Science and Mathematics Education Centre

# The Influence of Teachers' Content Knowledge and Pedagogical Content Knowledge in Science When Judging Students' Science Work.

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ABSTRACT

Primary and secondary teachers in Western Australian have adopted a new *Curriculum Framework* (Curriculum Council, 1998a) which is outcomes-focused and endorses a constructivist approach to science for school students. This research examines the influence of teachers' science content knowledge on how they make judgements about students' conceptual understandings and the extent to which follow-up activities they suggest reflect a conceptual change approach to teaching science.

Primary and secondary teachers, from a range of science education histories and experiences teaching students of different ages, responded to a science task involving concepts of heat energy, combustion and ignition. They were asked to judge a student work sample about the same task, and suggest follow-up activities to support further learning.

How teachers made their judgements was found to vary in accord with their science knowledge, categorised as high, midrange and low. Teachers with high science knowledge were the most adept at making accurate and appropriate judgements and had the lowest frequency of problems with their judgements. Teachers with high and midrange science knowledge were more able to link their suggestions for follow-up activities to students' science concepts, and showed greater familiarity with activities commensurate with a conceptual change orientation to teaching. Non-recognition of students' concepts as critical evidence of development was a key aspect of the judgements of teachers with low science knowledge.

Recommendations are made for professional development to assist teachers to develop appropriate science content knowledge they can use to support their pedagogical content knowledge so they are able to foster students' conceptual development.

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# INTRODUCTION

## 1.0 The Problem Area

Primary school teachers in Western Australia are typically involved in supporting the learning of students in a broad range of subjects, including mathematics, English, society, health, physical education and the arts. Due perhaps to competition from these other subjects, there is a general lack of science teaching as a core part of primary students' program (Australian Academy of Science [AAS], 1992; Education Department of Western Australia [EDWA], 1994a; Goodrum, Cousins, & Kinnear, 1992).

The Department of Education, Employment and Training's *Discipline Review of Teacher Education in Mathematics and Science* (Speedy, Annice, & Fensham, 1989) suggested that this low profile of science teaching was linked to a lack of confidence of teachers of primary science, and that this was partially due to low levels of science understanding by primary teachers.

A report of the Science Education Focus Group of the Australian Academy of Science (AAS, 1991) in an identification of "the existing weaknesses of primary science and technology education" (p. 4) listed factors contributing to the poor state of primary science: insufficient professional development release time and preparation time; insufficient assessment tools; teachers do not possess appropriate teaching strategies such as hands-on and investigation, due to their own experience in teacher-domination of lessons and rote-learning; the transition to high school is too demanding for students; and students do not value science. It concluded that

> many primary teachers have only a rudimentary understanding of what science and technology is, how it operates, and how it relates to everyone's life. They may lack confidence in—or even resist—teaching it, particularly if they have not studied any of the science disciplines since secondary school. (p. 5)

These disturbing reports highlight two components of teaching—teachers' own knowledge of content and their practice of teaching—which had earlier been

recognised by Shulman (1986). In a seminal, defining paper he introduced the terminology of content knowledge and pedagogical content knowledge. His paper referred to all subjects, but his specific examples used science as a vehicle to argue that knowledge of a subject discipline (teachers' content knowledge) was critical because teachers needed to know basic science in order to teach it. Shulman also saw teachers' pedagogical content knowledge as influential in the classroom. This term meant knowing what problems students may have, what their misconceptions might be and included

> the most usual forms of representation of those ideas, the most powerful analogies, illustrations, examples, explanations, and demonstrations—in a word, the ways of representing and formulating the subject that make it comprehensible to others [and] the teacher must have at hand a veritable armamentarium of alternative forms of representation. (p. 9)

The consequence of low levels of teachers' science content knowledge and inadequate pedagogical content knowledge in science is a negative effect on students' progress. Work by Carré and Ovens (1994) suggested "each child's progression in understanding ... may have been hampered" by a teacher's uncertainty about "subject content knowledge" (p. 62). Their work reported low levels of teacher knowledge and that 11-year-olds knew as much as their student teachers. They implicated poor teacher science content knowledge with teachers' subsequent inability to support changes in students' science concepts:

> The implication from many research findings is that teachers should explicitly plan to restructure children's knowledge. Basically, conceptual change teaching involves helping children to articulate openly what they think and to challenge their own misconceptions by using a variety of teaching strategies. The methods which teachers select depend as much on their children's levels of understanding, as on their own pedagogical and subject content knowledge. (p. 39)

A critical aspect of schools' responsibility, and the society which gives schools this responsibility, is to support student learning. One of a teacher's responsibilities is to judge what a student knows and understands, in order to plan an appropriate program to support further learning. Making accurate and appropriate judgements about students' work is an important part of science teaching because it is critical to supporting students' learning.

The problem which stimulated this research is the negative impact of teachers' inadequate science content knowledge on student learning. The study examines the effect of teachers' science content knowledge on the pedagogical decisions they make when they judge students' work and frame subsequent instruction.

Shulman's (1986) pedagogical content knowledge and its implications for effective science teaching forms the theoretical basis for this research. It provided a framework to explore how teachers' own science content knowledge influenced the interpretations they made of students' science work, whether they recognised their role of challenging students' understandings, and whether the teaching strategies they suggested were appropriate to foster subsequent conceptual development. Because primary teachers are not specialists in science, they lack, in Shulman's terms, science content knowledge. Their science pedagogical content knowledge—how to present science to students and how to best support students' progress—is also affected. The inherent problem is that content and pedagogical content knowledge can combine to cause teachers to experience difficulty when teaching for conceptual change, and as a consequence, this can have a negative effect on student learning.

This research is timely within the context of Western Australia, as concerns about teachers' science content knowledge and pedagogical content knowledge in science are being taken seriously by education authorities. The Education Department of Western Australia funded a three year strategic initiative to support teachers to improve the science education they provided in schools (EDWA, 1997a, 1997b) in response to a need identified in a state-wide monitoring project (EDWA, 1994a). Part of this initiative was to train science teacher-leaders in teaching new methodologies (Schibeci, 1995; Venville, Wallace, & Louden, 1995) and to provide content knowledge to support growth in the science understanding of primary classroom teachers (Schibeci & Hickey, 1997a, 1997b). Another extensive project trained

primary teachers to conduct workshops for teachers to use the *Primary Investigations* curriculum (AAS, 1994) [hereafter referred to as *Primary Investigations*] which supported a conceptual change approach through a structured series of lessons and also contained background information for teachers on the science concepts.

The release of the *Curriculum Framework* by the Curriculum Council in Western Australia (Curriculum Council [CC], 1998a) [hereafter referred to as the *Curriculum Framework*] made the issues of teachers' content knowledge, and how this is translated into pedagogy, a continuing imperative. In science, its outcomes-focused approach set the teachers' role as fostering conceptual change in students rather than "delivering content and testing the learning of this content" (p. 25). Through its *Professional Development Guidelines* (CC, 1998c) the Curriculum Council recognised that the focus on students developing conceptual understandings meant a professional development response was needed so that teachers themselves could understand the concepts, and that this was particularly true for primary teachers. The demands of conceptual change teaching were also noted as likely to cause problems for teachers assessing students' work.

## 1.1 Purpose and Research Questions

The purpose of this research is to investigate the ways that teachers' science understandings affect the support they are able to provide to foster conceptual change in students. Thus, the focus is on teachers and their work as judges and planners, not on the students themselves.

The research purpose can be described through a general research question: What effects do teachers' science content knowledge and pedagogical content knowledge in science have on the way they make their judgements about students' science work?

In order to make the general question researchable, a specific science-related context was needed. The context of lighting a candle, watching it burn and blowing it out, was chosen because it gave considerable scope for teachers' responses. It also served as a familiar context, allowed a wide range of responses and was linked to many science concepts. These aspects are described in more detail in Chapter 4.

### *1.1.1 Research Questions*

Three specific research questions were developed, guided by Shulman's (1986) distinction between content knowledge and pedagogical content knowledge. These questions provided the focus to identify what teachers recognised in students' work, how they made inferences and judgements about students' conceptual understanding, and what teachers proposed to do as a result of their judgements through the follow-up activities or teaching strategies they suggested.

*Research Question 1*

"What do teachers know and understand about the science concepts involved in a selected science-related task?" is the first research question. This question required data to be gathered on teachers' science knowledge when they made explanations about lighting and burning a candle, such as the role of friction in making the match ignite, how candle wax burns and what happens when you blow out the candle.

*Research Question 2*

The second research question, "How do teachers interpret, and how do they make their judgements about, students' work?", focused on teachers' pedagogical content knowledge in science. It required data to be collected on what aspects of students' work they recognised and responded to, and what they used as the basis for making judgements about students' understandings and concept development. Associated questions included: What sorts of judgements did teachers make about students' science understandings? In what ways did teachers' science knowledge influence what they saw in students' work? Was there a difference between how teachers with extensive science education judged students' work when compared to teachers with limited science education? To what extent were teachers' abilities to support students' science development enhanced or constrained by their own conceptions?

*Research Question 3*

The third question, "What strategies do teachers suggest to support students' further learning?", looked at one specific aspect of teachers' pedagogical knowledge: the choice of follow-up activities. Teachers' suggestions followed on from the judgements they made about students' work completed as part of research question 2. Part of the analysis for this question was to analyse teachers' suggestions to determine

the extent to which they can contribute to conceptual change in students' science understandings. The research does not extend to determining what support teachers actually provided in a classroom but it did establish their knowledge of strategies. Associated questions included: What activities did teachers suggest? To what extent are their suggestions likely to contribute to enhancing conceptual change in their students?

### *1.1.2 Outline of the Research Design*

The research design was qualitative, small-scale, but intensive. It was based on individual, face-to-face interviews between the researcher and practising teachers. Interviews were built around a science task which was developed and trialed. During the interviews teachers described the scientific processes and events involved in the task, made judgements about students' science work and suggested follow-up activities.

Instruments were developed: an appropriate task, the interview questions, a method to determine and describe teachers' science knowledge about candles and another to elicit teachers' judgements.

Thirty teachers for the sample were selected on the basis of their science background (as extensive or limited) and were from both primary and secondary sectors. This broad representation of Western Australian teachers ensured rich data. Teachers were interviewed and transcripts prepared. The interview transcripts provided the data source and were analysed to provide answers for the research questions.

Analysis for the first research question, which involved describing teachers' science content knowledge, occurred as a three stage process. In the first stage, a basic structure of the science concepts in students' work was developed, then a sample of teachers' interviews was used to develop various ways to describe their knowledge, and one way was chosen that allowed for a consistent description of an individual teacher's knowledge as well as a comparison to others' ideas. During the second stage, teachers' concepts were coded to show the level of sophistication of their ideas about the concepts involved in the task, such as burning, heat exchange, combustion, change of phase and production of smoke. Analysis of these codings was the basis for the third stage, which resulted in descriptions of a range of science

content knowledge. These descriptions for teachers with high science content knowledge were compared to those for teachers with midrange and low science knowledge.

Analysis of the judgements teachers made about students' work (the second research question) was done in two stages. The first stage was to identify what aspects in students' work teachers used as the basis for their judgements. Teachers' interview transcripts were compared and the different aspects of students' work they responded to were identified; similar aspects were grouped and the use individual teachers made of these aspects was coded onto recording sheets; these were then compared to identify the most common bases used. The next stage was a continuous comparison of the judgements made, teachers' science knowledge, and the students' work they judged, to identify how teachers' science knowledge had supported or impeded their judgements. Problems that teachers had with judgements due to their science content knowledge were described.

Analysis of the data on follow-up strategies (for the third research question) began by identifying all of the activities teachers suggested, then determining the extent teachers took students' science concepts into consideration when devising their suggestions. This analysis was reinterpreted to identify the various orientations towards school science teachers demonstrated, such as a discovery or a conceptual change orientation.

A recurring aspect of all analyses was a description of the differences between teachers within the high, midrange or low ranges of science content knowledge and the judgements or follow-up suggestions they made.

Trustworthiness of the data (Lincoln & Guba, 1985) was increased during data collection by using multiple sources from 30 teachers. Evidence for teachers' science content knowledge was collected through different data collection modes: a direct approach when teachers responded to the science-related task; and an indirect approach when teachers again accessed their science knowledge as they made judgements and suggested follow-up activities. Confidence in the analyses of the data was achieved by means of repeated codings of data within a system of inbuilt checks for accuracy of the frequency and variation in teachers' responses; steps to make the

analysis more transferable and dependable; and inclusion of details of instrument development and interview transcripts as part of an inquiry audit.

## 1.2 Significance of the Study

That primary teachers' science content knowledge is generally low with consequent negative effects on students' learning has been established in the literature. This research builds on this previous work. However, the form and extent of these effects have not been analysed in depth, especially in regard to pedagogical content knowledge in science in assessment and remediation.

There is little in the research literature that provides a detailed description of the criteria teachers use to judge students' work and how this links to teachers' own science knowledge. With the increased emphasis on using teachers' judgements to support students' conceptual change, it is critical that teachers and teacher educators fully understand these criteria. The contribution of this research is to analyse and describe precisely how teachers' science content knowledge can enhance and inhibit their support of students' learning.

The study is significant in three ways. First, an important methodological outcome of this research will be a detailed description of teachers' understandings of candles, and related concepts such as heat energy and transfer, melting and combustion. The methodology developed to describe these understandings, and to build up a conceptual map of the specific task, is a model that could be used for other tasks. Second, the major outcome of the study will be a description of how teachers' science content knowledge influences the way they assess and evaluate students' science work. The problems teachers had with their judgements suggests the need for teachers to develop their science content knowledge, not for its own sake, but because it has the potential to impact on the quality of support they can provide to students.

Finally, the outcomes of this research form the basis for recommendations which will contribute to improving the design of science professional development courses that focus on making accurate and appropriate judgements. It is important that professional development in science education results in increased effectiveness of the judgements teachers can make about students' science work, their ability to recognise

clues to students' conceptual growth, and to increase their confidence in teaching science using a conceptual change approach.

### 1.3 Position of the Researcher and Expectations

Identifying personal beliefs is important in qualitative research as a way to explain the position of the researcher and expectations of the research findings (Lincoln & Guba, 1985) A succession of experiences contributed to the formulation of my research and established my position. I have 20 years experience in schools, as classroom teacher, principal, and English language curriculum writer, but it was only relatively recently that I took notice of science. A student teacher's trouble with science knowledge was the stimulus. In response to a question asked by a Year 2 student, she said that spiders could walk on water "because it was magic." Quizzed after her lesson, she said that was all she could say, as she had no idea why spiders could do that. I asked her why she didn't just say she didn't know; she replied she thought teachers were always supposed to know. I asked if she knew of surface tension, she said she had never heard of it. My interest in the importance of knowing science was aroused and continued to grow. Another experience was during observation of a pre-service teacher's lesson on endangered animals. A 10-year-old student asked why cloning was not used to save the animals. The teacher was totally flummoxed and unable to use this plausible suggestion as the basis for some lively science discussion.

With the introduction at my school of the *Primary Investigations* curriculum it became apparent that staff did not understand much of the content and had difficulty understanding why they were teaching it. I used an Education Department of Western Australia Research Fellowship to conduct a four day professional development course for five teachers (Hickey, 1995a, 1995b). This course crystalised into the rationale for this thesis—how teachers' personal science knowledge was hampering their ability to teach science effectively. I began to appreciate what conceptual change teaching really meant, because during the course, teachers were surprised at the diversity and richness of students' ideas and how younger children unexpectedly had more sophisticated ideas than older students. It was a new approach for these teachers to ask what students already knew and proceed from that point, rather than tell students

what they wanted to them to learn. For this group, a conceptual change approach about what was appropriate science lesson structure was revolutionary; and they started to move away from the dispenser of knowledge approach, to one that was open to the directions students gave.

During this course I helped teachers develop their science content knowledge linked to *Primary Investigations* lessons. Of surprise to me was the extent of misunderstanding, and lack of understanding, by teachers about topics they commonly taught (for example, causes of the seasons, role of colour in camouflage, why things float) and the reason for inclusion of some activities in the curriculum (even though they were teaching the lesson they could not place it in a sequence of ideas that students would develop later on). Although the gains were tentative, as teachers' understanding of the concepts improved, so did their confidence in accepting a diversity of concepts from students. The motivation of these teachers for learning new concepts was not to pursue a personally satisfying understanding of concepts but because the ideas were highly relevant to their teaching.

This was similar to my experience with another group of teachers while I was doing a *Primary Investigations* trainer course. Many of these teachers, all of whom had extensive interest in primary science, had difficulty with basic ideas of energy, energy changes, and the nature of materials, which were critical to understanding the conceptual change approach of the *Primary Investigations* curriculum. Few of these teachers had read the background information provided in the curriculum, and relied on their current, unexamined knowledge and unrecognised misconceptions.

These experiences with the effects of teachers' lack of science knowledge confirmed to me both the value and the difficulty of a conceptual change approach to teaching and influenced the selection of the research questions.

The introduction of the *Curriculum Framework* made teachers' understanding of teaching for conceptual change overt and required. I wanted to identify the problems that teachers with low science knowledge had with their judgements, and use this to make professional development focused, practical, useful and relevant. I had to accept that my own personal interest was not a sufficient reason to expect others to share my enthusiasm.

Based on these background experiences, I had several expectations about what I would discover. My general expectation was that teachers of upper secondary science would have higher science knowledge of the candle task than teachers of junior classes, due to their extensive science education. In comparison, I expected teachers with a limited science education (that is, most primary teachers) to describe the candle with elementary concepts and to have more misconceptions.

I expected that teachers with an extensive science education history would use their own concepts as a benchmark to assess students' concepts. Also, they would apply recollections of how their own concepts developed over time (for example, they might recall that they understood that flames produce heat and light before they understood the role of gases in burning) and seek to recognise similar aspects in students' work. It was expected that teachers who teach Year 11 students would make the most use of conceptual progression in their judgements, as would those who had attended science professional development.

I expected the activities teachers suggested as science follow-up would be about doing more of something (for example, more exercises or more experiments), using hands-on activities, or using the latest technology such as the internet. I also expected that teachers who knew about conceptual change would be able to determine activities that were appropriate to a student's science learning needs, rather than suggest activities that went over concepts that students already possessed.

These expectations unavoidably shaped the research questions, but by acknowledging them, I was able to remain aware of the possibility of making judgements based on my expectations rather than the evidence, and to counter this by efforts to make data collection and analysis more trustworthy.

## 1.4 Possible Limitations

There are several limitations arising from three aspects of the research design: teachers responded to only one science task, data were collected by interview, and follow-up was suggested but not practised in a classroom.

Data to answer the first research question are limited to asking teachers to respond to only one science task, that of lighting and blowing out a candle. This one context covers only a small number of the science concepts that teachers are likely to

hold and which are included in science curricula. However, this task is representative because it has multiple links to three of the mandatory outcomes of the *Curriculum Framework's* Science Learning Area Statement used in Western Australian schools: Natural and Processed Materials, Energy and Change, and Science in Daily Life. Thus, although only one task was used, the data are very detailed and provide some coverage of several content areas.

The second research question was answered using data from interviews about the judgements teachers made based on one sample of a student's work. Data are limited as teachers did not have the opportunity to make multiple judgements about a familiar student and using familiar activities. However, the research approach does simulate discussions teachers and students may have on which teachers can base judgements. It also maximises teachers' opportunity to do their considered best for that student, as it ensures they are focused on the evidence of students' conceptual development and are not influenced by expectations they may have based on students' appearance, age, gender, behaviour or previous performance in science.

Both of these questions rely on data restricted to comments verbalised by teachers. This limitation is a consequence of the think-aloud format that cannot tap into tacit understandings, relies on teachers' verbal facility, and cannot code for aspects of teachers' pedagogical content knowledge in science that do not arise in the interview.

The third research question asked teachers what follow-up they would suggest for the student whose work they had examined. It is recognised that what respondents say they would do may not reflect their actual practice. However, the data will indicate the extent to which teachers are aware of the practices mentioned in the science education literature as supportive of conceptual change, even though no data are provided of the extent of actual use.

In a study of this scale, such limitations are unavoidable. However, in all aspects, attempts were made to obtain the richest description possible to maximise the information obtained. Further, it is hoped that the research approach can be replicated with other tasks, which would increase knowledge of this important topic and also test the generalisability of the findings from this study.

## 1.5 Overview of the Thesis

In Chapter 2 the educational scene in Western Australia will be examined, with reference to the implications for increased demands on teachers' science content knowledge and pedagogical content knowledge in science due to the *Curriculum Framework* and outcomes-focused education. The science education literature on good science practice is reviewed and the research questions are re-examined in terms of issues and contexts such as conceptual change and misconceptions.

In Chapter 3, the research design is explained and linked to the research questions. The selection of the sample of teachers is described. The development of the candle task through trialing and production of student transcripts representative of a broad range of ages and abilities is summarised. Hierarchical concept grids are developed to quantify increasing levels of sophistication. Data analysis based on the transcripts of the interviews is undertaken. Attempts by the researcher to achieve trustworthiness of data and confidence in analysis are explained.

