to harmonise the two. Ausubel recognised that each student's "cognitive structure is unique, and hence subsumption of new knowledge produces a cognitive *interaction product* that is dependent both on what concepts or misconceptions the learner already has and the material presented" (p. 608). Pretests and formative discussions that regularly revisit prior conceptions in light of current conceptions are very effective ways to monitor and consolidate student cognitive growth (Hashweh, 1986).

*Progressive differentiation* of concepts was particularly useful because most students treat heat and temperature as if they are equivalent; heat capacity and specific heat are transposed and heat transfer mechanisms are poorly differentiated. Not only must students differentiate these concepts, they must learn to reconcile each in an integrative way so that once they recognise how heat and temperature differ, they then need to understand how they are related. Students also need to develop the ability to use heat and temperature in a mutually constructive manner to make sense of thermal interactions: temperature differences explain why heat is lost and gained but there must be an understanding of the quantity of heat flowing and its effect, namely temperature or phase changes in the interacting objects. In Ausubel's scheme, students often engage in *superordinate learning*, that is, the generation new hierarchies and relationships between new and old knowledge. Concept maps are especially useful for identifying new hierarchies and new connections between propositions and concepts. Ausubel also proposed the use of *advance organisers*. This device, often an analogy, is more general and more inclusive than usual learning episodes and directs the student to new knowledge and may be "perceived by the learner to act as a cognitive bridge between what he or she already knows and what is to be learned" (Novak, 1984, p. 608).

Carey (1991) also found that children consistently fail to distinguish between entities like mass and density. She argued that students need to *differentiate* incompatible concepts (e.g., mass/density, heat/temperature - Wiser & Carey, 1983) and *coalesce* separate concepts that belong together (e.g., humans are animals). There seem to be strong similarities between Ausubel's and Carey's differentiations and between integrative reconciliation and coalescence; however, Ausubel's theory of meaningful learning is more comprehensive and seemed more useful in this study. The learning theories espoused by Posner et al., (1982), Novak (1984) and Duschl and Gitomer (1991) all emphasise the centrality of the student consciously examining his/her understandings and knowledge structures. These perspectives were believed to be important in this study. Because student alternative conceptions of heat and temperature are highly resistant to change, strategies which cause the students to repeatedly examine their beliefs offered the best opportunity to restructure student understanding. The theories of conceptual change and meaningful learning therefore offered the researchers a sound base for interpreting the learning events that occurred in the classroom.

## HEAT PREDICTIONS

This is not a test. It will not affect your marks in any way. It will be most helpful to this study if you write as much as you can for each question.

NAME ..... DATE .....

1. In your own words explain what you think heat is. Try to say where your ideas come from.
2. Suppose that you have two cubes of the same size, one made of wood and one made of metal. Both have been sitting in the room for some time. How do you think the temperature of the two cubes will compare? Explain your answer.
3. Suppose the oven is turned to 60° C and the following things are put in the oven and left there for a few hours: some flour, a bowl of water and some nails. After a few hours, how will the temperatures of the substances compare with each other? Explain your answer.
4. Suppose I have two bricks made from the same kind of clay, but one is large and the other is small. Suppose I put them both in an oven at 120° C for a few hours. At the end of a few hours how will the temperatures of the two bricks compare?

[An oven containing the two bricks at 120° C was visible during this period.]

5. Suppose I have pot of boiling water on the stove. If I turn the stove up to a higher setting, what will happen to the temperature of the boiling water?

*Figure 1. Heat pretest administered in lesson 1.*

### Results and Interpretations

The results are limited to a brief discussion of the conceptual development of one student who will be called Ken. Ken was chosen because his prior conceptions were clearly enunciated (verbally and in writing); he regularly volunteered his opinions and explained his views; and he did change his conceptions during the course of instruction.

During the heat and temperature pre-test (Figure 1), Ken described heat in typically unscientific terms: "Heat is a sort of energy which [is] created by burning things. ... Heat is easily conducted by some substance (i.e., metal) while not as easily conducted by others (i.e., non-metals). My ideas are just common knowledge." During the pre-test discussion with the teacher, Ken explained the behaviour of an iron and a wooden cube left in the sun in this way:

the wood would stay just one temperature, the same temperature, the other one changes. Like if you put [the iron cube] in the sun it would get hot. ... I think it changes no matter what.