In Chapter 4, the first research question, pertaining to what teachers know and understand about the science of candles is answered. The performance of teachers with limited or extensive backgrounds in science is described and linked to the sophistication of their science understanding. The second research question is addressed in Chapter 5. The manner in which teachers make judgements about students' work is analysed, and problems relating to teachers' science content knowledge are identified. The follow-up strategies teachers suggested are described in Chapter 6 and evaluated in terms of the extent to which they can be construed as teaching for conceptual change.

In Chapter 7 the results from all three research questions are reviewed and summarised. The study and its conclusions are linked to implications for further research, and are developed into recommendations for professional development of science teachers.

# CHAPTER 2
# LITERATURE REVIEW

## 2.0 Introduction

Helping students construct science understandings, learn the disciplined inquiry approach characteristic of science and develop an understanding of the myriad concepts linked to issues in modern, socially referenced curricula is the goal of science education. To achieve this daunting goal, teachers need to continually appraise their students' development, choose appropriate learning activities, and seek direction from curriculum guidelines and from their own pedagogical beliefs. The interplay between teachers' own science knowledge and their judgements about their students within the complexities of modern science pedagogy is the focus of this chapter. The education scene in Western Australia is the locus and the impact of major pedagogical reform in science education within the State is the theme. What constitutes good practice in science education, particularly the conceptual change approach, is examined to present a rationale for the research questions using science education literature from within Western Australia, Australia, the United Kingdom (UK) and United States of America (USA).

This chapter begins by presenting the context of the research, the adoption in Western Australia of an outcomes-focused approach to education. Science content knowledge is discussed, particularly what is appropriate knowledge for teachers, and problems the research literature has shown teachers have when their science knowledge is inadequate. Pedagogical content knowledge in science, and its links to teachers' science content knowledge is described, with particular attention paid to its effect on teachers' abilities to make accurate and appropriate judgements. The different orientations towards science teaching that teachers hold, and how these affect professional knowledge and form the basis for planning further lessons or learning activities are discussed. This discussion includes a brief overview of strategies for making judgements appropriate for conceptual change teaching, such as work samples that describe levels of development. The chapter concludes with a review of the research questions.

## 2.1 The Educational Scene in Western Australia

The *National Statement on Science for Australian Schools* (Curriculum Corporation, 1993) specified student learning outcomes and a companion document, *Science: A Curriculum Profile for Australian Schools* (Curriculum Corporation, 1994), described students' achievement as an hierarchical progression of eight levels of increasingly sophisticated concepts and skills. This was influential in the development of the *Curriculum Framework* (see also Curriculum Council, 1998b, 1998c, 1998d) which was adopted formally by all sectors and schools in Western Australia in 1998. Its advocacy of outcomes-focused education represented a major review of curriculum.

The *Curriculum Framework* established the outcomes students achieve as a result of schooling in eight Learning Areas (English, Mathematics, Society and Environment, Science, The Arts, Health and Physical Education, Languages Other Than English (LOTE) and Technology and Enterprise). It was a pedagogical shift away from a focus on delivery (an inputs approach) to a focus on learning outcomes for individual students achieved as a result of teaching, learning and assessment. What is distinctive about the Western Australian *Curriculum Framework* is that outcomes are specified in broad terms for all students irrespective of age or ability and are not specified as a series of developmental levels as in *Science: A Curriculum Profile for Australian Schools* (Curriculum Corporation, 1994).

The Science Learning Area of the *Curriculum Framework* has five outcomes that relate to the methodology and uses of science. These are grouped together as Working Scientifically (Investigating, Science in Daily Life, Communicating Scientifically, Science in Society, and Acting Responsibly). For example,

> Investigating
>
> Students investigate to answer questions about the natural and technological world using reflection and analysis to prepare a plan; to collect, process and interpret data; to communicate conclusions; and to evaluate their plan, procedures and findings. (p. 220)

The other four outcomes in the Science Learning Area are grouped as Understanding Concepts (Life and Living, Natural and Processed Materials, Earth and Beyond, and Energy and Change) and represent "scientific understandings, theories, ideas and knowledge, and draw from the traditional scientific disciplines" (p. 221). For example,

> Energy and Change
>
> Students understand the scientific concept of energy and explain that energy is vital to our existence and to our quality of life.
>
> Natural and Processed Materials
>
> Students understand that the structure of materials determines their properties and that the processing of raw materials results in new materials with different properties and uses. (p. 220)

These science outcomes are to be interpreted rather than followed. Outcomes-focused education has increased the necessity for teachers to be sensitive to students' conceptual understandings, to interpret outcomes in terms of the needs and abilities of their students and continually reinterpret them as students' understandings become more sophisticated. Teachers must be attuned to the needs, interests and abilities of students as they judge progress, and modify lessons and activities to cater for students who are conceptually advanced or who hold less sophisticated understandings. Rather than moving to a predetermined topic set by the curriculum developers, outcomes-focused education relies on teachers' judgements to manage the curriculum: to decide what their students understand now, do not yet understand, and need to understand, to achieve the outcomes.

The principles of teaching, learning and assessment of the *Curriculum Framework* provide guidelines for schools to support and evaluate the progress of their students. In science, these principles support a conceptual change orientation:

> Learning will occur more effectively in science if students are able to use such challenges to critically examine their existing concepts and to find ways to accommodate new perspectives or information. Constructing new ideas in

science requires students to acquire and make sense of other, more powerful ideas. (p. 239)

This constructivist view of learning captures the idea of active learning, as students construct new knowledge, fitting it into what they already know and building on earlier understandings (Ausubel, 1968; Bodner, 1986; Driver, Guesne, & Tiberghien, 1985; Driver & Oldham, 1986; von Glaserfeld, 1995) and requires a different approach for the teacher to foster rather than control learning (Geelan, 1996). Bell (1991) described this type of curriculum in general as one that promotes students constructing their own science understandings rather than internalising a defined set of knowledge determined by others: "A constructivist curriculum ... would contain more guidelines as to how to develop students' conceptions, and in what knowledge areas, and less prescribed scientific knowledge" (p. 39).

The *Curriculum Framework* provides direction for teachers to implement a constructivist approach by recommendations on pedagogy and suggested learning activities appropriate for students at different ages. For science, the Early Childhood phase of development (typically Year 1 to Year 3) suggested that activities should allow for free exploration of interests and use all of children's senses in describing changes in their world. During the Late Adolescence phase, vocational relevance with students linking "theoretical ideas with scientific applications" (p. 237) was supported.

Reflecting the outcomes of the *Curriculum Framework*, the Education Department of Western Australia (the government sector, distinguished from the independent and catholic school sectors) developed an *Outcomes and Standards Framework* (EDWA, 1998) [hereafter referred to as the *Outcomes and Standards Framework*] which specified outcomes in far greater detail. Sets of eight linked outcomes (termed strand outcome statements) are expressed as levels of increasing sophistication from the first year of schooling (Level 1) to post-compulsory years (Level 8), as well as a foundation level for students with learning difficulties. See Appendix A for the science outcomes for the Western Australian curriculum documents. In science, level descriptions for the Energy and Change outcome (EDWA, 1998) included:

Foundation Level

Demonstrates an awareness that energy is present in daily life.

Level 2

Understands ways that energy is transferred and that people use different types of energy for different purposes.

Level 4

Understands that energy interacts differently with different substances and that they can affect the use and transfer of energy.

Level 6

Understands the principles and concepts used to explain the transfer of energy that occurs in energy systems.

Level 8

Understands how to assess the role of science in helping us to explain energy systems, production and use. (p. 52)

Outcomes expressed in this form support teachers—by virtue of detail—to interpret and recognise student progress by describing what is appropriate or expected for students to understand at successive levels of sophistication. In the *Outcomes and Standards Framework* each outcome is supplemented by explanations, ideas for learning activities and aspects of student thinking for each strand outcome statement, for example,

Level 4

Students compare different ways of enabling or impeding the transfer of energy and how different forms of energy interact with different materials. They explain that insulating with different materials varies the amount of heat that is transferred, such as insulating houses and containers that hold hot or cold drinks. They describe how surface features, e.g. colour and texture, affect the absorption of heat and the comfort of cars .... They discuss processes of energy transfer in everyday situations using terms such as absorbing, conducting, working, heating and forcing. (p. 57)

The *Curriculum Framework* and *Outcomes and Standards Framework* both stopped short of heavily mandated or detailed specification of programs of study, instead they specified desirable outcomes for students, couched either in general terms or as a series of successive outcomes. Both advocated flexibility by leaving local schools and teachers to design or choose the most suitable program for their students but both provided a range of suitable topics, appropriate terminology and learning activities to support this decision making. The balance between flexibility and prescription is variable even for curricula labeled as outcomes-focused and when so-called outcomes are linked to grades or years of schooling they may not "support the curriculum flexibility that OBE [Outcome Based Education] demands" (Willis & Kissane, 1995a, see also 1995b). Thus, the very specificity of the *Outcomes and Standards Framework* may reduce its adherence to the outcomes approach, although it is based on this, and does not link content precisely to students' year of schooling.

The impetus for the adoption of an outcomes approach in Western Australia can be found in both the political, academic and educational literature. It was part of a broad movement to outcomes-focused education in Australia, the UK and the USA. Adoption of an outcomes approach to education was seen as a way to improve standards. With particular focus on science, at the political level, the 1989 *Discipline Review of Teacher Education in Mathematics and Science* (Speedy et al., 1989) used the term crisis to bring the standard of science teaching in Australia into focus: "the great majority of Australian primary school children are being denied access to learning in the important area of human knowledge and endeavour, and are thus carrying a great handicap when they confront this subject in secondary education" (p. 80). There were demands for increased student achievement in science to support Australian development (Willis, 1990); calls for Australia to be more economically competitive through better science education (Goodrum, 1993); the need for science education to strengthen the vocational preparation of students (Commonwealth of Australia, 1995); and a reaffirmation of the importance of science at primary school (Australian Science, Technology and Engineering Council, 1997). Pressure in Western Australia also came after

publication of a Monitoring Standards in Education report (EDWA, 1994a; see also Hickey & Brady, 1994) that assessed the science achievement of 8,000 students in Western Australian government schools. This report concluded that students at the end of Year 10 were typically achieving at a lower level in science than was expected from the *National Statement on Science for Australian Schools* (Curriculum Corporation, 1993) and *Science: A Curriculum Profile for Australian Schools* (Curriculum Corporation, 1994).

Whether the adoption of outcomes-focused education will be successful in raising students' science knowledge may be determined not only by the students, but by teachers' science knowledge as well. Work by Shulman (1986, 1987, 1992) refocused attention on teachers' knowledge as a forgotten determiner of students' knowledge. Shulman (1986) saw competence in a subject as an essential prerequisite for teaching and described content knowledge as the "missing paradigm" (p. 6). His view was that teachers cannot teach effectively unless they understand the content (i.e., know what they teach). His concern was that the focus on what was then considered adequate and appropriate teacher education had under-emphasised content knowledge because too much attention was given to pedagogy that was not subject-specific (such as praise and wait time). Shulman positioned pedagogical content knowledge as the wellspring from which teachers draw their activities, questions and explanations.

The distinctions made by Shulman between content knowledge (knowledge about what you teach) and pedagogical content knowledge (specific knowledge about how to teach it) are used as the framework for this research because they are the two sides to the coin of good practice in teaching.

## 2.2 Science Content Knowledge

Science knowledge is held by individuals and collectively by humanity. For school teachers it is their knowledge of the content of science they teach: concepts, principles, propositions and theories. It may be presented through textbooks, teachers' guides, curricula or student work books, or through the public media or internet. It can be organised in different ways: as outcomes of concepts and skills (e.g., the *Curriculum Framework*); subjects (e.g., chemistry); topics (e.g., birds);

within a career base (e.g., horticulture); integrated with other subjects (e.g., environmental studies); or as cross-curricular (e.g., study the social, scientific, economic and artistic aspects of desert life).

Educators use a variety of terms to refer to science content knowledge (Fensham, Gunstone, & White, 1994) and describe various properties of content such as abstraction, complexity, alternative models, links between concepts and emotive power (White, 1994). Content may refer only to the factual knowledge of the traditional disciplines of science (e.g., the content of chemistry in Schibeci & Hickey, 1997b) to distinguish it from the processes of science (e.g., classification, observation and experimentation). Developers of the *Curriculum Framework* maintained this tradition of separating working in a scientific manner from understanding concepts, but directed that "learning experiences should link the Working Scientifically outcomes with the development of scientific conceptual understandings and the process outcomes in other learning areas" (p. 222). Other educators, such as Black and Harlen (1993), preferred not to separate process skills from concepts, reasoning that students use and modify their concepts through their involvement in practical science. In the broadest sense, Cochran, DeRuiter, and King (1993) described teachers' science subject knowledge as "dynamic", encompassing "pedagogy, subject matter content, student characteristics, and the environmental context of learning" (p. 266).

In the context of the task for this research—lighting and burning a candle—science content knowledge will be used in this broad sense to include knowledge of science concepts (e.g., what teachers know about the behaviour of matter and its links to energy transformations through concepts of heat, energy, friction combustion, and changes of state) and knowledge of skills of the discipline (e.g., observation, measurement, inference) and the ability to use both to interact with their students.

Science concepts form an important part of science content knowledge. T. Russell (1988, p. 108) explained a science concept as a general idea that can be explored in a variety of contexts, for example the concept of hibernation which may be explored by reference to mammals or invertebrates. Black and Harlen (1993) in related work suggested that science concepts can be simple ideas like a

chair, more complex like the idea of force, a sentence such as "Light travels in straight lines." (p. 210), and "abstractions which are generated and changed through encounter with the specific content and contexts in which they are embedded" (p. 218).

Concepts are constructed by people and interlinked and reformulated by each individual. Work by Novak, Gowin, and Johansen (1983) captured this individuality of concepts as idiosyncratic, and how concepts are not held as separate entities, but form linkages as propositions. Novak (1989) defined a concept as "a *perceived regularity* in events or objects designated by a label (usually a word). Two or more concepts linked together semantically form statements about how some piece of world appears or behaves" (p. 227, author's emphasis).

Fensham (1980), in a discussion of the aims of science education within a constructivist view of learning, suggested that students learn to define concepts, appreciate how they are over-simplifications, identify concepts associated with natural phenomena and technology, and use them through exemplification to a variety of examples which would help them apply the concept broadly and also see its limitations. He saw concepts as useful and convenient because of their representative power, and the way they group substances or events which have common properties.

### *2.2.1 Appropriate Science Knowledge for Teachers*

Knowing the content of the science—especially the concepts—is appropriate for teachers so they can support students' learning. Some conceptual knowledge is fundamental for both students and teachers as it is the basis for a wide range of applications. Nussbaum (1985) argued that knowledge of the nature of matter is critical: "In modern science, the fundamental notion that all matter is particulate and not continuous is of prime importance for all causal explanations of any kind of change in matter" (p. 124). Concepts about the behaviour of molecules have been successfully taught to elementary students (M. Lloyd, 1996) using role-playing activities. Kruger and Summers (1989) appealed for urgent consideration to be given in the UK to teachers' science knowledge, and argued that it is appropriate

for teachers to have a sound grasp of the particulate theory of matter even if they teach young children:

> It is difficult to see how children can correctly be led along the experiential path leading to understanding of changes in materials and the associated role of energy unless the teacher guiding them has some deeper understanding of the processes involved. Moreover, how else can a teacher achieve this more profound understanding of the behaviour of materials other than in terms of a molecular model? (p. 26)

What else should teachers know? Definitions of what constitutes appropriate or essential, content and pedagogical science knowledge for teachers vary in response to the beliefs of curriculum developers, political pressure from education systems, societal pressures and teachers themselves. Different groups define school science in their own ways (e.g., Cross & Price, 1992; Fensham, 1995; Galbally, 1989; J. D. McInerney, 1996). Teachers need to provide a culturally appropriate science curriculum for Indigenous students, for example, to compartmentalise Indigenous and Western views of science such as the causes of craters and of rain (Linkson, 1999; see also Baker, 1996). They need to respond to environmental issues, such as renewable energy (Qualter, 1995) and involve students in appropriate action to develop appropriate values (e.g., Donnelly & Thiele, 1996; Worley, 1995).

Schubert (1986), in a study of curriculum, presented eight criteria used for selection of content, and while not specifically in science, the diversity of interest groups and pressures described makes it clear how difficult it can be for teachers to decide what they need to know in order to manage science education in their classes. The groups Schubert described may push for science content for society's needs to equip students to enter the workforce, or allow the content to be determined by political pressure perhaps to foster a democratic, cooperative orientation to society. Other groups may select content to develop in students a deep or intuitive understanding of the discipline, or because its considered useful to the learner. Content may be determined by the textbook, by the learners themselves deciding what they wish to learn, or it may be due to historical precedent where the

argument is that content such as biological digestion or chemical reactions has always been taught, therefore it must be worthwhile.

Within Western Australia, the *Curriculum Framework* reflected a similar variety of interest groups. Examples of topics in the science learning area are linked to outcomes, not students' ages, and are appropriate to students' diverse interests and locations. They include making models to explain the structure of matter, understanding the significance of change in an ecosystem, looking at the problems in establishing a crocodile farm, establishing a data base on local gastropods, looking at safety in storing chemicals, understanding the effects of exercise on our own biology, finding out why chert is better than sandstone to make tools, having a sense of the history of science, and ensuring that measurements are accurate, sufficient and relevant. This diversity of topics, each with its own content knowledge, has made the boundaries about what is appropriate teacher science knowledge hard to define.

Pressures from interest groups and a rich, diverse curriculum have contributed to making science teaching today more complex than it was for most of this century, especially in primary education, where up to the 1970s nature study was virtually all that was required in terms of teachers' knowledge (Goodrum, 1993). Similarly, a review of primary science education by the Australian Education Council in 1990 reported that science was given a low priority in primary schools and had a simple curriculum structure of few topics.

For teachers who did not study much science at high school or who have not kept up their own science education to cope with the science content signalled as appropriate in the *Curriculum Framework*, such a flexible curriculum places a conceptual burden on them to update their own content knowledge so it will be readily accessible for the myriad directions an outcomes-focused and conceptual change approach demands. In this environment of flexibility, a teacher's role is no longer to deliver a prescribed content but to respond to the influences of students' interests and abilities and to rely largely on his or her own decisions about science content. This places considerable pressure on teachers' own science knowledge: for teachers who have a strong science knowledge this type of curriculum offers

freedom and individuality, but for those unsure of their science it appears more characteristically as ill-defined and a planning nightmare.

It must also be accepted that primary teachers have less opportunity to become familiar with science terms and concepts than secondary science teachers, since they typically teach science for only one hour a week or less (Adams, Doig, & Rosier, 1991; EDWA, 1994c; T. Russell, 1988) and have non-science subjects to teach concurrently. Few primary teachers have a degree in science and typically study pedagogy rather than science content during their initial teacher training.

In recognition of the difficulty primary teachers have with planning appropriate science programs (Kinnear, 1995) the *Primary Investigations* curriculum provided direction and thus removed the burden of choice for unconfident teachers. It was for this reason that *Primary Investigations* has been so successful in Western Australian schools, with over half of the government primary schools implementing the curriculum (EDWA, 1997a). It specified the concepts, gave detailed instructions for weekly activity based lessons, included appropriate questions to ask and provided sample student answers in detailed teachers' guides. Released in 1994, it was developed to support the *National Statement on Science for Australian Schools* (Curriculum Corporation, 1993) and it is consistent with the *Curriculum Framework* and *Outcomes and Standards Framework* as it is outcomes-focused and developmental, and takes a constructivist approach to science learning and teaching. Conceptual development is managed through revisiting concepts over seven years, with each unit's lessons evolving through initial engagement with the concept, exploration of its effects, and applying the concept to other phenomena by explaining and elaborating. The last lesson of each unit serves an as evaluation activity to support teachers to evaluate students' development with the concepts of that unit.

Powerful concepts such as systems, order, change, patterns, properties, evidence, interdependence, diversity, balance and energy are linked to skills of observation, organisation, measurement, prediction, analysis, investigation and decision-making, within an emphasis on cooperative group work through activity based lessons with reduced dependency on the teacher—all new for many primary teachers. In clear recognition of the increased load on teachers' own conceptual

knowledge, many of the units in *Primary Investigations* contain background content for teachers to provide the conceptual understandings, principles and science paradigms that extensive trialing of the materials indicated were needed for teachers to successfully give the lessons. In the case of Book 6, which has a focus on energy, this background explains kinetic, potential, elastic and stored energy (in Western Australia these concepts were traditionally reserved for secondary science). *Primary Investigations* managed a controlled series of revisits of key concepts such as change, diversity, interdependence and energy. While such a set progression has made planning easier and defined what content knowledge is required to support student learning, this may not necessarily be the most appropriate pedagogy to respond to the individual needs of students as endorsed by the *Curriculum Framework*.

Another aspect of science curriculum increasing the demands on teachers' science knowledge is the requirement that knowing the ever widening content must be supplemented with increasingly sophisticated knowledge about the discourse of science. For Grossman, Wilson, and Shulman (1989), subject knowledge was not just a collection of facts, but had three parts: content as the facts and the concepts; syntactic knowledge as the methods of the discipline; and substantive knowledge referred to conceptual models and paradigms used to explain data. Similarly, Aubrey (1994) described knowing about a subject as "knowing about the fundamental activities and discourse of a particular discipline, showing an awareness of competing perspectives and central ideas within this field, as well as understanding how seemingly incompatible views can be justified and validated" (p. 5). Within the Western Australian science documents—the outcomes of the *Curriculum Framework* and their equivalent in the *Outcomes and Standards Framework*—both the substantive (meaning the content) and syntactic (the discipline of science which includes science methodology, such as issues of validity, reliability, researcher bias, controlled and uncontrolled variables) knowledge are represented, and extended by the inclusion of knowledge of science communication, of social uses of science and the impact of science on daily life.

So, for Western Australian teachers, what constitutes content knowledge for their students and therefore for themselves is more indeterminate than definitive.

Science content—theories, principles, concepts, science as a discipline—depends on and is determined by what teachers personally see as needed by their students, the influences of students' interests, the currents in society and the views of curriculum developers. The demands on science teachers are complex, fluid and comprehensive, and ultimately challenging, especially for primary teachers for whom science is just one of many subjects competing for their attention and expertise.

### *2.2.2 The Consequences of Inadequate Science Content Knowledge*

Teachers' content knowledge is not always seen as relevant to student success. From her study of mathematics, Willis (1989) suggested that student performance was the result of a collective effect of a variety of factors, such as parents' careers, student gender, knowledge and attitude, and the media. But one of the factors not investigated was teachers' knowledge in mathematics. Shulman's (1986) call for a re-emphasis on teachers' content knowledge has stimulated studies in science education on the effects of inadequate science knowledge. Teachers' science content knowledge became an issue when it was appreciated that it may be inhibiting students' development by confusing students or providing misinformation, and when it is unable to support students to achieve at their conceptual level, irrespective of their chronological age.

During the 1980s, when reform in science teaching in the UK resulted in a move from a process to content orientation (Kruger & Summers, 1989; Kruger, Palacio, & Summers, 1992) and conceptual change (Osborne, 1982), there was concern about effects on student learning if teachers' science content knowledge was inadequate. McDiarmid, Ball, and Anderson (1989) stressed the need for teachers to have sound understandings of subject matter. Kruger (1990) stated:

> The preconceptions which children bring to science lessons are known to cause difficulties for the secondary teachers and the teaching of conceptual science to primary children could compound this problem if the science conceptions of primary teachers themselves are at variance with those currently accepted by scientists. (p. 86)

One clear view in the UK, was that too much science content knowledge was being asked of teachers. Osborne and Simon (1996) stated that for science "the demands of the National Curriculum are simply beyond the capabilities and knowledge of the average primary teacher" (p. 139) and suggested that teachers only teach in aspects in which they are confident, and less where their confidence is low. They advocated a solution in which the curriculum was a less prescriptive framework which reduced the content so it "would be more appropriate to the current skills and resources of existing teachers" (p. 140). Aubrey's (1994) work on the knowledge teachers have about specific subjects suggested that (at least for electricity): "there is some evidence to suggest that teacher's understanding of subjects they teach reveals gaps and misconceptions like those of their pupils" (p. 11). She suggested that teachers would of necessity turn to alternative sources of information:

> to expect teachers to have adequate subject knowledge across all the nine subjects of the National Curriculum will be neither fair nor realistic. Suffice it to say that where knowledge is limited the teacher may rely more on scheme work, text books and in occupying pupils with individual work. (p. 5)

Others have demonstrated that often teachers do not have adequate science content knowledge. Carré and Ovens (1994) noted situations when students outperformed the teacher who was unable to respond at the level of sophistication of the student. Their research suggested the teachers' uncertainty about the "subject content knowledge" was implicated so that "each child's progression in understanding ... may have been hampered" (p. 62). They gave examples of how "teacher responses can enhance a child's learning, redirect it or even negate it" (p. 6). Enhancement occurred when a teacher used an analogy of a waterproof jacket to explain the waterproofing effect of a duck's feathers, or redirected a student's comment by suggesting another avenue of exploration for the child to find out an answer to a question. Another anecdote showed when a teacher's response had a negative effect on learning: a teacher said to students working with electrical

circuits that they should not focus on why things happened but just state what happened.

This is not a new problem, and is not confined to primary teachers. Work by Happs in 1987 provided an example of how Western Australian secondary teachers taught misconceptions when operating out of their content knowledge depth. Dealing with the topic of rocks, one teacher did not clarify the distinction between rocks and minerals, referred to Moh's Scale as measuring the hardness of rocks not minerals, and consolidated the intuitive view (i.e., not a scientifically correct view) that rocks can be usefully sorted by their colour and that pumice was formed when lava formed holes to allow steam to escape. In another example students (and apparently the teacher) retained incorrect intuitive views that oil was heavier and denser than water. Happs reported that the teacher made incorrect statements and did not challenge students' views: "the teacher appeared to be oblivious to the disparity between the learner's intuitive perspective and the practical observations" (p. 73) of oil on top of water.

In Australia, the problem was recognised in primary teacher education students. Symington and Mackay's (1991) survey of primary teacher educators' reaction to the *Discipline Review of Teacher Education in Mathematics and Science* (Speedy et al., 1989) reported "very strong support of the inclusion of studies designed to improve the science knowledge and skills of primary teacher education students" (p. 310). Also in response to this government review, and its view of a problem of confidence in Australian primary science teachers, research by Appleton (1992) concluded that "self-confidence should not be confused with competence" (p. 17). He suggested that any subject knowledge included in pre-service courses must be carefully structured to give students an increased positive sense of themselves as science teachers, not to confirm their negative self-view. Skamp (1991) also reflected that pre-service and practising teachers' confidence about subject knowledge may be misplaced, as they may hold misconceptions. In Western Australia, a study by Pears and Skinner (1994) which compared the science knowledge of Year 7 students and pre-service teachers and concluded that "current Western Australian primary teachers do not possess the required levels of cognition nor the conceptual grasp of science content to teach science with any

degree of competence" (p. 75). They reported that there was usually "little difference between the abilities of future teachers and the primary students they will be teaching" (p. 75) and called for better teacher training courses and professional development for practising teachers.

In the UK, a response to the awareness that teachers' science understanding was insufficient to support student progress in the National Attainment Tasks (part of the National Curriculum) was through an extensive professional development project funded by the UK Department of Education and Science (Tresman & Fox, 1994). These courses did not provide handy "tips for teachers" but asked teachers to significantly upgrade their "personal proficiency in and knowledge about science" (Tresman & Fox, 1994, p. 234; see also Summers, 1992). In Western Australia too, recognition of, and response to, this problem has been through extensive support for professional development in content (EDWA, 1997a, 1997b; Hickey, 1995a, 1995b; Schibeci & Hickey, 1996a, 1996b, 1997a, 1997b; Venville et al. 1995) and working scientifically (Hackling & Fairbrother, 1996) and currently continues (CC, 1998c).

### *2.2.3 Adequate and Appropriate Science Knowledge*

So what science knowledge is appropriate for a teacher? When is a teacher's science content knowledge adequate? Drawing from the discussion so far, a teachers' science content knowledge to support student learning, should:

1. respond appropriately to the level of sophistication of students' conceptual development;
2. be scientifically accurate and not contribute to misconceptions in students;
3. be adequate to support individual student's learning as indicated by an outcomes-focused education and a conceptual change approach;
4. reflect the varied views of curriculum developers (e.g., a science curriculum for utility, social justice or personal satisfaction of the learner) as they define content; and
5. include a knowledge of both science content (factual or substantive knowledge) and the nature of science (syntactic knowledge) and reflect uncertainty when their knowledge is inadequate for students' needs.

## 2.3 Pedagogical Content Knowledge in Science

Shulman (1986) used the term pedagogical knowledge to refer to teachers' thinking about how to "manage their classrooms, organize activities, allocate time and turns, structure assignments, ascribe praise and blame, formulate the level of their questions, plan lessons, and judge general student understanding" (p. 8). His paper was disparaging towards this type of generic pedagogical knowledge when its application was insufficient for effective teaching because it was devoid of content. He argued that when allied with content knowledge, pedagogical knowledge was enriched. Shulman described the specific knowledge teachers have about teaching and how students learn the content of subjects as pedagogical content knowledge:

> the ways of representing and formulating the subject that make it comprehensible to others ... and understanding of what makes the learning of specific topics easy or difficult: the conceptions and preconceptions that students of different ages and backgrounds bring with them to the learning of those more frequently taught topics and lessons. (p. 9)

How do teachers develop pedagogical content knowledge? This can be through formal professional development for a particular subject or age of students (e.g., special primary or early childhood conferences) and through curriculum documents. For example, the *Curriculum Framework* reinterpreted its generic pedagogical principles for each learning area, and for science made suggestions such as "science activities and investigations should be undertaken in contexts that have meaning for students, using issues that are relevant to their lives and local environments" (p. 240). Pedagogical content knowledge is also developed through research, for example, the idea of relevancy in science curriculum was studied by Rennie and Parker (1996) who found setting physics problems in real-life contexts improved students' interest and performance. Reflective practice (Schon, 1987) about classroom experiences also supports pedagogical content knowledge. For example, Arena (1996) argued that to catch a student's attention by a personally relevant investigation was an effective way of teaching process skills. Dale (1998)

reported classroom based observations with similar effects for the value of student choice in investigations:

> From my own experience, students find investigations that they have chosen for themselves to be far more meaningful and far more self-motivating than any selected by the teacher. (p. 9)

### *2.3.1 Orientations to Science Teaching*

Pedagogical content knowledge in science means the specific knowledge teachers hold about teaching science and what they regard as appropriate for students to learn as school science. It is their professional knowledge and forms part of classroom decisions.

Part of the complexity in making such decisions is the different orientations that curriculum developers or colleagues advocate and place on the bargaining table of good practice. The decisions teachers make about what to teach (content) and how to teach it (pedagogy) are based on their beliefs about what is relevant and important about content (e.g., should my students understand energy?) and pedagogy (e.g., should I just tell them what energy is or should I structure a learning activity so they can develop their own understanding?). Such beliefs orient teachers' practice in different ways. For example, case studies, by T. Russell and Munby (1989), provided a comparison of how two teachers' understandings of the nature of science translated into their professional knowledge as constructivist and transmission orientations.

Orientations towards science teaching also include discovery, processes, didactic or content mastery, and conceptual change (D. C. Smith & Neale, 1991). Discovery is essentially about motivating students and getting them to try things, and the processes orientation has a focus on science method. The content focus uses a didactic approach to present science content clearly so that students understand it. Teachers with a conceptual change orientation focus on identifying and challenging students' varied ideas. Similar categories of approach, in addition to process and discovery, have been suggested, such as interactive and

transmission (Fleer, 1995), expository (Symington & Kirkwood, 1995) and integrated (Brass & Duke, 1994).

Whether teachers find such choice confusing or enriching is a moot point. While the aim of teachers holding each orientation is to help students learn, what is different is that each has its own pedagogy about what is best practice in science. The recurring issue is that pedagogical techniques of each orientation flow on from the teachers' own science content knowledge. For example, Hargreaves (1988) saw transmission teaching as a fall-back for teachers who are working outside the security of their specialist area. For teachers holding a content mastery orientation, their own understanding provides the basis for clear explanations, coupled with a regime of frequent testing of students' understanding. The provision of interesting activities within the discovery approach requires minimal teacher input and makes less direct demands on teachers' science content knowledge. In the processes approach, the teachers' own knowledge of the discourse of science may affect how well they explain terms such as variable, hypothesis and selection of a control. In a conceptual change orientation, teachers' content knowledge helps provide appropriate direction to a student to replace misconceptions with more scientifically correct views, which may occur in group discussions about unexpected or inconclusive events.

### *2.3.2 A Conceptual Change Orientation*

The conceptual change orientation towards science teaching has received significant recent support from science education research and is viewed as good practice. Teaching for conceptual change is one of a number of teaching approaches linked to a constructivist view of learning. Its basis is that knowledge is actively built by each individual, not merely received. The changes may be pronounced and fundamental, or be better described as gradual growth as new knowledge is added to existing frameworks (Duit & Treagust, 1995). The impact of this approach on science pedagogy has been to reduce the emphasis on the transmission mode and to increase the importance of, and time allocated to, students discussing, comparing, and trying out their own ideas, rather than just listening to the teacher.

Carré and Ovens (1994, p. 39) credit Wittrock in 1974 with first describing a generative approach which proposes that teachers assist students to generate new

meanings and concepts which are personally relevant and useful. Proponents of conceptual change (Cosgrove & Osborne, 1985; Osborne & Wittrock, 1983, 1985; Posner, Strike, Hewson, & Gertzog, 1982) have argued strongly for the teacher to determine what concepts students already have and use these as the basis to plan appropriate activities to promote conceptual change through challenge and application in problem solving. As Ausubel (1968) suggested, start from the students' ideas. This view is shared by Osborne and Freyberg (1985) who saw the teachers' job as to begin from the theories young children have already formed and "devise situations which sharpen up their [children's] ability to test those theories, which help them to assemble systematically the facts of the case before jumping to conclusions, and which highlight the consistencies and inconsistencies in their own explanations" (p. 150). Gunstone (1995) qualified good science learning for the student as

> learning in which the student undertakes the tasks of: integrating appropriately what is being learned with what he or she already knows and believes; extending what is being learned into appropriate different contexts; monitoring the learning, including progress through tasks and towards known purposes and goals, which he or she is undertaking. (p. 11)

Promotion of the student as an active learner is part of the lexicon for teachers' pedagogical content knowledge in science if they adopt a conceptual change orientation. To emphasise the value for teachers of ideas that students have that may not be scientifically correct views, a variety of terms have been used: children's science (Osborne & Freyberg, 1985), "hybridized constructions" (T. Russell, 1993, p. 79), "schemes" (Bliss & Ogborn, 1993, p. 120), vernacular science (Ryder, 1993), "personal constructions" (Driver, Squires, Rushworth, & Wood-Robinson, 1994, p. 1), conceptual models about science phenomena (Sprod & Jones, 1996), with alternative conceptions (e.g., Taylor & Coll, 1997) emerging as a popular term. Solomon's (1993b) social theory of the construction of science knowledge discussed these ideas as models which may be at odds with scientific

knowledge, for example, children's models of where we get energy and how we lose it.

The common element in all these terms that has influenced science pedagogy is a reappraisal of the value given to students' ideas. Accepting and appreciating the value of misconceptions is one of the most powerful pedagogic strategies of the conceptual change approach. Rather than just plain wrong or counter to accepted scientific views, these ideas are seen as informal, naive or intuitive ideas. Examples of misconceptions are given by Carré and Ovens (1994), such as "a worm is an insect" and "all rocks are grey and hard", as well as more sophisticated misconceptions such as "gravity is strongly associated with the presence of air" or "forces are often thought of as being something inside a moving body, acting in the direction of motion" (p. 38).

*Strategies Within a Conceptual Change Orientation*

A review by E. L. Smith, Blakeslee, and Anderson (1993; see also Hewson et al. 1999) reported on strategies that promote conceptual change in students. Smith et al. explained that students need to be encouraged to be dissatisfied with their present understanding "through becoming aware of their own ideas, asking for explanations of familiar and discrepant events, and debating alternative conceptions" (p. 113). They specified the teachers' role as "eliciting preconceptions, asking for explanations, pointing out discrepancies or inadequacies, and encouraging debate and deliberation" (p. 113). Other strategies reviewed included conceptual conflict and cognitive dissonance, ideational confrontation (which had students present their pre-instruction view of events), hearing the teacher's scientific explanation which is followed by a comparison of different views, using laboratory activities that are not consistent with students' initial conceptions, using class discussion to resolve discrepancies, and arranging multiple opportunities for students to apply and use their concepts in different contexts.

Carré and Ovens (1994) listed appropriate activities such as read and find information, listen to an explanation, follow written instructions, design and make, problem solve, prove an idea, do a survey, complete part of or a whole investigation. They also suggested teaching strategies that support the

constructivist approach, particularly "helping children to articulate openly what they think and to challenge their own misconceptions" (p. 39; see also Carré & Howitt, 1983). Carré and Ovens were also very clear on the need for talk in assessment, "the more a teacher tries to tap instances of a child's understanding, in terms of speaking and recording, the more complete the picture of assessment" (p. 72). Also recognising this, Wilson and McMeniman (1992) highlighted the role of the teacher in mediating science learning, by helping students negotiate shared meanings and understandings, and metacognition: "if students are aware of what they know, they are able to change it" (p. 14).

Teachers should elicit students' misconceptions and focus on explanations in open-ended and closed discussions, practice and application (Roth, Anderson, & Smith, 1987). One of the problems for teachers adopting the conceptual change orientation is that students' misconceptions may not be applied reliably, as there is evidence of students using conflicting models in different contexts (Solomon, 1993a). These misconceptions often prove resistant to change and persistent even for older students, as reported by Tasker and Osborne (1985) in their work on mental models of electricity. They demonstrated how students of diverse ages can hold the same model or viewpoint and provided an example of a first-year University student who defended an incorrect idea (that in a circuit the direction of flow is circular, but there is less current returning), and another student who rejected the (correct) view (that the direction of current is one way without a reduction in current in either wire) as impossible.

The endorsement by the *Curriculum Framework* of a conceptual change approach as good practice promotes this view that students' informal ideas are seen as valuable alternatives that teachers can use productively for planning their teaching strategies. Teachers who hold that science is factual transmission of fixed truths (the didactic or mastery orientation) may find a teaching approach in which they are asked to actively promote uncertainty and discussion and even value incorrect ideas (conceptual change) represents a radical departure from their existing view of the value of students' misconceptions, as described in the *Curriculum Framework*:

> The development of science concepts can be a slow process. Concepts need to be continually revised, reconsidered, and reworked. Students [*sic*] intellectual progress will be supported when the diversity of their views and their experiences is recognised and valued. Because of this, it is important the learning environments are planned and structured so that all students feel comfortable with any uncertainties they may have about their scientific understandings. Students may be surprised (but should not feel threatened) to find that someone disagrees with their interpretations of a scientific situation. Encouraging students to use their own ideas is an excellent starting point for investigations. (p. 241)

Part of teachers' pedagogical content knowledge in a conceptual change orientation is the different ways that science content can be represented, for example, hands-on activities, concept maps, the predict-observe-explain strategy, analogies and simplifications. Many of these strategies value the difference between students' ideas and those of more scientifically correct views.

Representing content through hands-on or practical work is widely recognised as good pedagogy in science, as such activities assist students to use concrete materials to visualise abstract ideas. For example, applying physics formulae to rocketry (McClennan, 1997; Stubbs, 1996), using a planisphere to locate bodies in the night sky (Lowe, 1997), or using plasticene to model the gut (Paterson, 1996). Concept maps also help students visualise relationships between ideas and can be used to track changes in understandings, for example, students make a concept map of their ideas at the start of a unit, and add to these as their ideas change over the course of study (Elliot, 1995; Jesson, 1995; D. Lloyd & Wallace, 1996; Ruiz-Primo & Shavelson, 1996; Nannestad, 1996; Novak, 1989, 1996; Vance & Miller, 1995). The predict-observe-explain strategy, for example where a tin of water is suspended over a candle, students are asked to draw a graph of the temperature of the water (predict), record the temperature over time (observe) and gather support or not for their prediction (explain), was described by Champagne, Klopfer, and Anderson (1980).

Analogies are another effective way for teachers to represent abstract content and stimulate conceptual change in students (Treagust, Harrison, Venville, & Dagher, 1996; Sumner, 1997). T. Russell (1993) suggested that analogies are ways to represent ideas that are impossible to experience directly, because they are too small, as in particle theory, or too large, as the movement of stars, or can't be sensed, as in magnetism. The ability of multimedia, animated, analogical models to help students visualise the "abstract, unobservable, particulate basis of chemistry" was reported by Garnett, Hackling, and Oliver (1994, p. 25). Venville (1996), in a survey of genetics teachers in WA, described the variety of analogical models and activities used, for example, poppit beads for meiosis, and the twisted ladder for DNA.