Further detail suggested that Ken reasoned teleologically because he states that objects react to thermal environmental changes based on the their macroscopic properties, function or use, and imposed events rather than in accordance with the principles of thermal interaction (Erickson & Tiberghien, 1985). Even when faced with sound contrary reasons from other students, Ken was adamantly satisfied with his explanation. Ken's thinking was guided by the iron cube feeling colder than the wood and by how he expects objects to respond when heated. For instance, he answered the third pre-test question saying that "the nails would be the hottest, then the water and least the flour. Because the nails trapped heat, the water would be boiling by then, but the flour is just about 60°C." He was quite sure that the water would boil in an oven at 60°C and verbally defended this position the following day. Ken knew that water boils at 100°C because he argued this concept when discussing Question 5. It is therefore intriguing why he insisted that the water would boil in an oven at only 60°C? The context may be important. When he said that the nails would be hotter, Ken may have thought the nail's exceeded 100°C. Everyday experience says that metal objects in

ovens are very hot and will burn you, water boils or evaporates, and cereal type foods like flour are reasonably safe to handle. Ken may have ascribed greater importance to the oven ("is hot") rather than the temperature ("is 60°C"). If the oven's properties and function dominated, then this supports the claim of teleological reasoning and illustrates the degree to which prior knowledge interferes with science learning.

### *Teaching and Learning by Concept Substitution*

During the pre-test and discussion, Ken displayed a rudimentary conception of heat and temperature and initially described temperature as a measure of the amount of heat in an object (i.e., extensive rather than intensive). One week later, the difference between heat and temperature was the subject of a lengthy discussion led by the discussant. The intervening activities asked the students to examine a variety of substances at different temperatures using their senses and thermometers to develop an operational definition for temperature. The transcript reveals that two of the students retained heat and temperature as equivalents and Ken's comments suggest that he was still unsure of the difference between the two terms, because he was unable to articulate a working definition of temperature. A review of the students' sensory experiences with different materials at different temperatures led to a unanimous conclusion that 'feel' is an unreliable determinant of temperature due to differing conductivities. Ken's concluding statement was that heat "is what causes the temperature to change." However, when asked to "go on", Ken was unable to extend this idea and disengaged from the conversation. At this juncture, concept substitution was employed by the discussant. Each student had volunteered his current understanding of heat and temperature and it was evident that these two concepts were still poorly differentiated (Novak, 1984). The focus for concept substitution was the question "what is heat?" and, "what is the importance of temperature in thermal interactions?" The discourse took this form:

- Disc            Heat in fact, we can only talk about something being transferred, can't actually talk about an object as having heat, they have temperature and we can measure that with a thermometer but they don't have heat. Heat is something, we can't say exactly what it is, but it is something that is transferred. Now under what conditions will heat be transferred to another object?
- John           When they have a different temperature.
- Disc           And that process of transfer, we give that process a name, does anyone know what that name is?
- Joe            Conduction.
- Disc           That's certainly one of the ways that heat can be transferred, but more generally when two objects interact because they are at different temperatures, and they exchange heat, its general term is ...
- Des            Radiation.
- Disc           We call this a thermal interaction. Whenever heat is transferred between two objects that are at different temperatures, that process is called thermal interaction. Now if you have two objects in contact with each other at different temperatures, will that thermal interaction continue forever?
- John           No, only till they get to an eventual temperature ... equilibrium.
- Disc           They reach the same temperature or reach thermal equilibrium ...

The discussion continued with the discussant and the students restating and reinforcing their understanding of these ideas. The scientific definition of heat was developed as an *interaction product*

between the students' ideas and the discussant's conception. Heat was progressively differentiated as energy that is "something being transferred" in contrast to temperature which was a measure of the intensity of the object's internal energy. Thermal interaction was introduced as a superordinate heading (Novak, 1984) for all forms of heat transfer, and when John introduced the equilibrium concept, the discussant was able to expand this into thermal equilibrium by building on the students' prior and current knowledge. Even though substantial scientific ideas emerged during this and previous discussions, the students did not adequately respond to the cue, "they exchange heat, its general term is?"; therefore, the discussant had to volunteer the concept "thermal interaction." The discussant conceptually substituted "thermal interaction" for all forms of heat transfer mentioned by the students.