While teachers' pedagogical content knowledge in science can support their attempts to represent content, inadequate science content knowledge can frustrate their attempts to foster student learning. For example, analogies as a pedagogical strategy, can have a detrimental effect (Duit, 1991), and can support inaccurate understanding by students or be "fundamentally flawed" (Harrison, 1993). A study by Treagust, Venville, and Harrison (1994) of Western Australian teachers found some had difficulty working with analogies because their own science content knowledge was inadequate, and that using analogies in this situation would compound the problem unless the teacher fully understood the concept. Venville (1993) described how an analogy is not productive when the teacher has not considered how familiar students are with its terms, such as describing a bird opening a shell by hitting it on a stone being like a blacksmith's anvil. Panizzon (1998) warned that analogical models to teach diffusion may actually be teaching convection, and suggested that students need to understand the difference between models that "illustrate but do not represent the concept" (p. 39) and discuss the difference with the teacher. Just using analogies is insufficient for a teacher's pedagogical content knowledge in science, as use would have to be coupled with recognition of how an analogy could be counterproductive (e.g., the ball and stick analogy of molecules is misleading because it shows the links as static and mechanical). This would have to be countered by using other analogies (e.g., to help students understand the role of electrical charges in the links).

Shulman (1986) spoke of teachers having "a veritable armamentarium" (p. 9) of pedagogical strategies at their disposal and he included teachers' pedagogical content knowledge as necessary to undo errors or misrepresentations in textbooks. As an example of the currency of his argument, the simplification of complex ideas presented in a primary students' book can foster misleading ideas that are potentially long-lasting. In *How Things Work: Heat* (Dunn, 1992), heat is treated as an entity: "Heat moves from one place to another, and always from a hotter place to a cooler one" (p. 6). The text implies that molecules themselves get hot: "Since hot molecules move more, they need more space" (p. 8) and that heat is somehow different from heat energy: "burning fuel in air—combustion—can either be used simply to produce heat, or to produce heat energy that can then do some other useful work, like driving an engine" (p. 12). Teachers rely on their science content knowledge to challenge such misrepresentations and modify the information that curriculum support materials pass on to students.

### *2.3.3 What Does a Conceptual Change Orientation Mean for Teachers?*

So what does a conceptual change orientation mean for teachers? A science pedagogy based on a conceptual change orientation emphasises the place of students' existing concepts, personal theories and explanations, and how these often personally satisfying constructions are long-lasting. This orientation means that teachers:

1. encourage students to develop their own ideas, not rely on the passive transmission of teachers' ideas;
2. view science knowledge as a construction of each individual which changes with exposure to new ideas and is fine-tuned as new information is added;
3. accept as valuable the misconceptions students develop, and view them as different or partially evolved ideas;
4. use misconceptions productively as the basis for supporting students to construct new understandings or scientifically correct views or use them as a signal that the student is not intellectually capable of understanding the scientifically correct view and so their view needs to be accepted for the time being; and
5. are aware of the importance of representing content through strategies such as analogies, concept maps and discussion.

The second and third research questions relate to the ideas of teachers' pedagogical content knowledge in science, knowledge of different orientations to teaching, awareness of misconceptions and ways of representing content. They focus on the judgements teachers make and the follow-up strategies they suggest which are both critical aspects of teachers' pedagogical content knowledge in science. A review of the literature specific to these two questions is undertaken in the following two sections.

## 2.4 Making Judgements About Students' Science Work

Teachers make judgements about students' science work at different times and for different reasons: during a lesson (e.g., recognising an idea is too difficult for a student); when planning (e.g., selecting a topic that will be of interest); when finding out what a student knows (e.g., discussing an experiment); or when planning future lessons (e.g., deciding what is the best follow-up activity for this student). Judgements can be summative (e.g., a student's work for a whole unit), or on-going (How well did the student perform today?). D. M. McInerney and McInerney (1997) suggested judgements can involve assessment (e.g., What does this student know?) and evaluation (e.g., How does this student compare to others? Is this student more or less advanced than the standard the teacher applies?). In von Glaserfeld's (1995) view, judgements are a critical aspect of a teacher's role: "The teacher must listen to the student, interpret what the student does and says, and try to build up a 'model' of the student's conceptual structures" (p. 15) and while acknowledging that this process is fallible, he saw it as necessary in order for the teacher to modify the student's "conceptual structures" (p. 15).

The adoption of the *Curriculum Framework* and the *Outcomes and Standards Framework* has refocused teachers' attention on identifying what students need to learn, what they are interested in learning, and what they are capable of understanding as they achieve the outcomes at their own level of conceptual sophistication. The judgements teachers make about students, and the means by which they gather information to make these judgements, are both under review.

Focusing on the outcomes that students achieve has placed a greater demand on teachers to make valid, reliable, appropriate and accurate judgements about

students' science development. By accepting the endorsement by the *Curriculum Framework* of a conceptual change orientation, teachers will need to respond to the diversity of students' conceptual development by flexibly programming for individuals. They will need to reduce their reliance on the ready-made program of a textbook approach based on students' age or year of schooling and base a significantly larger proportion of their science lessons on responding to students' understandings, and rely even more on their own science understandings when diagnosing students' progress and determining a level of development or achievement of an outcome.

### *2.4.1 Good Practice in Making Judgements*

A search of the literature results in a variety of methods that utilise ideas of conceptual change and which are advocated as good practice when making judgements about students' work. Each method provides information which helps teachers make judgements, and influences the form of judgement so that it is often couched in terms of levels of development.

Outcomes-focused education suggests that judgement of the type "a student's score of 50% based on a test" should be replaced, or at least supplemented, with more informative judgements, such as a description of what a student understands or can demonstrate in terms of the outcomes. For example, the *Primary Investigations* curriculum provided checklists for teachers to gauge students' achievement of learning outcomes.

The movement is away from traditional paper and pencil tests of the extent students can reproduce the enacted curriculum at the end of a unit of work, towards judgements made through "authentic assessment" (Willis & Kissane, 1995a, p. 32). This is where students demonstrate their achievement of the outcomes, through carrying out a project or presenting a portfolio, and the teacher makes judgements based on a variety of an individual student's work (Spady, 1994; Wagner, 1993). This portfolio strategy is recommended as supportive of conceptual change and involves students collecting evidence and managing their own assessment (Alessandrini, 1998; CC, in press; Forster & Masters, 1996; Gitomir & Duschl, 1995). Students assemble photographs, worksheets,

independent research and statements of goals, as evidence of their progress and discuss these with their teacher to renegotiate their learning goals.

Three other methods for teachers to gather information to make judgements about students' science understandings are particularly relevant to this research: interviews, work samples and tests to establish students' levels of understanding.

*Interviews.* Interviews are used in research and are also appropriate for classroom use. Osborne and Gilbert (1980a, 1980b) used an interview-about-events (using props) and interview-about-instances (line drawings on cards) to prompt the interviewee to explain what was happening. Bliss and Ogborn (1993) successfully used comics as props—rather than direct questions—to investigate children's ideas of motion as in the cartoon world normal rules "were suspended, so it was reasonable to ask if the normal rules apply, and in this manner elicit what they are" (p. 123). This technique involved probing a student's understandings using the comic as a stimulus, interpreting what the child said and then deriving a set of categories that traced the development of the concepts.

*Work samples.* Practical advice about interpretation of work samples as a judgement strategy for students' written work is provided by the Education Department of Western Australia (EDWA, 1997c). This book of work samples demonstrated what statements or judgements are seen as appropriate for a teacher to make, and promoted the use of levels as descriptors. Many of the examples suggest links to teachers' science knowledge. In the extract below (EDWA, 1997c), describing Kym's case, it is clear her teacher would need to understand energy forms and transfers (at least to Level 4) to make this judgement:

> This sample provides some evidence that Kym is achieving at level four in this strand. Her phrase "In wet weather the plasticene would be great but in dry conditions it wouldn't be the best because the plasticene would slow it down" is evidence that she understands *how the use of different materials and structures affects the transfer of energy and its use.* Kym compared the effect of plasticene recognising that there will be significantly different effects under wet and dry conditions. (p. 69, author's emphasis)

The use of levels—as in the extract about Kym—as a way for teachers to recognise a student's existing concepts and then decide what is feasible as conceptual change to the next level has support as good practice by state and national educational bodies (Curriculum Corporation, 1993a, 1993b; EDWA, 1997c; 1998). This approach requires teachers to recognise how students' ideas become increasingly sophisticated, for example, students at Level 1 use terms such as hot, cold or steam, which are appropriate for the early stages in development. Teachers working with students at Level 6 deal with concepts such as gaseous exchange, phase change of materials or specific heat, possibly with an abstract mathematical equation of heat transfer.

*Tests to describe a level of understanding.* Some tests provide more than just a score or the number correct because they can assist teachers recognise the changes in students' concepts from simple to sophisticated. They have been used in a 1986 national assessment in the Unites States of America, when Mullis and Jenkins (1988) reported in terms of student attainment of proficiency in five levels, for example, a description of an early level included "students at this level know some general scientific facts of the type that could be learned from everyday experiences" and at the highest level "students at this level can infer relationships and draw conclusions using detailed scientific knowledge" (p. 38).

References to facts and knowledge were downplayed in later developments of this style of test. Testing in Victoria in 1990, reported by Adams et al. (1991), asked students to respond by short answers to a series of questions about cartoon-style children in a variety of contexts (e.g., gardening, making lemonade or riding on a skateboard). By using response categories developed from Item Response Theory, students' views were valued in accord with their level of development towards a higher complexity or level of abstraction. For the structure of matter, Adams et al. (1991), described ideas at the least sophisticated level when responses "rely upon simple observations and definitions" and at a higher level, students "can identify key components but have little or no recognition of things or processes beyond the directly observable" (p. 13). More advanced students were aware that "changes occur which are not directly observable", then they begin to use the

"particulate model of matter" in their explanations, until at the top of the scale they "have a notion of chemical reactions" (p. 13).

Of particular relevance to this research, one of these Victorian tests was also used in Western Australia (see EDWA, 1994a) and made available for classroom teachers to use (1994b). It determined understanding of conservation of energy and chemical reactions in burning. A cartoon showed two children lighting a gas burner with a match, asking "Where does the wood go when the match burns?" and "Does a match have the same weight before and after it burns?" (Adams et al., 1991, p. 88). Levels of sophistication in the responses were described:

> Level 0
>
> Responses suggest that burning uses up the match. Some of the match has magically disappeared.
>
> Level 1
>
> Responses that tie only the substantial products, ash and gas, while ignoring heat and light. There is a plausible description of the weight of the products.
>
> Level 2
>
> Responses that indicate the products of burning are heat, light, gas and ash with a supporting description of the weight of the products. (p. 88)

Tests of this type continue to be developed. For example, Jones, Collis, Sprod, and Watson (1996) posited a "developmental map" (p. 56) based on Ikonic and Concrete Symbolic modes for children's explanations of how we see. Another test developed by Mann and Treagust (1998) allowed the teacher to determine the misconceptions of a whole class about breathing, gas exchange and respiration.

### *2.4.2 Teachers' Science Knowledge and Making Judgements*

The ultimate role of teachers' pedagogical content knowledge in science is to support students' science learning. When making judgements, teachers need to value students' ideas, and use these as the starting points for students' learning. Making judgements also involves teachers' science content knowledge, and the judgement process can be a "challenge to the teacher's own understanding in terms of determining the direction in which children's learning might proceed" (Qualter,

Schilling, & McGuigan, 1994, p. 24). Teachers' science knowledge becomes an issue when they have difficulty inferring a student's level of conceptual understanding whether interviews, work samples or other methods are used. Aubrey (1994) took the view that subject knowledge "does make a difference" and that more knowledgeable teachers are better teachers:

> Where subject knowledge is richer, deeper and better-integrated it is more likely that the teacher will be confident and more open to children's ideas, contributions, questions and comments. This is not to under-estimate the problems of identifying and responding in appropriate ways to the disparate understandings of a large class of pupils. A teacher skilful enough to recognize the scientific merit of an unexpected comment and to encourage the child to share the reasons for making such a response may experience more difficulty in dealing with an individual misconception without confusing the rest of the class. (p. 5)

Black and Harlen (1993) also emphasised that it is the teacher who must specify and justify if a concept is to be presented at a low or high level and that this required a high degree of understanding on the part of the teacher, especially when interpreting curriculum content in terms of conceptual change.

> It may or may not be sensible to propose that a concept such a 'energy' be studied at the primary stage, but it certainly cannot be sensible if no distinction is made between the primary study envisaged and the study of 'energy' that might be appropriate in a course for a physics honours degree. (p. 216)

On this basis, the *Curriculum Framework* which specified outcomes to be interpreted by teachers for all Western Australian students in Year 1 to Year 12, but did not differentiate between levels of development, places very high cognitive demands on teachers' science knowledge and pedagogical content knowledge in science to achieve this interpretation. By comparison, the *Outcomes and Standards*

*Framework* provided eight levels of sophistication for each outcome, but the element of interpretation was still significant.

In Australia, explicit demands are being made for teachers to use assessment frameworks that support a conceptual change and outcomes approach to science learning. D. M. McInerney and McInerney (1997) referred to the 1996 *National Competency Framework of Beginning Teaching* (a National Project on the Quality of Teaching and Learning by the Australian Teaching Council) and listed relevant aspects of teacher competence, including "justifies assessment processes and strategies in terms of planned student learning outcomes; uses assessment procedures consistent with content and process goals; values collaborative approaches with parents and others in assessing student progress" (p. 292).

In Western Australia, the *Curriculum Framework* defined assessment in science as "the collection and interpretation of information about students' science knowledge, understandings, skills and attitudes relating to the science outcomes" (p. 242). It required that "assessment practice should be explicit, comprehensive and fair. It should be a collaborative process between students and teachers, and have educational value by providing feedback on both learning and teaching" (p. 242). It specified that assessment was not just of facts but of understandings and skills, advocated that a variety of methods were used to assess students' work, and that teachers must develop students' own "skills for self-assessment ... so that students become more reflective and self-directed in their learning of science" (p. 242). In a list of principles the *Curriculum Framework* stated that

> Assessment should monitor learners' progress towards achieving the science learning outcomes. Students' conceptual understandings, abilities to investigate and to use and apply concepts develop over time, and assessment tasks should gradually increase in complexity to reflect students' progression in these areas. (p. 242)

Thus, for teachers, the notion of seeing how well a student is going in science is a multi-dimensional one that has to cater for a variety of purposes and audiences. Teachers are interpreting the science outcomes to gauge students' levels of

achievement and looking for areas that are proving problematic, in order to adjust future lessons or to seek alternative materials as the basis for planning. They are coping with the diversity of students' understandings and the demands on their own science content knowledge for increasing sophistication. They are engaging in on-going dialogue with students about progress and involving students in the process of making judgements about achievement of learning outcomes. They are reporting to parents about individual student's progress. They are making evaluations about the suitability of the curriculum they are using by examining the general progress of the whole class and are comparing the work of their own class with others in the school, or the system as a whole, through shared assessment tasks or tests. For the primary school teacher, each of these demands for accurate and appropriate judgements needs to be met for a wide range of subjects, science being only one of them, and for secondary teachers the list of demands is equally daunting.

Descriptions of what assessment is supposed to achieve are challenging to say the least. It is not surprising that in Western Australia, making judgements in line with the *Curriculum Framework* will be a high priority for teachers as it was in the UK. It is important in the Western Australian context to see how well teachers are coping with these demands, and to provide guidance for the type of professional development teachers need in order to support students' learning in the terms of the *Curriculum Framework*.

### *2.4.3 Difficulties in Making Accurate Judgements*

Implementing assessment in a conceptual change approach is by no means a simple task, even when working with young students. Clarke (1995) suggested that

> Assessment is concerned with understanding children's understanding. This involves knowing how best to question children, when to intervene, when to let children use invented methods, when to teach them something new, how to make the most of science starting points and how to help children become successful, confident scientists. (p. 165)

Other difficulties teachers are likely to have include identifying what ideas students have, coping with the diversity of concepts even for students of similar age, working with complex descriptions at many levels of a multitude of science concepts, coping with pressure to move through a set curriculum, allowing for the effects of language, and adopting an individual, rather than a whole class, focus.

*Identifying concepts.* Determining students' science knowledge by taking their existing concepts into account is a key tenet of a conceptual change orientation for science teaching. As such, Geelan (1997) asked teachers to "measure the students' existing conceptions" (p. 27). Simple though this sounds, it places significant demands on the teacher to access, identify and assign levels to the diversity of students' concepts in their class or classes. Osborne and Freyberg (1985) warned that teachers also need to be convinced that the "existing conceptions of children are important" and to understand that present ideas will influence future learning to a marked extent, as students' misconceptions will "inevitably be incorporated in future learning" (p. 150). Grossman et al. (1989) suggested that assessment of science understandings is difficult as people's understandings vary, they can only be inferred and are hard to verify. According to Aubrey (1994) this is partly because such knowledge is changeable, it cannot be directly observed and it is difficult to tell subject knowledge and beliefs apart.

*Divergent ages.* Another reason making judgements is complex is because students of divergent ages can have similar science concepts, and students of the same age can have concepts of widely differing sophistication. For example, extensive interview studies by Tasker and Osborne (1985) of students' ideas of electricity, indicated that their "ideas are often similar, despite considerable differences in age and learning experiences" (p. 21).

State wide testing in Victoria (Adams et al., 1991) for science understandings about burning a match showed some students at Year 5 had concepts equivalent to Year 9s for ideas about burning and gases; also a large proportion of Year 9s retained simple ideas about using up the wood. A similar spread of levels of achievement across ages in all science understandings was found by equivalent testing in Western Australia (EDWA, 1994a). Work by Jones et al. (1996) found similar results in their analysis of students' abilities in explanation, as very young

(i.e., 4- and 5-year-olds) and older (13 and 14 year-olds) used the same mode of explanation.

Few teachers would assume that all students in their class hold the same science understandings. A typical pedagogical coping strategy is having extension or remediation groups. In contrast, the individual focus of an outcomes-focused education represents a significant undertaking for teachers. The demand on teachers' content knowledge and pedagogical content knowledge is to recognise the level of the students' understandings, respond either at that level or above it in order to foster further increases in development. This is made increasingly difficult if students who are 4 or 14 years hold the same ideas.

*Complex level descriptions.* Black and Harlen (1993) argued that levels are useful for teachers (when selecting content and concepts) as a guide to the hierarchical structure of concepts and of the resulting cognitive demands on the learner of easier, or more difficult, concepts. To assist teachers respond in general terms rather than cope with the fine-grained detail for every one of hundreds of concepts, Black and Harlen (1993) described a "spectrum" of concepts from the "commonplace and readily acquired by all without formal education" to the "abstract principles that emerge from years of study of related phenomena" (p. 214). They described some general properties of changes at each level: "At the low level, there are to be found very many concepts, each with a limited range of categorization" which "act upon collections of instances, on common features and on links between phenomena which are unproblematic. At the high-level end are to be found few concepts, each with wide range of categorization" (p. 214-215). An example they provided compared low-level concepts about an overcoat (knowledge about coats, based on personal experience, linked to what coat to buy, using terms such as warm and cool) to high-level concepts about entropy (knowledge of energy in a variety of temperatures, categorised for all natural phenomena, involving mathematical formulae, and using terms such as entropy and coefficients). Black and Harlen provided four general criteria for primary teachers when selecting what concepts and at what level for their students: the concepts should help children understand everyday events and should relate to their experiences; children should use their process skills to generate and test concepts;

concepts should be at a level that children "can learn with understanding"; and provide a "foundation for later learning in science" (p. 217).

*Pressure to move through a curriculum.* Helping students make changes to their beliefs requires more than just providing them with new information in a directive approach. Happs (1987) provided an excellent description of the difficulty facing teachers of science, in this case secondary classes, particularly when engaging in appropriate probing to assess students' understanding, and why teachers so often move on when not all students have achieved the outcome:

> Teachers, operating with student numbers in excess of 30, have limited opportunities for assessing the individual student outcomes of practical activities ... A trained overseer, who can move around the classroom talking to individual students, is better placed for probing learning outcomes. Further more, when teachers are faced with the real need to cover copious quantities of curriculum content, they often ask for, and receive, the "required" response from those few students who can be relied upon to provide the answers sought. Thus, encouraged by their apparent success, teachers move on to the next activity or topic, unaware of the lack of understanding that might prevail within their student group. This case study epitomises such a problem which could be exacerbated when teachers themselves are not conversant with either the topic being taught or the difficulties students encounter with concepts such as "density". (p. 73)

*Language.* Judging students' work is also made complex because language is the medium for eliciting students' understandings and judging them. Students, when trying-out new terms, may use specialised language, but not fully appreciate its more scientific meaning, as when a young child blames gravity on something falling, or says he has run out of energy. Fensham et al. (1994) talked of conceptual change as involving students revising and adding new meanings for words, and learning which of a number of meanings is appropriate for a particular context. Teachers may use inappropriate language to teach and this can be a source of student' misconceptions. Stocklmayer, Zadnik, and Treagust (1993) in a study

of students' conceptions of electricity, implicated language difficulties in problems students had which hindered their learning, for example, the "fluid language so often associated with electricity was avoided where ever possible, with current 'travelling' rather than 'flowing' " (p. 74). Akatugba and Wallace (1998) found that "students tended to associate scientific terms or phrases with their everyday understanding of similar words or terms" (p. 64) and demonstrated how students generated their own misconceptions by relating science terms to equivalent terms in their everyday language, which affected future learning. Therefore, teachers need to be aware of the complexities of science language during instruction and when making judgements about students' understanding.

*Individualistic nature of understandings.* Best practice involves making judgements and this involves identifying and interpreting students' concepts. The individualistic nature of children's concepts makes the task extremely difficult. Bliss (1993), in a discussion of Kelly's Personal Construct Theory, suggested that Kelly's focus "on the individual and on the uniqueness of each person's construction of the work and the different construct systems each will develop" (p. 31) would prove too difficult for teachers. She argued that if each construction is as different as personalities, then this is too demanding, and suggested that Piaget's broader descriptions of "a general picture, domain by domain, of how a particular idea develops" (p. 31) would be more appropriate. Bliss correctly pointed out that this still leaves a problem: "the picture is not quite so simple because no two individuals' developments are alike in term of pace, varying due to factors such as maturation, learning, social influence, motivations, etc., even though the pattern of their development is the same" (p. 31).

It is not sufficient, as Solomon (1993a) stated, to just categorise common errors, but teachers must work out why is it that students hold these ideas, "the criterion is deliberately exploration of the students' misconceptions, and not just an analysis of incorrect performance" (p. 5). If decisions teachers take about the science material they present to their students are dependent more on the understanding of individual students, then the demand on teachers to interpret students' conceptual development must increase (McGarry, 1997). Using individual interviews, interpreting a student's level by work samples, and

discussing a student's development as shown by a portfolio are good techniques, but they are very time consuming, and primary teachers have many competing demands. On this basis, such techniques are unlikely to be used widely by teachers. Bliss and Ogborn (1993) demonstrated how difficult tracking conceptual change is, even for specialists, as it is intellectually very demanding, particularly since children change their ideas as a result of the questioning, as the authors found:

> Thomas (7 years), who previously said that running fast helps to give you more strength, added: 'then the end of the wood (drainpipe) pushed it (the door) open'. (So who has got the strength, the wood, the man, who ...?). Thomas replied immediately, 'the wood', then hesitates, 'er no, the man ...'. (p. 131)

### 2.5 Facilitating Students' Further Development

Follow-up activities facilitate further development in students' concepts. Deciding what activity and getting the timing right are decisions ideally based on teachers' judgements of the understandings displayed by each student.

Work by Rennie and Jarvis (1994) on students' learning in technology is relevant because it established follow-up as important as it offers students "opportunities to consider and clarify their own understanding" particularly as students needed many opportunities to "grasp ... complex ideas" (p. 31). Their work specified that the teacher "needs to decide which aspect, or aspects, are the most important to focus on after considering the children's responses to whichever technology task they have done" (p. 31). In the USA, the *National Science Education Standards* document described as important teachers' level of understanding because it will help them to determine what it is that students understand about science, and then to use this information to formulate activities that aid the development of sound scientific ideas by students (National Research Council, 1995).

Deciding what to notice to form the basis of future science work is difficult for teachers, as so many things are going on in the class at one time. Many researchers stress the value of discussion as a way to explore concepts, either individually, or

in a group situation (Cosgrove & Osborne, 1985; Bodner, Bauer, Lowrey, & Loudon, 1994). Hayton (1995) stressed the value of talk in science but found the practical demands of keeping track of the huge diversity of students' ideas a real problem. She used mind maps, note books and tape recorders to help keep track of the dozens of different ideas a group brought up during a half hour discussion of electricity and which served as the basis for planning. As a partial solution to this problem, Clarke (1995) suggested that teachers assess only what is "significant achievement" which will "affect all future science work" (p. 161) and suggested that for younger children this included setting up a fair test, making a prediction, cooperating in a group investigation, or expressing enjoyment of a lesson. Clarke stressed the link between assessment and follow-up, the need to share records with the children who should contribute their own ideas about progress, and the necessity of interacting with the child on a one-to-one basis as an on-going dialogue to comment specifically on achievement. She stated that this "points the teacher to future strategies of the development of that child" (p. 162).

Numerous suggestions for follow-up activities are found in curricula, professional development books and teachers' guides (although often they are used at other times, for example, to introduce a topic). For example, *Primary Investigations* built-in follow-up as each lesson revisited concepts in different contexts, and also included ideas for extension activities. These suggestions reflect the views of curriculum developers (Schubert, 1986) and teachers' orientations towards science teaching discussed earlier in this chapter. Follow-up activities may include telling information quickly and concisely (expository), students finding out for themselves (discovery), repeating an experiment to perfect a technique (process) or building on students' questions (interactive). Teachers may prefer to use follow-up activities such as a work sample, watch an educational video or rote learn formulae, which would reflect a mastery of content orientation (D. C. Smith & Neale, 1991).

Devising problem-solving situations so students can experiment and apply their ideas has been advocated as promoting and supporting conceptual change. "A conceptual change orientation stresses fundamental concepts, the evolution of ideas and opportunities provided for children to construct and reorganize their own

knowledge through problem solving and the consideration of alternative views" (Aubrey, 1994, p. 6). Discrepant events have also been shown to be an effective way of fostering conceptual change teaching (Appleton, 1997; see also conflict situation or cognitive dissonance in Driver & Oldham, 1986). Symington and Kirkwood (1995) suggested that curriculum documents usually adopt or endorse only one approach, whereas teachers are more effective and flexible if they hold a variety of teaching approaches.

Students' interests and an integrated approach must also play a part in follow-up. Aubrey (1994) made the point that science alone is not the only factor a teacher may take into consideration when planning: "taking account of young children's interests, preferred activities and out-of-school experiences as these relate to teaching subject matter is vitally important" (p. 5). Fleer (1995) suggested students' interests be incorporated into an integrated curriculum approach to revisit ideas in new contexts. Using students' interests in follow-up is not just recommended in primary schools, the National Board of Education, Employment and Training (1995), in a report about retaining students after compulsory schooling in Australia, recommended an integrated program of case-management for subject selection, with a focus on "improving the students' school experiences, rather than the quality of the information provided to students" (p. 34). In the case of science, this means that rather than follow-up being to help students achieve better understanding of content, follow-up would ask teachers to programme at the level of interest, need and capability of the individual to help each student select the most appropriate science content, dovetailed into career choices.

So what should teachers do to facilitate students' further development in science? Guidelines from the literature focus on the need for teachers

1. to see students' individual and alternative ideas as important;

2. to respond to their judgements in the form of appropriate follow-up activities that will foster conceptual change;

3. to take account of students' age, interests and language, as these all impact on the appropriateness of selected learning activities; and

4. to plan follow-up that matches students' conceptual levels.

## 2.6 Summary and Review of Research Questions

In this chapter, concern about the standards of student achievement in science has been raised within the context of increased demands on teachers to adopt and use constructivist approaches within outcomes-focused education. A refocus on Shulman's (1986) pedagogical content knowledge is timely in today's conceptual change environment. His views are relevant to science: the importance of knowing science content in order to teach it accurately, and having a strong understanding of what students will find problematic about the content are part of good pedagogy.

The science education literature examined has placed emphasis on the teacher's role in supporting the development of students' conceptual understandings through a conceptual change orientation. But, as has been described, there is concern that primary teachers are not sufficient in their own science knowledge to adequately serve the needs of their students. Also, a host of factors have been identified that make judging students' work complex, time-consuming and demanding.

This research is set in Western Australia where supporting students' conceptual change to ensure they achieve the stated science outcomes is one of the key concerns for Western Australia teachers adopting the *Curriculum Framework*. The demand for flexible curriculum planning, in response to the diverse conceptual development of students is particularly problematic for primary teachers for whom science is only one of many competing subjects. This has implications for the difference that teachers' science content knowledge may make—primary teachers may not have sufficient science content knowledge to teach effectively, particularly if students are outperforming teachers. It also has implications for teachers' pedagogical content knowledge in science, particularly from the point of view of making judgements about students' knowledge and skills, and the appropriateness of what follow-up activities are selected on the basis of teachers' perceptions of student development.

This relationship between teachers' science content knowledge and their ability to recognise what students already know in order to provide accurate, scientifically acceptable judgements is the key concern of this research: if teachers

do not have science concepts of the level of sophistication appropriate to their students, then what are the effects on their abilities to make accurate and appropriate judgements? Teacher-induced failure to support student progress is suggested in the literature with case studies and incidental descriptions, but a broader based study that looks for general trends and patterns within the curriculum change environment in Western Australia is needed.

It is important to investigate how confidently and competently decisions are made by practising science teachers, and determine the problems teachers have in managing an outcomes-focused education which asks them to help individual students to construct new, increasingly sophisticated science concepts. It is important to find answers to questions such as: In what ways does limited or extensive teacher science knowledge advantage the judgement process? When teachers' knowledge is insufficient, how is it counterproductive to the judgement process?

The major problem this research addresses is how teachers' science knowledge affects their ability to make accurate and appropriate judgements about students' work and to foster students' science development through appropriate follow-up. Two influences on teachers' ability to achieve this have been chosen as the focus: (a) teachers' science content knowledge (which is addressed through research question 1) in terms of what teachers know about a particular science task, and (b) their pedagogical content knowledge in science, addressed through what they know about making judgements about students' work (research question 2) and what follow-up they suggest (research question 3).

The first research question focuses on a detailed description of teachers' science content knowledge that relates to concepts of energy and changes in materials involved in lighting and burning a match and candle, in order to identify teachers' knowledge about this event. Findings will be used to help define what science content knowledge is adequate to meet the conceptual development needs of students.

Literature reviewed in this chapter has demonstrated concern about the adequacy of teachers' science knowledge to support student learning. Extensive professional development in science content knowledge in the UK and Western

Australia, and the inclusion of background information in national curricula such as *Primary Investigations* indicated action by system level education bodies to meet the concerns expressed by education researchers.

Ideas of what constitutes an adequate science literacy have changed over time, from a comparatively simple nature study to a marked broadening of the knowledge base with which teachers need to deal. In Western Australia, concepts traditionally in secondary science may now be included in primary science. The demand on teachers' science knowledge, needed to support the learning of students, has increased markedly, concurrent with the requirement (in order to teach science constructively) to rely less on a set curriculum determined by specialist authors.

While an outcomes-focused curriculum such as the *Curriculum Framework* does not specify activities such as "learn about candles" the concepts involved constitute a significant proportion of the science outcomes of the *Curriculum Framework*, the *Outcomes and Standards Framework* and *Primary Investigations*. Knowing about energy forms and transfers, and materials and changes in properties, is representative of what primary teachers in Western Australia are likely to need to support students' learning. These concepts are readily transferable to a large number of other contexts that involve heat, burning, energy transfers, friction, structure of matter, molecules, changes of state and forms of energy, and are important because these are concepts that will provide the base from which teachers can respond flexibly to students' interests as they access their own science knowledge.

The second research question, "How do teachers interpret, and what assessments do they make, about students' work?", is linked to the emphasis in the literature on the necessity for accurate and appropriate teacher judgements to support students' conceptual change. Making judgements is a complex event, because students' knowledge is variable. Their knowledge is hard to gauge because judgements are based on inferences and involve comparing students' work to a set of detailed descriptions of levels of achievement.

This research will analyse how teachers' knowledge of the physical and chemical processes involved in a candle influences what they respond to and

comment on when they judge students' science work. It will provide answers to concerns such as: What aspects of a student's work do teachers use as the basis when making decisions about the conceptual level of a student? Do teachers subscribe to the conceptual change approach to dealing with misconceptions or are they more likely to see things as wrong or right? What problems do teachers have when they make judgements about students' science work? Answers are relevant to formulating professional development focused on assisting teachers to meet the demands of a conceptual change orientation.

The third research question asks "What strategies do teachers suggest to support students' further learning?" Literature on good practice suggested following the students' interests, challenging misconceptions and identifying the level of development of the student. Setting follow-up strategies such as doing the exercises at the end of the textbook chapter are no longer regarded as good practice in the science education literature. Replacement activities include a focus on extending students' ideas into the next level, clarifying in a supportive way any confusions or misconceptions students have, helping them develop more scientifically correct views, helping them apply concepts in other contexts, leading students to more abstract representations of ideas through the teachers' own knowledge of particulate matter, making science personally relevant by following local and global issues and planning an investigative curriculum around students' interests to ensure they find science interesting and satisfying. This research will answer questions such as: Do teachers tend to suggest follow-up strategies that are identified as good practice in science education literature? How do teachers make decisions about appropriate pedagogical methods to support and enhance conceptual change in their students? If indeed the extent that the quality of the follow-up strategies suggested are a consequence of teachers' level of science education, it is important to describe this, because it has implications for the type of professional development teachers should receive.

# CHAPTER 3
# RESEARCH DESIGN

## 3.0 Introduction

The research study aims to identify how teachers' content knowledge in science affects their pedagogical decisions as they make judgements about students' science work and the extent to which these judgements, and the follow-up strategies suggested, are supportive of a conceptual change orientation to teaching science.

In this chapter the research design for the general research question, "What effects do teachers' science content knowledge and pedagogical content knowledge in science have on the way they make their judgements about students' science work?", is described. Aspects such as the development of instrumentation and the rationale for selection of teachers for the sample are explained in terms of the three specific research questions. Collection and preparation of student work samples for teachers to judge and steps to refine data collection procedures through field testing of the task and interview procedures are discussed. Limitations of the design and how these were overcome, and issues of the position of the researcher and trustworthiness of the researcher's analysis are discussed. Results for the three research questions follow in Chapters 4, 5 and 6.

## 3.1 Design

The research design is a qualitative, in-depth study with 30 teachers. Data, in the form of interview transcripts built around a science task, were gathered from face-to-face interviews between the researcher and teachers. Analysis of the data was by examination of and comparison between teachers' transcripts, leading to identification of science content knowledge and pedagogical content knowledge in science.

The science task was to observe, describe and explain the events involved as a match was struck, a candle lit and then blown out. This provided data for the first research question: "What do teachers know and understand about the science concepts involved in a selected science-related task?" Analysis focused first on the identification of teachers' science content knowledge, then developed into a

comparison of understandings of teachers categorised as having high, midrange and low science content knowledge.

To provide data for the second research question, "How do teachers interpret, and how do they make their judgements about, students' work?", each teacher judged a work sample from an unknown student. Analysis established the aspects of students' work that teachers used as the basis for their judgements, and the problems teachers had with making judgements. These pedagogical aspects were related to teachers' content knowledge in science, and general types of judgements for teachers with high, midrange and low science knowledge were described.

Also related to teachers' pedagogical content knowledge in science is the third question: "What strategies do teachers suggest to support students' further learning?" This focused on the follow-up strategies teachers suggested after they had judged a student work sample. Their ideas were examined for the extent to which they reflected a conceptual change orientation to science teaching.

A key aspect of the research design was that both teachers and students responded to the same task. This gave teachers familiarity with the task which assisted their judgements, and heightened the effect of their own science knowledge on their judgements. It also permitted comparison between teachers' and students' knowledge of the task.

### *3.1.1 Sample*

The selection of teachers for the sample was aimed at ensuring a broad representation of science education and teaching experiences to ensure a wide range of responses. Practising teachers with a minimum of five years of teaching experience and currently teaching science classes or lessons were included. Five males and 25 females, with a range of teaching experience from 5 to 36 years (average 18.1 years) were aged 26 to 56 years (average 42.2 years). These demographics are consistent with those in Western Australia of a predominantly mature, female workforce. All worked in Perth metropolitan schools including high to low socio-economic areas, government and private, with students from a variety of ethnic backgrounds in small (200) to large (over 1000) student populations. All teachers were known to the researcher and recruited by invitation. Random selection could not have ensured the

broad representation of science education background and teaching experience required.

*Science Education History*

Teachers were selected to include a range of science education histories. Science education history refers to experiences that have contributed to teachers' science content knowledge or knowledge of pedagogy relating to science, for example, science studied at high school, attendance at science professional development or postgraduate study in science education. All had done at least one science education course as part of their initial teacher education.

On the basis of their self-reported history teachers were described as having extensive science education history if they fulfilled at least three criteria, or as having a limited science education history if they fulfilled no more than one of these criteria:

1. had completed at least one science subject at Year 11 or Year 12;

2. had studied science at tertiary level (e.g., science degree or units such as biology, geology, chemistry, physics, botany);

3. was enrolled in, or had completed, a science education course at post graduate level (e.g., Graduate Diploma or Master's Degree);

4. had completed five days or more of science education professional development (e.g., science education conferences, science network meetings or inservice course on using a science curriculum);

5. had been or currently active in science education (e.g., as science curriculum leader, member of a science professional organisation, judged science competitions, written science curriculum, been a marker for external examinations).

*Ages of Students Usually Taught*

Teachers were selected if they were currently teaching and usually taught either Year 3 (junior primary, students aged 8-9), Year 7 (upper primary, students aged 11-12) or Year 11 (upper secondary, students aged 15-16). The choice of these age bands was appropriate as Western Australian teachers characterise themselves using these terms to reflect a specific range of competency, preference or experience.

*Science Background Groups*

Teachers were allocated to five groups according to their science background (their science education history and the age of students usually taught). One teacher

from each group judged the same student's work, for example, teachers 5, 12, 14, 24, and 25 judged Student 6's work. This ensured each student's work was judged by teachers with a range of science background.

The Year 11 teachers—all with extensive science history—formed group 1 (see Table 1). It is normal practice in Western Australia for upper secondary science to be taken by teachers with a science degree, therefore no secondary teachers with a limited science education history were included. Teachers in this group had expertise in different science subjects: two each for chemistry, physics and biology.

Table 1

*Teachers in Group 1*

| Teacher | Science History | Students Usually Taught | Sex | Age | Experience (Years) | Student Work Judged |
|---|---|---|---|---|---|---|
| 1 | Ext. | Year 11 | F | 31 | 9 | 1 |
| 2 | Ext. | Year 11 | F | 42 | 20 | 2 |
| 3 | Ext. | Year 11 | F | 38 | 5 | 3 |
| 4 | Ext. | Year 11 | M | 42 | 22 | 4 |
| 5 | Ext. | Year 11 | F | 48 | 26 | 6 |
| 6 | Ext. | Year 11 | M | 46 | 25 | 5 |

Note: Ext. refers to extensive science education history.

Teacher 6, for example, had an extensive science background (he fulfilled all five criteria): he had completed physics and chemistry in high school, undergraduate and post graduate study (completed a one year Post Graduate Diploma in Science Education) and had been active in science education (worked as a consultant on implementing the Western Australian outcome statements full time for two years). He was Head of the Science Department at a school with special facilities for science.

Twelve Year 7 teachers were allocated to groups 2 and 3 (see Table 2) and 12 Year 3 teachers formed groups 4 and 5 (see Table 3). Teacher 8 fulfilled three of the criteria: she had done two science subjects at Year 11 and 12; attended in excess of 20 days at science conferences; had participated in writing the *Curriculum Framework's* Science Learning Area Statement, had been filmed in a science

professional development video as an exemplary teacher and was a committee member of a science professional body. She was a deputy principal of a primary school of 600 students in a high socio-economic area with responsibility for a Year 7 class "by choice" for over 10 years, and said science was her "favourite subject."

Table 2

*Teachers in Groups 2 and 3*

| Teacher | Science History | Students Usually Taught | Sex | Age | Experience (Years) | Student Work Judged |
|---|---|---|---|---|---|---|
| Group 2 | | | | | | |
| 7 | Ext. | Year 7 | F | 35 | 7 | 1 |
| 8 | Ext. | Year 7 | F | 50 | 26 | 2 |
| 9 | Ext. | Year 7 | M | 40 | 17 | 3 |
| 10 | Ext. | Year 7 | F | 43 | 25 | 4 |
| 11 | Ext. | Year 7 | F | 41 | 21 | 5 |
| 12 | Ext. | Year 7 | F | 52 | 13 | 6 |
| Group 3 | | | | | | |
| 13 | Lim. | Year 7 | F | 37 | 9 | 1 |
| 14 | Lim. | Year 7 | F | 56 | 36 | 6 |
| 15 | Lim. | Year 7 | F | 41 | 20 | 4 |
| 16 | Lim. | Year 7 | M | 49 | 28 | 5 |
| 17 | Lim. | Year 7 | F | 28 | 8 | 3 |
| 18 | Lim. | Year 7 | M | 50 | 20 | 2 |

Note: Ext. and Lim. refer to extensive and limited science education history.

Teacher 18 fulfilled one criterion as he had studied biology and physics while at high school. He had taught upper primary for the last five years and stated he takes science but is "not very keen on it" and tries to get a colleague to take it for him. His only professional development in science was a half day course on *Primary Investigations* two years ago. He worked in a high socio-economic area in a school of 600 students.

Teachers 22 and 30 both said they preferred junior primary classes. Teacher 22 fulfilled three of the criteria: she had studied biology at high school; she had many days of science professional development through a *Primary Investigations* course including a recently completed 5-day science course in science content; and was active in science education as she organised the science resource kits at her school. She had also selected science as her major subject in her initial teacher qualification, as well as completing all the science options. She worked in a low-socio economic area with a high Aboriginal and European migrant population. Teacher 30 fulfilled none of the criteria: she couldn't recall doing any science at high school and was absent for the school's science *Primary Investigations* course. She worked in a mid-socio economic area, with high Asian population, and has never taught beyond Year 3.