A further examination of the last transcript then revealed a view of heat interaction that is static rather than dynamic. The conceptions of thermal interaction and thermal equilibrium still need to have the conflicting ideas of static and dynamic behaviour discussed, differentiated and reconciled. Only then will heat's dynamic nature be satisfactorily integrated into the students' conception of thermal interactions and equilibrium. The discussion returned to the pre-test question about the nails, water and flour left in the oven at 120°. This became a context for applying the differentiated concepts of heat and temperature and the new concept, thermal interactions. Ken had previously asserted that the water would be boiling and the nails even hotter. He believed there could be some temperature differences between these materials even though he conceded that they should all be at the same temperature.

Ken's conception was changing, but it had not yet reached the scientific conception and he again expressed his uncertainty in the next exchange by ending a confused attempt at applying thermal equilibrium with "...I dunno ...". Later, however, Ken mastered the idea of thermal interaction and thermal equilibrium and for the 'method-of-mixtures' section, devised an elegant form of proportional reasoning for determining the final temperature of mixtures. Ken's approach to learning was characterised by greater intellectual honesty than any other student in the class. He consistently took risks by expressing his ideas irrespective of the status quo and he was unwilling to agree with either his peers or the teacher unless he could internalise the concept and fruitfully use it to solve his problems. Meaningful learning does not stop at the differentiation of, for example, heat and temperature; it pursues superordinate learning (here, thermal interactions and thermal equilibrium) and makes use of reconciliatory integrations where the conceptions are brought together to solve abstract or difficult problems. Teachers are often tempted to effect lesson closure once the desired concept emerges. Keeping the discussion 'open' is essential if real conceptual gains are to be made.

### Summary

At the start of this eight week unit of study, Ken possessed a highly intuitive conception of heat and temperature. He visualised heat and temperature as similar entities and even though he believed that heat energy in an object can move into other objects, he lacked the systematic conceptions to explain heat transfers. Thermal interaction and thermal equilibrium concepts were nonexistent for he held that different objects can have different temperatures in the same environment. The use of pre-tests and carefully planned investigations, questions and discussions utilising concept substitution enabled Ken to address the

incommensurable aspects of his knowledge. Ken progressively added scientific concepts like thermal interactions (involving heat gained = heat lost) and thermal equilibrium by conceptual capture. He concomitantly differentiated heat and temperature by constructing new conceptual hierarchies culminating in the integrative reconciliation of heat and temperature. Ken's mental model of thermal interactions was certainly intelligible and plausible and probably fruitful.

By the unit's conclusion, Ken viewed temperature as an intensive characteristic of objects and thermal interactions were described qualitatively and quantitatively. It is claimed that this student underwent a form of conceptual change in which the status of the scientific conception rose at the expense of his intuitive conceptions; but whether this change was a weak or radical restructuring is unclear. A sound argument can be made that Ken's conceptions evolved, that his conceptual changes were cumulative and piecemeal (Duschl & Gitomer, 1991) and that this required a dynamic social environment that provided consistent support for Ken and his peers as they struggled to accommodate new and counter-intuitive ideas.

### Conclusions and Recommendations

Students have difficulty in differentiating concepts such as heat and temperature because their naive conceptions are robust and resistant to change. During traditional teaching, students appear to assimilate the scientific view of heat and temperature; however, this study shows that alternative student conceptions need to be revisited in a variety of contexts before student frameworks are adequately restructured. The significant factors in this process are *time*, *authentic problems*, *open-endedness* and a *socially supportive classroom*. It is likely that both the teacher and the students will be initially challenged by an open-ended student-centred learning environment like the one described in this paper. Nevertheless, this case study provides valuable insights into the variety of conceptual developments that take place in a group of students with differing intellectual and social backgrounds.

This case study also highlights the teaching and learning difficulties that accompany teaching for understanding rather than for content and quantitative problem solving. The observation that Ken's conceptual development was incremental and piecemeal supports Duschl and Gitomer's position (1991). Whenever learning is gradual and accretive, considerable time needs to be spent on progressively differentiating fundamental concepts so that students can build new conceptual hierarchies in which the fundamental concepts are integrated in a scientific way. Finally, this study re-emphasises the need for teachers to probe the understandings of their students before, repeatedly during, and at the close of instruction. To that end, this paper describes some of the methods that can be used by teachers to monitor the conceptual development of their students.



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