Table 3

*Teachers in Groups 4 and 5*

| Teacher | Science History | Students Usually Taught | Sex | Age | Experience (Years) | Student Work Judged |
|---|---|---|---|---|---|---|
| Group 4 | | | | | | |
| 19 | Ext. | Year 3 | F | 41 | 15 | 1 |
| 20 | Ext. | Year 3 | F | 48 | 12 | 4 |
| 21 | Ext. | Year 3 | M | 33 | 13 | 3 |
| 22 | Ext. | Year 3 | F | 26 | 5 | 5 |
| 23 | Ext. | Year 3 | F | 34 | 13 | 2 |
| 24 | Ext. | Year 3 | F | 47 | 20 | 6 |
| Group 5 | | | | | | |
| 25 | Lim. | Year 3 | F | 39 | 17 | 6 |
| 26 | Lim. | Year 3 | F | 52 | 30 | 1 |
| 27 | Lim. | Year 3 | F | 54 | 32 | 5 |
| 28 | Lim. | Year 3 | F | 51 | 25 | 1 |
| 29 | Lim. | Year 3 | M | 35 | 12 | 2 |
| 30 | Lim. | Year 3 | F | 37 | 14 | 4 |

Note: Ext. and Lim. refer to extensive and limited science education history.

## 3.2 Instrumentation

Three instruments were designed for the interview: the science task, the interview questions and the student work samples. Two teachers and two students (all four from primary and secondary schools) participated in developing the science task and the interview questions.

### *3.2.1 Selecting the Task*

The task had to meet three selection criteria.

1. The task, and the concepts linked to it, had to be relevant to the Western Australian science curriculum and practice for two reasons: first, teachers would have a positive attitude to the task, and second, research findings had a practical application to science teaching in this State.

2. The task had to be accessible to students and teachers with diverse science histories. It needed to be simple enough so that they could respond to it effectively using unsophisticated concepts, yet complex enough to stimulate higher level knowledge of students in post compulsory years and teachers with specialist science knowledge. This meant that tasks such as "draw a diagram of an atom" were not appropriate as they required specialised knowledge to make an informed attempt.

3. The task needed to link to multiple concepts rather than have a narrow focus, because primary teachers are generalists and teach and judge students' work from many science disciplines.

Six tasks using props were trialed: describing a candle being lit and blown out; predicting which container in a set would keep an ice block the longest; describing a flowering eucalyptus branch; suggesting how a kiosk owner could keep drinks cold when the electricity failed; predicting and observing changes with oil and water; and explaining the causes of the seasons by drawing a diagram.

The candle task was selected as a stimulus for a range of concepts such as energy forms and transfers (Duit & Haeussler, 1994), natural and processed materials, and science process skills such as explanation, observation, inference, deduction and causality which had status in the outcomes in the *Curriculum Framework* and *Primary Investigations*. It was accepted in the science education literature as appropriate for science testing (e.g., Adams et al., 1991; EDWA, 1994a, 1994b; see also T. Russell, 1988). The candle was familiar (e.g., birthday parties), did not pose

unacceptable safety risks (the researcher was present), was easy to transport and quick to set up (for interviews at different schools), was visually engaging which maintained interest and aided observations. Props had been successfully used in other research using interviews about heat (Magnusson, Borko, Krajcik, & Layman, 1992). The simplicity of the task was effective—students and teachers were asked to make observations about the candle. This gave access to their content knowledge (A. Russell, Black, Bell, & Daniels, 1991). It allowed students and teachers to operate successfully with simple ideas like "hot fire" and "melt", yet generated more complex concepts such as "melting point" and "molecules" within a deceptively simple event.

How was the task used? Students and teachers were asked to describe events in three phases: (a) watching the researcher striking a match on the side of a matchbox, and lighting the candle using the flame, (b) watching the candle burn and the wax melt, and (c) blowing the flame out and observing smoke and other changes. These three phases involved many concepts (e.g., heat and light energy, energy transfers, different sources of fuel, the role of gases in combustion, ignition temperature), concepts that related to only one phase (e.g., friction), and concepts common to each phase (e.g., the properties of materials affected by temperature changes, chemical reactions).

### *3.2.2 Interview Questions*

The most suitable format to obtain students' and teachers' ideas was the face-to-face interview. This (a) reduced the interference of reading and writing skills (Shrubb, 1989) which was important as respondents could express their thoughts and change their answers more readily orally than by writing, (b) allowed respondents to engage with the interviewer who could prompt and encourage, (c) allowed the interviewer to probe for more precise observations, clearer explanations and to verify what was meant through questioning, and (d) simulated discussions teachers may have with students during science lessons.

The interview style selected was characterised as 'prompt but not lead'. The interviewer prompted for more ideas or a more detailed response, responded to what teachers said, but did not provide science terminology (i.e., specific terms such as wick, temperature, or smoke could not be used unless the student or teacher used them first). Questions could not be in the form of 'What do you know about heat

energy?' as this may provide a term or concept not already in the students' or teachers' science understanding. Support for this methodology is found in work by R. Osborne and Freyberg (1985) who used an interview-about-events technique. In this technique, interviewees observed events, such as boiling water, and were asked to describe what was happening. The interviewer made no evaluation or comment about the acceptability of the science concepts involved. Only when a specific term such as bubbles or heat was mentioned were respondents asked further questions about those terms or phenomena. Practical advice about conducting interviews effectively using this method provided by Bell, Osborne and Tasker (1985) proved invaluable.

This extract from the interview with Teacher 19 demonstrates how the semi-structured interview technique followed her lead, used only terms she introduced first, asked for clarification and expansion, and supported her to go far beyond her first response to demonstrate or attempt more sophisticated concepts:

Teacher: You've struck the match, and you've lit the candle. The candle's burning. So do I describe the way the candle's burning?

Researcher: Yes. Can you tell me more about when you said 'I struck the match'? What actually happened then?

Teacher: Um, the match head went against the side of the match box and the friction caused it to ignite. And there'll be com' [incomplete] There'll be a chemical compound on the head of the match, and the side of the box will make that easier.

Researcher: So tell me more about 'chemical compound'. What do you mean by that?

Teacher: Um, oh, it's something not akin, not unlike, like a gunpowder. Um, it's probably phosphorous—no—something like that. But, but there'll be a chemical in the head of the match.

Researcher: You mentioned it was on here 'on the side of the match box'.

Teacher: Yes, it's either on there or, um, it's because it's roughened and creates friction. (Teacher 19)

This interview style was also used when interviewing teachers about their judgements of student work samples and suggested follow-up activities. Teachers were asked for clarification or evidence for judgements, but strategies were not suggested to find out what teachers thought of them, and comments on the accuracy or focus of judgements were not made.

### *3.2.3 Student Work Samples*

Student work samples formed the instrument used to elicit teachers' judgements. To gather a pool of student work, interviews with 20 primary-aged students were conducted at a metropolitan school with an ethnically mixed (over 25% non-English speaking background), diverse (low to high) socio-economic background, that had specialised programs for both remedial and advanced students. Students were in the normal age range for Year 3 (7 or 8 years old ) or Year 7 (11 or 12 years old). Interviews with six Year 11 (15 or 16 years old) students from four metropolitan high schools were conducted at the students' homes. Students were suggested by their class teacher and identified as having high or low ability in science. Written permission from parents (and teachers and school principals when the interviews were conducted at a school) was obtained.

Transcripts were made of all interviews. Six were selected from the pool to represent the range of sophistication in students' concept development that teachers experience. Students 1 and 2 were in Year 3, Students 4 and 5 in Year 7 and Students 5 and 6 in Year 11; each odd-numbered student was of lower ability than the paired even-numbered student. Few primary science classes are streamed for ability, and with the increase in retention rates in post-compulsory years, more upper secondary teachers are working with students of low science ability. While the situation of a Year 3 teacher assessing work of a Year 11 student would not normally occur in schools, for the purposes of this research, this strategy represented the range of science conceptual development—not chronological age—that could be met by teachers (e.g., either a young child with a high level of understanding, or a student with unsophisticated concept development in upper secondary).

Table 4 briefly describes the students and some characteristics of their work. The terms low or high ability describe students' work only in comparison to other students of the same age in the selection pool.

Table 4

*Outline of Student Work Samples*

| | |
|---|---|
| Student 1 | Year 3, female, low ability: the least developed work, contained stilted language and used only simple (e.g., "hot") or unusual terms (e.g., she called the match a "fire stick"). |
| Student 2 | Year 3, male, high ability: used simple language to express early concepts of heat (that scraping made the special stuff on the side of the box hot, that wax drips when it gets hot from the fire) and purpose (the wax column is to hold the string in) and change (the wax will go hard again). |
| Student 3 | Year 7, female, low ability: suggested the smoke was steam, believed the candle turned into another substance called wax when heated and melted, that stroking "the brown stuff made the match light" and had some unusual ideas that wax was formed through melting (e.g., "the candle light is making the heat from the wax ... into this special stuff ... the flame makes heat to burn the candle so it makes wax). |
| Student 4 | Year 7, male, high ability: spoke of the "sandpaper" on the matchbox, explained that the "chemicals on the end of the match heat up" and catch fire, wax melts because it's hot, the flame burns all the string in the wick and so the wax gets lower, the "wind hits the flame and it goes out." |
| Student 5 | Year 11, male, low ability: used high level science terms such as phase change, plateau, kinetic and heat energy, explained some differences of heat and temperature, stated he was unable to explain smoke, said wax was there to slow down the rate the wick burned, suggested less smoke was produced when the flame was hotter. |
| Student 6 | Year 11, male, high ability: the most sophisticated conceptual development, explained the role of heat and friction in ignition competently, confused chemical and physical change, suggested flammable oil on the wick kept the flame alight, explained transfers of heat and flame in match and wood, suggested sulfuric head, used ideas of gases exhaled as the reason the flame went out. |

Selection of transcripts suitable as work samples acted as a pilot for later analysis of teachers' concepts and was based on a general framework of increasing conceptual sophistication with ideas of increasing abstraction (Rennie, 1993); conceptual change in heat and materials (Driver, 1985a, 1985b; Driver et al., 1994; Erickson & Tiberghien, 1985); increasing use of generalisation of concepts and terminology (Black & Harlen, 1993); levels of understandings of light (Ramadas & Shayer, 1993); and learning outcomes as levels of increasing sophistication (Adams et al., 1991; Curriculum Corporation, 1993, 1994; EDWA, 1994a, 1994b).

Selections were also made so that students of diverse ages had similar concepts. For example, Student 2 had said the wax is "not actually burning, it's melting because the fire's making it" which was comparable and expressed in similar language to Student 6's comment "because the wax doesn't burn, it just melts." Work samples were included from students of the same school year with different sophistication of concepts. For example, the two Year 7 students had very different views on the candle smoke: Student 4 made a link between heat and smoke ("all smoke's coming off the wick and the flame's gone out because when I blew it out it went to smoke and cooled down and all smoke come off") while Student 3 equated smoke to steam with "steam—because the candle's being heated and you blow it out and it can't turn into [unfinished] it just turns into steam."

Student work samples were presented to teachers as typed transcripts of an interview between the researcher and the student. Typed transcripts were appropriate as they facilitated revision and reflection by the teacher, such as checking first impressions and comparing what the student said at different times of the interview, and allowed teachers to read aloud parts of the text as evidence for their ideas. They provided the opportunity for the teacher to comment on other aspects of students' work they considered relevant such as the quality of the students' responses to the interview questions. They reduced teachers' preconceptions or expectations (which would be an undesirable consequence of presenting the work as video or audio) based on students' age, appearance, sex (Haggerty, 1987; Jörg & Wubbels, 1987; Kelly, 1988; Lewis & Davies, 1991; Scantlebury & Kahle, 1991; Spear, 1987), race or ethnicity (Linkson, 1999) or social class (Domingos, 1989). This helped teachers focus on students' ideas. The transcripts did not give teachers clues about students'

age through seeing students' handwriting, by gauging the difficulty of the questions in paper and pencil style tests, or inferring from the size of the typeface used in a written test.

Conventions were adapted from interview extracts in published research (Lucas, 1993; Taylor & Coll, 1997) when preparing work samples. All words and incomplete words were included (e.g., "um") to retain the sense of spoken language. Minimal punctuation was used as students' sentences were often not fully completed and imposing the researcher's punctuation for written language changed the impression of spoken language and this could influence teachers' interpretations. A single dot ( . ) indicated a short pause or change of topic; pauses of up to five seconds were shown as ( ... ); and longer pauses as ( ... ... ). Comments in square brackets were used to record relevant non-verbal information (e.g., if the student gestured this was shown as [points at wick]). Comments that were judgements by the researcher were not included (e.g., student appears unsure, or student shows confidence). There was a new line for each change of speaker; the letter R for researcher and S for student. The extract from Student 3's work sample shows some of these conventions (see Table 5). The work samples for Student 1 and Student 6 appear in Appendix B.

### *3.2.4 Field Testing*

The task, interview questions and student work samples were field tested with three teachers. Refinements were subsequently made to the interview style and interview protocol, and a method of stimulating more detailed judgements of students' work was devised.

*Refining the Interview Style*

The interview style was refined into a semi-structured style with general, specific and follow-on questions prepared on prompt cards. General questions introduced each phase (e.g. "Tell me what you saw", "Can you tell me what happened?"). Specific questions were asked if the teacher had not mentioned an important aspect in response to the general prompt (e.g., "What do you think this stuff is here for? [indicate wax column]"). Follow-on questions responded to the interviewee's lead (e.g. "You said before about 'the heat moving'. What did you mean by that?").

Table 5

*Extract From Student 3's Work Sample*

| Speaker | Dialogue |
|---|---|
| R | tell me what happened and what I did |
| S | you lighted the match and put it onto . that little thing in there and the . fire went from the match to the top of it so it burns and wax comes out |
| R | what happened with this part [show match box] |
| S | you got that match and you put it onto the side bit here and you stroked it and . from that part there it came alight . from . and you lit the ... |
| R | is that this part on the side [indicate striking plate] |
| S | yes ... and you lit it |
| R | so why did it light? |
| S | ... [no response] |
| R | try and tell me what do you think makes this [point at the match] light? |
| S | when you . like stroked it . because that . probably some special thing on . like something special |
| R | what sort of something special might it be? |
| S | mm ... sort of like something that lights . fire |

Note: R refers to researcher; S refers to student.

Similar prompts were developed to guide teachers to give evidence from the transcript (e.g., "How would you assess or evaluate this student's work?", "What did the student say that makes you say that they are confident?" and "Which part helps you make that statement?"). No time limit was set for the interview. Teachers could make brief responses or examine their ideas at length. Interviews were terminated when the researcher felt teachers had reached a natural end to their deliberations (e.g., appeared satisfied with their comments and judgements or stated they had said all they could say).

The field test interviews were an essential training time for the researcher to develop skills to draw out teachers' understandings, avoid the use of terms until used by teachers, avoid providing feedback on the accuracy or sophistication of teachers' concepts, to judge when further questioning would be productive, and to provide

encouragement to teachers to verbalise ideas that are usually tacit—as one teacher said, "You use candles at every birthday party, but you never stop to think about why they go out." It was important to develop skill in probing until teachers had sufficient opportunity to think through their ideas, but to stop before discomfort, frustration or annoyance set in. Other issues that became apparent during the trial (e.g., use of non specific terms such as 'the student' rather than 'he' or 'she') were resolved.

*Refining the Interview Protocol*

What students and teachers chose to make as observations about the candle was affected by what they saw as the purpose of the interview. It was decided to specify to students and teachers that the researcher was "interested in what you know about science" so they made science observations rather than comments extraneous to the research questions (e.g., the colour of the plate the candle was standing on). The decision was also taken to not set a purpose for the candle (e.g., to ask students to tell the researcher how it could be used to heat up a saucepan or illuminate a room) as this would provide concepts students may not otherwise demonstrate (i.e., that candles emit heat or light).

Refinements were made to the format to determine teachers' science background. Initially, a tick-the-box style form was designed for teachers to read and indicate their history of science education, for example, "At high school I □ did no science studies, □ did science in lower secondary only, □ took one science subject in upper secondary, □ did two or more science subjects in upper secondary." This was altered to jotting down notes and taping the teachers' responses to the researcher's questions because this demonstrated interest by the researcher and established rapport as teachers commented on how they felt about science which helped the interviews start on familiar and personal ground before the intensive and often challenging science questions that followed.

*Eliciting Teachers' Judgements*

When asked to judge a student's work, the first teacher in the field tests made a very short, summative statement—"He knows a lot"—and had difficulty analysing the transcript in more depth. This was partially due to the non-specific nature of the prompt: "What can you tell about this student's work?" Perspectives which may have prompted more assessment or evaluation (e.g., set the scene that the student is

coming into the teacher's class or specific questions such as 'Do you think this student is having difficulty?') were rejected as too restrictive on teachers' comments. To elicit more detailed and purposeful commentary about students' science knowledge an age and ability instrument was developed (see Figure 1). Its function was not to test how accurate teachers were at judging a student's age or ability, but to prompt them to re-examine the student work sample. The instrument was a baseboard (60 cm x 40 cm) that showed five ability levels (vertical axis) against seven ages (horizontal axis). Teachers were given five blank cards (6 cm x 4 cm) and asked to "place one, two, or up to five cards that would best describe the student" whose work they were judging. For example, Figure 1 shows how one teacher placed three cards. This teacher described the student as 7-8 years old and of well above average ability, and discussed her reasons for this placement, such as the "student knew a lot if he was this age." She settled on the student being most probably 9-10 years old (and above average or average) because that was what she thought students of that age would know about candles. This information was used as data for analysis of what aspects of students' work teachers used when making their judgements.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Well above | | X | | | | | |
| Above average | | | X | | | | |
| Average | | | X | | | | |
| Below average | | | | | | | |
| Well below | | | | | | | |
| | 5-6 | 7-8 | 9-10 | 11-12 | 13-14 | 15-16 | 17-18 |

*Figure 1.* Age and Ability Instrument

Note: X indicates where the teacher placed three cards.

The age and ability instrument was successful at stimulating the other two teachers in the field test to review their judgements without implying they had not done it successfully the first time. The physical process of choosing and placing the

cards (like a card game) was a novel and indirect way of accessing teachers' methods of making judgements.

## 3.3 Data Collection

Teachers were interviewed individually, in an informal manner, in a quiet area at their home or school. Interviews were audio taped with permission and took between 20 minutes and 40 minutes. Data were collected in four parts during one interview: personal details, teacher's response to the science task, judging a student's work sample and suggesting follow-up activities.

*Personal details.* The procedure and purpose of the research were outlined, the confidentiality of the teacher's name and school explained and a permission form signed (see Appendix C). The teacher's name, age, number of years at this school, ages of students usually taught, teacher training, what year the teacher first started teaching, how many years the teacher has been teaching and history of science education were recorded (see Appendix D). Based on this information teachers were assigned to a group (i.e., had an extensive or limited science education and usually taught Year 3, 7 or 11), a code number and student work sample.

*Response to the task.* Teachers responded to questions from the interviewer (see Appendix E) to make observations and explain events in as much detail as they could as they engaged with the candle task.

*Judge a work sample.* Teachers were asked to judge a student's science understandings based on a work sample. They were prompted to review or extend their judgements by re-examining the student's work using the age and ability instrument.

*Suggest follow-up activities.* Teachers were asked to suggest two follow-up activities that they felt were appropriate for the student, and which would help the student in science. The interview was concluded by thanking teachers for their contribution to the research.

## 3.4 Data Analysis

Analysis proceeded in three stages corresponding to the research questions. In the first stage, analysis of the teacher interview transcripts focused on describing

teachers' content knowledge about the task. The second stage identified the aspects of students' work that teachers used as the basis for their judgements. In the third stage, teachers' suggestions for follow-up activities were examined.

### *3.4.1 Describing Teachers' Science Content Knowledge*

In order to describe teachers' science content knowledge a system of coding was developed. Initially, the student work samples were analysed to provide a basic structure and this was then refined using responses from teachers in the field test and interview data from the first 12 teachers interviewed.

*Analysis of Student Work Samples*

A detailed analysis of student work samples assisted the researcher to understand the students' concepts, misconceptions, abilities and problems. This developed the researchers' ability to recognise these aspects in teachers' science knowledge and to recognise which aspects teachers used—or did not use—when making their judgements.

Various formats to describe students' science knowledge were trialed. Initially students' responses were described separately as conceptual knowledge (factual knowledge) and procedural knowledge (of the processes or skills in science). This was guided by the work of Qualter, Strang, Swatton and Taylor (1990) and was in keeping with the division in the *Curriculum Framework*. This provided useful descriptions of students' knowledge, for example, students with the least sophisticated understanding said the purpose of the wax column was to protect you "from getting burned" or to "hold up the flame" (conceptual) and used specific verbs to describe actions (procedural) such as "scraped" or "rubbed" with the match. Students with more sophisticated ideas stated that the wax was there to slow down the rate at which the wick burned (conceptual) and made causal connections (procedural) in a series (e.g., "the wax is there so the wick just doesn't burn in two seconds because it takes time for it to heat up and turn to liquid so that more wick is exposed"). Three general descriptions of students' conceptual and procedural knowledge were constructed (see Appendix F, Table F1 for a sample of these descriptions).

*Analysis of a Sample of Teachers*

When this coding system was applied to responses by teachers in the field test and a sample of 12 teachers' interviews it proved too simplistic. Few of the teachers

fitted into one of the three descriptions (as the students had done) and often bridged two or more descriptions (e.g., one teacher held an unsophisticated concept that the wax was there to hold up the wick but also employed a sophisticated understanding about molecules becoming more active when wax was melting). The coding system was adapted to include transitional descriptions between the existing three descriptions (see Appendix F, Table F2), and expanded to include additional conceptual understandings about lighting the match (see Appendix F, Table F3). Two of the teachers had sophisticated understandings (they recognised the wax as a fuel source which none of the students had done) so a fourth level description was added (see Appendix F, Table F4).

However, this coding system of four descriptions and transitional descriptions proved increasingly inaccurate and ineffective as more of the 12 sample transcripts were coded. This was for two reasons: it attempted to fit all of a teacher's ideas into one discrete description whereas teachers' ideas had different degrees of sophistication, and as it became more complex it became too cumbersome to use.

Consequently, the coding system was modified: (a) to split the task into three phases, based on the three major activities of lighting the match, burning the candle and blowing out the flame, (b) to develop separate descriptions of increasing sophistication for each of the multiple conceptual understandings, and (c) to combine conceptual and procedural understandings to reduce the overall complexity. This precise analysis was effective as it did not exclude slight variations in teachers' knowledge from the analysis. This new system of a concept grid for each phase was refined using the sample teachers' transcripts until it produced consistent results between successive re-codings. Table 6 shows an overview of the phases for the concept grids, and what the concepts are about for each aspect.

One of the most difficult methodological decisions about the concept grids was how to treat misconceptions (e.g., "the wax moves up the wick but does not burn"). Not scoring ideas at all because they were misconceptions had the effect of penalising teachers who had sophisticated but misplaced ideas (e.g., one said that air filled the spaces between the molecules in the wax) and removed from the analysis an important sense of the level of abstraction (e.g., molecular theory). Influenced by the value a

Table 6

*Overview of the Phases for the Concept Grids*

| Aspect | Concepts Are About |
|---|---|
| Phase 1 Lighting the match | |
| Why does the match light up? | The match and box and reasons for the match to light. |
| What is transferred? | Transfers between the match, the box and the flame, such as heat or energy. |
| Phase 2 Burning the candle | |
| What's happening with the wick? | Burning of the wick and the flame. |
| What's happening with the wax? | Melting of the wax and the involvement of heat, and burning of the wax. |
| What is transferred? | Transfers between the wick, the wax and the flame such as heat or energy. |
| Phase 3 Blowing out the candle | |
| Why does the candle go out? | Why it could be blown out, why the flame goes out and loss of heat. |
| What about the smoke? | What causes smoke to form, gases, and incomplete combustion. |
| What is transferred? | Transfers involved in blowing out the flame such as heat or energy. |

conceptual change approach places on misconceptions, the decision was taken to accept misconceptions to represent the level of sophistication of the ideas within them. Thus, the concept grids include teachers' misconceptions, for example, for the concept "wax slows the rate the wick burns" teachers described this simply as the "wax slows the wick" burning (Level 1) or with sophistication if they specified that the "wax moved up the wick but did not burn" (Level 4). Similar decisions were taken with teachers' inaccuracies (e.g., location or type of chemical for the match) as it was important to register all ideas, not only those the researcher considered accurate. These levels are not designed to equate to those in the *Outcomes and Standards Framework* shown in Appendix A.

Empty cells on the grid indicate that no teacher made a comment that was of a greater sophistication than the ones shown, therefore concepts have two, three or four levels of sophistication. This is because the levels were derived only from students' and teachers' responses, and empty cells were not filled-in with responses invented by the researcher. As a consequence, those shown as the same level are not necessarily of the same sophistication (e.g., it cannot be assumed that understanding the "material of the wick burns readily" is the same conceptual sophistication as "the wick is revealed as the wax melts").The concept grids represent science understandings of teachers and students, to reflect the sense that teachers often held the same views as students

*Analysis for all 30 Teachers*

Appendix G shows the final form of the three concept grids used for analysis of all 30 teachers' science content knowledge of the task (for Phase 1, Phase 2 and Phase 3). Table 7 (an extract from Phase 2) demonstrates the features of the concept grids. Each consists of aspects (e.g., "the wick is burning") and each aspect has multiple concepts (e.g., the "the wick is held up", "the wick burns" and "wax slows the rate the wick burns" and "heat energy").

Teachers' responses for each concept were interpreted at different levels of sophistication and were assigned a level (0, 1, 2, 3 or 4) that best described the sophistication of their responses. For example, teachers demonstrated the concept that "the wick burns" at three levels. At Level 1 they simply said the wick burns without further elaboration, at Level 2 they specified that the wick burns slowly and at Level 3 they stated the wick burns readily. Teachers were scored only once for each concept, at the highest level they demonstrated (e.g., a teacher may have made responses coded as Level 2, 3 and 4 but only Level 4 was used in the analysis). Teachers did not always demonstrate every concept (e.g., most did not refer to molecules or gases in Phase 3). Some concepts were common to all three phases: heat energy, gases, chemical change, molecules, transfers and the mechanism of the transfer.

Results of the analysis of teachers' science content knowledge are discussed in Chapter 4.

Table 7

*Extract of Concept Grid for Phase 2: Burning the Candle*

| | | Level of Response | | | |
|---|---|---|---|---|---|
| Aspect | Concept | Level 1 | Level 2 | Level 3 | Level 4 |
| The wick is burning. | The wick is held up. | Wax holds the candle. | Wax holds the wick. | | |
| | The wick burns. | Wick burns. | Material of wick burns slowly. | Material of wick burns readily. | |
| | Wax slows the rate the wick burns. | Wax slows the wick's burning. | Wax melts so candle lasts long time. | Wick is revealed as wax melts. | Wax moves up wick (but does not burn). |
| | Heat energy. | Wick gets hot. | Heat energy is sufficient for wick to burn. | | |

### *3.4.2 Identifying Teachers' Judgements*

The second research question asked "How do teachers interpret, and how do they make their judgements about, students' work?" The focus was on what aspects of students' work teachers noticed when making their judgements, and how teachers' pedagogical content knowledge in science affected the judgement process.

Data about judgements were collected when each teacher was provided with a student work sample. Teachers were asked what the student "knows or understands in science" and were prompted with questions such as "What do you use to make that decision?" and "What do you notice about the student's work?" The age and ability grid was used as a stimulus for additional judgements.

*Analysis of a Sample of Teachers*

Trial analyses using data from the field-test teachers and a sample of 12 teachers initially established what aspect of students' work teachers recognised. Similar comments about students' work were grouped, for example, teachers showed an awareness that students have a science concept by comments such as "he knows what a wick is" (Teacher 30), "he knows what's burning—the fire is" (Teacher 10) and "he's got the concept there's a chemical on the match" (Teacher 16). These various judgement bases were then grouped into categories (e.g., all the different types of comments that related to students' science concepts). If teachers read aloud phrases from the student work sample but made no comment, this was not included in the data as it was not possible to determine if the teacher was making an interpretation or just reading aloud.

An extract of the interview with Teacher 8 shows how the age and ability grid elicited judgements based on her own experience, the student's language and general ability:

Teacher: Well, I'd say, I'd base it on what I know. If this came, if this was, um with my class, um I'd say it's probably an average child. Probably 9 or 10. An average 10 I'd say [places card] . Probably understands better than I do what's going on.

Researcher: What clues are in there, what do you see, that helps you make that judgement?

Teacher: I think part of it is the fact that there seems to be a lot more encouraging this kid to say things, or when you do, whenever they've been encouraged there is less information given at any particular time.

Researcher: What do you mean by that?

Teacher: Well quite often, when you're talking with children and you say something like that they will give you short answers [simulates student's voice ] 'So the candle can burn' and 'Because it's soft'. Possibly language. I guess language is the

clue that the child seems to have less language ability. It might be a younger child.

Researcher: What gives you that sense?

Teacher: In my experience with more able students, they tend to use full sentences. They don't just answer one word answers—minimum answers. (Teacher 8)

Building on this information, the ways that teachers' science knowledge supported or caused problems with making judgements were identified in trial analyses. The analysis method was continuous comparison between (a) a teacher's science knowledge about the candle, (b) the judgement bases that the teacher used, (c) the judgement made about a student, and (d) the student work sample. A table of results was developed and interpretations made. This proved a challenging task. First, a high level of familiarity with teachers' science knowledge was gained by repeatedly reading their transcripts, highlighting key phrases and noting these on recording sheets based on the concept grids. Secondly, analysis required familiarity with the student work samples to recognise in them what teachers noticed, and did not notice, about students' work. Finally, both these sources of information then had to be compared with the ways teachers made their judgements.

*Analysis for all 30 Teachers*

Analysis for all teachers was undertaken and results recorded. Analysis was extended to characterise the types of judgements teachers made, how teachers with high, midrange and low science knowledge typically made judgements, and the extent that the individual student work sample, the science education history or the ages of students usually taught affected teachers' assessments and evaluations of students' work. Results of these analyses are presented in Chapter 5.

### *3.4.3 Examining Follow-Up Activities*

The third research question examined teachers' suggestions to support students' further learning. The focus was on the types of activities teachers suggested in response to their judgements of the student work samples, and how aware teachers

were of the conceptual change approach to science teaching, as shown through these suggestions.

*Analysis of a Sample of Teachers*

Trial analysis of interview transcripts identified activities that fitted with the candle activity (e.g., talking about the candle, do a candle experiment) and others less often used which were in broader terms (e.g., trying blowing out by different methods, comparing how fast ice melted in different situations). Analysis then focused on the extent to which teachers recognised students' concepts as the basis for their follow-up suggestions. Some teachers made little direct reference to students' science concepts, for example, "I love making Anzac biscuits because you've got all those wonderful changes" (Teacher 27) while others explicitly based their decisions on evidence of conceptual sophistication, for example, "I might do a little bit of work on friction because that's something he didn't understand" (Teacher 14).

The activities were then reassessed to identify teachers' orientations towards science education and pedagogy, for example, the extent their suggestions could be viewed as supportive of a conceptual change or discovery orientation. This was determined both through the activities teachers suggested and their intention for what the activities would achieve, for example, if it was to change a student's understandings, to correct a student's error, or to pursue the student's own interests.

*Analysis for all 30 Teachers*

Both these descriptions about the ways teachers based their ideas on students' concepts, and their general orientations to science teaching and learning were combined to describe the typical pedagogical strategies about follow-up for teachers with high, midrange and low science knowledge. This information would paint a picture of the extent to which teachers' orientations towards science pedagogy included that of conceptual change. These results are presented in Chapter 6.

## 3.5 Increasing Trustworthiness of the Data

Lincoln and Guba (1985) established the "trustworthiness" (p. 301) of naturalistic research design as important because it reflects on the quality of an inquiry. They presented three main criteria of trustworthiness: credibility, transferability and dependability. Methods of establishing trustworthiness appropriate to my research

relate to those which make the research more likely to produce credible interpretations and findings through prolonged engagement and triangulation; an attempt to improve transferability through use of a conceptually rich task; and the audit trail (Lincoln and Guba credited Halpern in 1983 with its development) used to establish dependability of the inquiry process.

These criteria are discussed for data collection and data analysis. Much of this discussion shows the tension between one aspect of research design that advantages trustworthiness, but can also mitigate against it.

*Collecting the Data*

*Prolonged engagement.* Qualitative research in one's own professional field is perhaps the ultimate form of prolonged engagement, in the case of this research, many years as a primary classroom teacher and over eight years involved with conceptual change and outcomes-focused education has built a sound base of understanding of the complexity of teachers' work, an appreciation of the pressures of planning and assessing for a whole class of students for many different subjects. This was advantageous during the interviews, due to a sense of shared school-based experiences which facilitated communication—teachers felt the researcher-as-audience was comprehending their ideas, particularly during the judgements and follow-up parts of data collection.

*Motivation.* Lincoln and Guba (1985) referred to work by Bilmes in 1975 of "situated motives" (p. 302). Selection was based on teachers being known to the researcher, which may have affected their motives during the interview situation, by enhancing the science knowledge they demonstrated (due to wanting to appear knowledgeable to a known audience) or reducing it (discomfort and avoidance when an explanation was personally unsatisfactory). Teachers may also have distorted the judgement and follow-up practices they demonstrated. However, the issue of motivation also advantaged the credibility of data collection through interview, as interviewing teachers who were familiar meant they were generally candid about their knowledge or lack of knowledge, and had an openness to consider alternative ideas. This gave exceptional access to detailed information about their science knowledge and knowledge of pedagogy in science. This was probably most evident as a positive distortion as teachers generally worked hard to explain their science knowledge and

during the judgement process were prepared to spend much longer times in making considered observations and comments about an individual student than would be likely in the classroom. Thus, the interview was a strategy to gather rich data that represented teachers' ideas in a positive and supportive situation.

*Interviewer bias.* One of the greatest threats to credibility was that only the researcher conducted the interviews. Expectations or biases not recognised by the researcher may have influenced teachers' responses and have affected the comparability of the interview data, for example, the expectation that all teachers with extensive science background would outperform those with limited science background. During data collection this was reduced by not interviewing teachers from the same group in sequence. This was also compensated for by the semi-structured interview style: a balance between unscripted questions following the teachers' lead controlled by general or specific prompts to reduce the openness of the discussion style. The consistent sequence of the interview style increased the similarity of the interview experience for each teacher so their transcripts were comparable.

*Triangulation during data collection.* Interviews with 30 teachers acted as multiple sources. Lincoln and Guba (1985) used this term in a discussion of Denzin's 1978 work on triangulation. Instances of the effect of science knowledge or pedagogical knowledge in individual teachers could be verified as patterns became more coherent and probable in this diverse sample. Using six student work samples also as multiple sources for teachers to judge made patterns of response in teachers more credible than if these were based on the work of only one student.

The research method also attempted to meet Lincoln and Guba's (1985) criterion of triangulation by using different data collection modes for teachers' science content knowledge. This was achieved by three occasions when teachers' science content knowledge was called upon: (a) when they responded to the task themselves, (b) revisited their own knowledge as they judged students' work, and (c) again when suggesting follow-up activities. Also, although all data collection was within an interview situation, the age and ability instrument was a different approach to eliciting teachers' judgements that did not rely on the question and answer interview style.

*Data Analysis*

*Transferability.* To improve the trustworthiness of the findings, teachers were invited for interview on the basis of the ages of student they usually taught and the extent of their science education. This selection meant the sample was representative of teachers from a wide range of teaching and science experience. While results for this research are applicable to the sample and not necessarily to the whole population, they are more credible because they are representative of teachers with diverse backgrounds, and are applicable to the locus of curriculum change in Western Australia.

Teachers only responded to one task, and will have science knowledge other than that demonstrated in this research. However, the "candleness" of the task was less important than the transferability of powerful concepts (of fuel sources, combustion, heat and energy, change of state, friction) in that one task to other contexts. It is these that make the research the "thick description" (Lincoln & Guba, 1985, p. 316) that can enable others in the science education field to find links to their own work.

*Dependability throughout the inquiry audit.* The inquiry audit is an approach to make research transparent. For this reason, raw data (i.e., work samples from two students, see Appendix B), the interview transcript from one teacher (see Appendix G) are included, as is information about development of the instruments (e.g., pilot forms of the concept grids, the age and ability grid and a semi-structured interview style).

The concept grids were developed specifically to ensure that all aspects of teachers' science knowledge in all three phases of the task were attended to, to reduce the "selectivity of perception" (Dieckman, 1993, p. 1) and to maximise the openness of the researcher to what the teacher knew (not what was expected of them because of their group's science education) termed "ethnocentric posture" by Lincoln and Guba (1985, p. 302). The concept grids proved an effective instrument to determine science knowledge in a coherent and consistent manner, and some unexpected results for teachers' science knowledge suggested that this was a successful strategy to reduce the effect of the researcher's expectations. Assigning a numerical value to the teachers' science content knowledge assisted in comparison between individual teachers and the five teacher groups in quantitative terms. The lengthy process of

development of the concept grids caused multiple re-analysis of the original transcripts which served to reduce the bias possible from only one coding. During development of the concept grids, a colleague coded the content knowledge of two teachers, differences with the researcher's codings discussed, and the concept grids' wording or levels were adjusted.

Another issue of the dependability became apparent during field tests—the quality of interviews and analysis depended on the researcher having a high level of understanding of the physical and chemical processes involved in the task. Ongoing reading in response to teachers' science content knowledge about the task was necessary to check unexpected responses from teachers that may have been a scientifically correct view (e.g., does the candle blow out because the wax gets cooled below its melting point?) or due to the researcher's own misconception (e.g., that matches have phosphorus in the head) or to facilitate the researchers' conceptual change (e.g. there are two types of reaction zones for gaseous combustion). For this reason, descriptions of scientifically correct views are presented as Appendix I.

*Triangulation during data analysis.* During the trial analysis with a sample of 12 teachers it became apparent that knowing who the teacher was, was influencing the coding due to the researcher's expectation that teachers with extensive science education history would outperform other groups. For example, registering surprise when a Year 3 teacher used a scientifically correct view of molecules moving faster was productive as it meant the task had resulted in diversity of teachers' science content knowledge, but it also warned that unless greater rigour was built into the coding, this bias may become entrenched. This was important because characterising teachers as having a high, midrange or low science knowledge was the basis for further analysis.

Simple techniques such as using a numerical code for each teacher were adopted. The large volume of transcript material also reduced the researchers' ability to remember who was who, but some teachers were readily identifiable by idiosyncratic expressions or ideas (e.g. it was not difficult to recall who used Bernoulli's principle to explain why the flame went out). Therefore, a technique of coding in different directions was developed. When coding for teachers' science content knowledge using the concept grids, the first direction was to code teachers in each group. A few

months later, this was repeated in a different direction—all teachers who judged the same student were coded in turn. These two coding sheets were compared, and anomalies (as when a teacher was coded for an aspect from one direction and then not from another direction) were resolved. Coding was repeated at point of need during the writing up phase of the thesis (when using the record sheets to identify teachers with particular beliefs or misconceptions to use as examples). Analysis by different directions was appropriate to draw out more subtle patterns from the data, and repeated interpretations from different perspectives resulted in a high level of accuracy, precision and credibility of coding. When confidence in the coding was established, this signaled that the final stages of analysis could be undertaken—to make the multiple links between teachers' science content knowledge, what they saw or did not see in a student transcript, and how these two aspects combined to influence judgements and follow-up suggestions.

Similar multiple directions were used for codings for judgements teachers made and follow-up activities suggested. Codings were repeated in three directions, and results from each compared, anomalies eliminated and the analysis refined. The first direction was an overview for each teacher, noting the most obvious ways science knowledge had supported or hindered judgements. The second direction was to focus on one phase at a time for each teacher. This provided a greater awareness of subtleties in the effect of teachers' knowledge and trends became apparent (e.g., which phase of the task proved the most challenging). The third direction was to focus on each student, and compare teachers' responses to the same student. This was also productive as it identified how teachers responded differently to the same student work sample. Confidence in coding for teachers' follow-up suggestions was increased by re-coding in two directions (i.e., teachers in the same group, then teachers who judged the same student). Codings were compared and anomalies resolved by refining the wording of the description for teachers' reliance on students' concepts, and their view of science education.

*Other Concerns*

After the interview was concluded, many teachers wished to continue informally, to find out about the student (e.g., "How old was the student?") to ask questions about their own understanding of the candle (e.g., "I'm dying to find out—why does

it go out?"). Through talking about their own performance and finding out about the students, teachers reported they enjoyed the interview experience, had learned about the candle and about assessing students' work. This post-interview discussion addressed concerns in the research community, raised in the *Australian Association of Research in Education Code of Ethics* (Bibby, 1997), that teachers are being researched but not benefiting themselves from the experience. Teachers were also informed their interview would contribute to professional development videos for primary teachers in science content knowledge (Schibeci & Hickey, 1997a).

## 3.6 Overview of the Report

Results of the data analysis are reported in three chapters. In Chapter 4, the results of the analysis of teachers' science content knowledge are presented, and the science content knowledge of teachers with high, midrange and low science knowledge are discussed for each of the three phases of the candle task. Other observations about science content knowledge typical for all teachers, and a comparison of the science knowledge of teachers in the five groups, are presented. In Chapter 5, the results of the analysis of how teachers made judgements about students' science work are outlined, showing the bases teachers tended to use when interpreting students' work and how these reflected the value they placed on students' concepts in their judgements. The type and extent of problems teachers encountered when making judgements are also identified. In Chapter 6, the results for the analysis of suggested follow-up strategies are discussed. Further analysis demonstrates how teachers' science orientation can be inferred by the types of follow-up activities they suggest, which indicate the extent of their adoption of a conceptual change orientation. Chapter 7 discusses results, draws conclusions and makes recommendations for teachers to adopt a conceptual change approach to teaching and learning and an understanding of the effects of science content knowledge and pedagogical content knowledge on their judgements and decisions about helping students in science.

# CHAPTER 4
# TEACHERS' SCIENCE CONTENT KNOWLEDGE

## 4.0 Introduction

This chapter provides results of the analysis of the interview data to answer the first research question, "What do teachers know and understand about the science concepts involved in a selected science-related task?" In the first section, the concepts common to all teachers about the candle are discussed. Each of the three phases, lighting a match, burning a candle and blowing it out, are examined, and illustrated with interview extracts. The second section presents differences in teachers' science knowledge linked to their science background. The major focus of the chapter is the third section where teachers are categorised as having high, midrange or low science knowledge, and their science knowledge is discussed in detail, including scientifically correct views and misconceptions about gases, combustion, melting, chemical change and energy transfers. This categorisation is used as the basis of further analysis in Chapters 5 and 6 of the effect of science knowledge on judgements and follow-up strategies. A summary concludes this chapter.

## 4.1 Science Knowledge for Each Phase

What concepts about the candle did teachers from all groups hold? All teachers had a clear idea that wax melts and linked this to an effect of heat gain or loss. Most involved friction when explaining lighting the chemicals on the match. Other concepts reasonably widely held related to the particular motion of striking the match and the series of transfers in lighting it and then the candle; that the wick burns and heat from the candle flame transfers to the wax so it melts; and that the candle flame is blown out by the sheer force of blowing and then smoke appears.

Teachers' concepts were classified in four ways: as scientifically correct views, well thought out and plausible misconceptions, as inaccurate ideas, and also as ideas that were partial explanations. Some scientifically correct views held by a high percentage of teachers in the sample included wax melts due to heat, matches have a special substance on them so they light, friction generates heat, and smoke is associated with burning.

Other concepts held by many teachers were misconceptions. The most pervasive was that wax did not burn, and that its only role was to slow down the rate at which the wick burned by acting as a barrier to the flames and slowly melting to reveal more wick. Individual teachers demonstrated other misconceptions: molecules in the wax have air between them, that wax is damp like water, and too much oxygen smothers the flame. Another misconception held by teachers was that molecules get bigger as they heat up. While recent work has suggested that molecules do expand during thermal expansion of a substance (Vos & Verdonk, 1996), this accounts for only a small proportion of the total expansion observed, and therefore, teachers who simply stated that molecules got bigger were coded as holding a misconception.

Other ideas teachers held were scientifically correct views in principle, but applied inaccurately, for example, because our lungs remove oxygen when we blow on the flame it only gets carbon dioxide, that blowing forms a vacuum around the flame and this puts it out, or that "hot air rises and spreads out so there's no air for the candle to burn."

Partial explanations, the fourth type of concept, were frequent, when teachers' understandings were not wrong, but they told only part of the full story of the event. For example, teachers were correct that the wax holds up the wick and this is important, but it is only part of the complete explanation—some did not continue with its other function of supplying fuel. Blowing out the candle was another complex event when many teachers included partial explanations, for example, some teachers recognised the flame goes out because of the force of the blow (e.g., Teacher 27), others that blowing lowers the temperature of the wax below that for combustion (e.g., Teacher 2) but few knew the full story that blowing had to be sufficient to disturb the reaction zone of burning of vaporised wax (e.g., Teacher 6).

Each of the phases is examined in detail to discuss the concepts that most, some, or few of the teachers demonstrated. Results shown in Table 8 (Phase 1), Table 9 (Phase 2) and Table 10 (Phase 3) are based on the three concept grids (see Appendix G) which provide the descriptions for each level.

In these tables, the number of teachers who demonstrated each level of understanding is shown. The percentage of teachers who demonstrated each concept

(at any level) is shown in the last column. Four concepts (that involve heat, gases and molecules, and chemical change) recur in each phase.

The numeral 0 in these tables indicates that no teacher in the sample demonstrated an understanding at that level, for example, in Table 8 no teacher was recorded as Level 1 for "striking action." These levels were retained as they were held by students and formed part of the range of responses used during development of the concept grids. They facilitated comparisons between teachers' and students' ideas during the data analysis stage of this research.

### *4.1.1 Phase 1: Lighting the Match*

Over eighty percent of teachers held concepts about friction and what was on the match head (see Table 8). Other widely held ideas related to striking the match, and the transfers between the match and the candle. Few teachers involved gases, chemical change or molecules, but over half made reference to transfers, perhaps because of the very visual movement of the match to the box, the flame to the candle.

Table 8

*Number of Teachers Demonstrating Concepts for Phase 1*

| | Phase 1 | | | | |
|---|---|---|---|---|---|
| | Level 1 | Level 2 | Level 3 | Level 4 | Percent |
| The Match Lights Up | | | | | |
| Striking action | 0 | 19 | 1 | | 66 |
| Substance on match | 10 | 1 | 3 | 11 | 83 |
| Substance on box | 4 | 11 | 0 | 1 | 55 |
| Friction involved | 3 | 2 | 17 | 4 | 86 |
| Heat involved | 0 | 4 | 8 | 5 | 56 |
| Gases involved | 3 | 0 | 1 | 2 | 20 |
| Chemical change | 0 | 0 | 2 | | 6 |
| Molecules involved | 1 | 0 | 4 | | 16 |
| Transfers | | | | | |
| Involved | 3 | 3 | 5 | 9 | 66 |
| Mechanism | 3 | 8 | 7 | | 60 |

Note: An empty cell indicates there was no description for that level.

*The Match Head Needs Friction to Light*

Friction was a common idea (86% teachers involved it in their discussion). Most of these said friction caused or generated heat, and linked this to the side of the match box (Level 3). Some were confident (e.g., "the movement of the match head against the side of the box creates heat. Friction creates heat") others more circumspect "all I know is that these little dots on this match box here obviously allow some sort of correct type of friction for whatever's in there [the match] that ignites it." Four teachers (Level 4) qualified the amount of heat as depending on the extent of the friction and linked this to the need for sufficient speed or strength to generate enough heat for the match to light. Not all teachers who used the term friction linked it to ideas of heat, flame or burning. Three (Level 1) restricted their explanations just to the term friction (e.g., "the side of the box will make that easier ... because it's roughened and creates friction") or a spark (e.g., "the friction and the two surfaces caused a spark that lit the rest ... and it must be because of the rough surface"). Fourteen percent did not refer to friction at all.

*Matches Have a Special Substance on Them*

A high proportion of teachers (83%) mentioned that matches had a substance that made them light. Most responses were unsophisticated (Level 1) and referred to a "special substance" on the match (e.g., "this little red head kangaroo head's got something in there. In Australia because we can't have it like the Americans do ... you know how you have all these cowboy movies and they can do [strike] it anywhere") or were more sophisticated (Level 4) as teachers suggested appropriate chemicals (e.g., "there'll be a chemical compound on the head of the match. It's something not unlike gunpowder. It's probably phosphorous or something like that"). Some provided an appropriate property of that chemical (e.g., "there's phosphorous on the head of the match which has got low activation energy"). Three teachers (Level 3) suggested inappropriate or misleading chemicals which were probably linked to materials that explode (e.g., "saltpetre"), that relate to friction (e.g., "graphite") or a version of phosphorus (e.g., "phosphate"). Nearly all responses were a scientifically correct view as they involved chemicals, but were usually inaccurate about the location or names of the chemicals due to changes in match design (see Appendix I for information on match design).

*A Striking Action is Used to Light a Match*

Sixty six percent of teachers made a comment about how the match was moved, with the majority using the term struck or strike (e.g., "you struck the match and you've lit the candle"). Only one used the key idea of "with sufficient speed." Their reasoning behind the term was not always a scientifically correct view that linked speed, heat and friction. Many held complex, plausible, alternative views, for example, that it was the angle for striking that made it a "safety match" so that "a very young child" would not be able to light it:

> The idea of the safety match is that it's got to be held just at the right angle and struck just in the right way ... you can't strike a match straight down. You have to actually hold the match at an angle and if you don't get it at the right angle it won't light. (Teacher 24)

*Substance on the Box*

Fifty five percent of teachers showed an awareness of the role of "the brown stuff on the box" (Level 1). Eleven saw it as a "rough surface" or "abrasive." Teachers generally saw the role of the striking plate related only to friction, not to chemicals. Only one teacher specified that a chemical was on the box ("probably some phosphorous base or um, nitrogen based compound."

*Transfer*

The mechanism of transfer referred to descriptions of how a transfer was effected: sixty percent made some reference to transfers between the match, matchbox and the candle in Phase 1. When describing the lighting of the match and the candle, three teachers used non-specific terms such as "moves" or "touches" (Level 1); eight used the term "transfer", for example "putting that flame near the string on the candle transferred over because the string can burn" (Level 2); and seven used more specific terms such as "dissipate", "released" or "converted" (Level 3).

### *4.1.2 Phase 2: Burning the Candle*

Phase 2 (see Table 9) had the only two concepts held by all teachers: that wax melts due to an increase in temperature, heat or heat energy, and that it solidifies due to a decrease in these same aspects. It was also distinctive because it revealed

widespread misconceptions concerning whether wax burns and melts, or just melts, and involved teachers demonstrating some quite complex, plausible and well thought-out arguments for their ideas.

Table 9

*Number of Teachers Demonstrating Concepts for Phase 2*

| | Phase 2 | | | | |
|---|---|---|---|---|---|
| Concept | Level 1 | Level 2 | Level 3 | Level 4 | Percent |
| Wick Burns | | | | | |
| Wick is held up | 2 | 11 | | | 40 |
| Wick burns | 16 | 3 | 3 | | 73 |
| Wax slows burn | 7 | 6 | 6 | 1 | 66 |
| Heat involved | 0 | | | | 0 |
| Gases involved | 4 | 2 | | | 20 |
| Chemical change | 3 | 9 | 2 | | 46 |
| Molecules | 2 | 1 | | | 10 |
| Wax Burns | | | | | |
| Wax burns | 0 | 1 | 1 | 6 | 26 |
| Heat energy | 0 | 1 | | | 3 |
| Gases involved | 5 | 1 | 2 | 2 | 33 |
| Chemical change | 2 | 1 | 1 | | 13 |
| Wax Melts | | | | | |
| Wax melts | 4 | 5 | 19 | 2 | 100 |
| Heat involved | 2 | 9 | 11 | 8 | 100 |
| Molecules involved | 1 | 1 | 2 | 6 | 33 |
| Transfers | | | | | |
| Involved | 4 | 7 | 4 | 5 | 66 |
| Mechanism | 8 | 7 | 4 | | 33 |

Note: An empty cell indicates there was no description for that level.

*Wax Melts Due to Changes in Heat*

All teachers provided evidence of concepts about the wax melting. Four (Level 1) gave a very simple description, for example, "the wax is melting" without reference to later setting. The majority (19 teachers at Level 3) used the terms "solid" and "liquid" to describe these changes.

All teachers involved temperature, heat or energy changes when discussing the wax melting; but these ideas varied in complexity from the simplest ideas (Level 1, "the wax melts because it gets hot"), to a reference to heat (e.g., Level 2, "heat melting the wax") to a specification of heat gain and loss (e.g., Level 3, "now the flame's gone out the liquid has turned into a solid because the ... heat source has gone"). Eight teachers (Level 4) stated the need for a certain temperature for melting (although only a few suggested what this temperature was).

*The Wick Burns (But the Wax Doesn't)*

Many teachers (73%) made the simple observation that the wick burns. The majority (Level 1) simply stated this without further explanation. Three teachers (Level 2) suggested "the wick is impregnated with something that slows it" and three held the opposite view, that the wick burns readily. Linked to this idea was the view that the prime function of the wax was to slow down the speed at which the wick burned (66% held this idea). Many explained this as a design feature, for example,

> Candle wax melts slowly. If the wax was to melt quickly and the wick to burn down very quickly then the candle wouldn't be a very useful piece of equipment, and it is useful when it goes that slowly, especially when the power goes out. The wax has an effect on the wick. It stops the flame from burning it. It's not until the wax has melted away from the wick that the flame can burn. (Teacher 20)

Others specified properties of the materials, for example,

> The wick needs to be sustained somehow. A combination of a substance that's going to melt and not catch on fire when it's melting, but also be able to stay in solid form so it can be useful to do its job. (Teacher 23)

Most of these teachers specified very confidently that the wick burned but the wax did not, for example, when a candle is nearly finished "the hot wax actually puts the candle out", "it's like a barrier" and "the candle itself resists the flame." It was often a case of what you understand is what you see:

> The use of wax is perfect because it doesn't catch on fire. It lasts a long time and gradually melts ... I can see a bit of wax being drawn up onto it [the wick] and so wax doesn't burn. (Teacher 23)

This misconception was persistent and robust, for example, one teacher applied scientifically correct views of energy transfers, of fuels and properties of materials to confirm her (mis)conception about the wax:

> You've transferred heat from one to the other and the wick would be a fuel. I'm not too sure what they make wick out of. I imagine it's some sort of cotton so it's long lasting. The wick won't melt away like nylon straight away. And the wax basically is just a prop to hold it up and to slow it down—to slow the burning down. (Teacher 7)

Few teachers (26%) recognised the wax was the fuel source. For some, this idea was certain, for others it was tentative:

> The wick would be drawing up a small amount of the wax for it to burn. Which gets me to think that the actual burning is the wick and the wax is providing the fuel for the wick ... the wax ... provide[s] the flame with an energy source to keep it burning. (Teacher 21)

Many teachers (and all of the students) identified subsidiary design functions of the wax: (a) to melt slowly so the candle "lasts a long time" (Teacher 23), (b) to "hold the string in" (Student 2), (c) "keep the candle straight and to keep it lit" (Student 3), (d) for "the candle so it stands up and also so that it supports the wick that's inside the candle" (Teacher 1), and (e) "the wax basically is just a prop to hold it [the wick] up and ... to slow the burning down" (Teacher 7). The pervasive misconception was

due to the wick's multiple purposes and plausible reasons for the wax's function which appeared sufficient to most teachers without having to involve the wax burning. Very few teachers recognised the wick provided a localised site where the wax can vaporise and burn.

Also within Phase 2, one-third of teachers commented on apparently well-remembered lessons from their own schooling that molecules "change", "spread out" or "move faster" in the context of wax melting (although molecules were far less often involved in other aspects of the task). References to gases and chemical change were generally low, except for 20% who commented that oxygen was needed for the wick to burn, many recalling a classroom experiment: "The fire needs oxygen because if you put a glass over the top of it that will put it out because it won't have any more oxygen." Teachers who knew the wax burned also mentioned oxygen; two teachers specified that burning "produced carbon dioxide and water" and that the wax turned to gas or vapour. Forty-six percent of teachers commented on the carbon of the blackened wick which is a simple indication of awareness of chemical change.

In both Phases 1 and 2, perhaps due to the very visible actions of striking matches and moving the resulting flame to the wick, two-thirds of teachers mentioned transfers, typically of the flame or heat to the wax. They used terms such as flame (Level 1, e.g., "ignited into a flame, putting that near the string on the candle transferred over because the string can burn"); heat (Level 2, e.g., "then you transferred the heat across to the wick of the candle") or the more sophisticated term heat energy (Level 3, e.g., the transfers of heat energy to the wax). Occasionally teachers specified multiple transfers (Level 4, e.g., "so the energy has changed again into light and also heat"), some with a hesitant flair for detail:

> I don't know what the brown stuff is ... You've created a heat, um but you've had to use energy from your own hand to move it of course. So you've transferred, transferred energy ... I forget what its called, but it's kinetic energy ... to the match and then ... then it's called, uh ... there's a word, it means you haven't done it yet. It's potential—the potential kinetic energy. And you've rubbed it, by rubbing it you've transferred energy into sound energy. You've got heat energy there, kinetic energy for the potential energy and with the potential

kinetic energy then transferred into kinetic energy, to lighting, to moving to light the wick. (Teacher 7)

### *4.1.3 Phase 3: Blowing Out the Candle*

Four simple observations in this phase were shared by approximately sixty percent of teachers: the flame goes out, due to the force of the blow, and smoke is associated with cessation of burning (see Table 10).

Table 10

*Number of Teachers Demonstrating Concepts for Phase 3*

| | Phase 3 | | | | |
|---|---|---|---|---|---|
| Concept | Level 1 | Level 2 | Level 3 | Level 4 | Percent |
| Candle Goes Out | | | | | |
| Flame goes out | 9 | 11 | | | 66 |
| Force of blow | 4 | 5 | 9 | 2 | 66 |
| Heat involved | 1 | 4 | 2 | | 23 |
| Gases involved | 5 | 1 | 5 | | 36 |
| Chemical change | 4 | | | | 13 |
| Molecules involved | 1 | | | | 3 |
| Smoke | | | | | |
| There's smoke | 0 | 15 | 2 | 3 | 66 |
| Comes with burning | 2 | 5 | 4 | 7 | 60 |
| Heat involved | 1 | 0 | | | 3 |
| Gases involved | 1 | 1 | 5 | 3 | 33 |
| Molecules involved | 1 | | | | 3 |
| Transfers | | | | | |
| Involved | 0 | 2 | 1 | 3 | 20 |
| Mechanism | 1 | 1 | 2 | | 14 |

Note: An empty cell indicates these was no description for that level.

*Flame Goes Out Due to the Force of the Blow*

Two-thirds of teachers commented that the "flame goes out" (Level 1) or hinted at more complex explanations by using terms such as "smothered", "choked" or "snuffed" (Level 2). Some employed a simplistic, circular explanation that blowing out the candle meant blowing out the flame:

> Well what happened when I blew out the candle is that I blew out the flame ... the air just sort of snuffed it out and when the air snuffed out the flame then the wick didn't have any more—didn't have any more flame. (Teacher 25)

The force of the blow was another common concept (66%). One of the suggestions (Level 1) was that the sheer force of the blow of air blew the flame out, often with an idea of greater or lesser force (e.g., "because the force of the air that you create—the wind that you create is greater than the force of that flame—that puts it out" and also "the energy force of air pressure was greater than the force of energy working to burn itself, so I blew it out"). Five teachers (Level 2) explained that your breath pushed the flame off the wick; nine at Level 3 employed ideas of force, air pressure, changes in temperature and convection currents to support their ideas on why the flame went out. These explanations were diverse, inventive and showed teachers' ability to involve a host of ideas to try to formulate an explanation that was feasible and satisfactory:

> Researcher: Ok, so what is it about you blowing that made the candle go out?
>
> Teacher: Because the forces were not, you know, the forces were not equal at the point where that flame was burning before I blew it out. The air pressure around it was fairly well in balance. I mean it flickered a little bit occasionally and it was heating and you were altering it slightly with the temperature because air was rising. And obviously cold air was moving into replace it but not to ... such as extent that it blew it out. As soon as that pressure coming in greater than the pressure around it ... that force will do so—differential. (Teacher 12)

*Smoke is Associated With Burning*

Many teachers (66%) stated the obvious, that they could smell or see smoke or stated its source (e.g., "well, um, the wick smoked"). At more complex levels, two teachers suggested they could smell wax; and three suggested they could see visible particles (e.g., "some sort of particles in there to make it that white colour"). Sixty percent of teachers linked smoke with burning. For two teachers (Level 1) this was the extent of their explanation; five (Level 2) specified there was smoke when a flame goes out but gave a non-causal link of association (e.g., "Just like when you put any fire out there's smoke. Like the same sort of principle. Obviously when you put a house fire out you get smoke"). Four teachers (Level 3) suggested that the smoke was residual (e.g., "Just residual from the carbon I suppose ... What's left over"). Seven teachers suggested a scientifically correct view (Level 4), some in simple language, recognising an insufficiently high temperature for complete combustion as the cause of the smoke:

> The wick smoked because for a very short time after the ... flame's gone. There's still enough temperature to combust the wick. But it's not actually doing it to burn all the little bits away so it's making smoke. (Teacher 28)

Other Level 4 responses expanded on these ideas, linking a variety of gases, unburnt carbon, and suggesting what it could be if the teacher was not sure:

> The smoke is unburned carbon particles which are partially burnt. But it could be a mixture of either carbon monoxide, carbon dioxide, unburnt carbon particles and water vapour. All of these things together—that was that white smoke that came off. (Teacher 4)

### *4.1.4 Concepts Across All Three Phases*

Some concepts are specific to one phase of the candle task (e.g., striking the match) but others are generalisable and are involved equally in all three, for example, heat, gases, chemical change and molecules (see Appendix G). These broader, abstract concepts are powerful ideas that can be effectively used in multiple contexts

that involve melting, burning and heating, but were generally used infrequently by teachers even though very simple references to the terms and ideas were included as (e.g., Level 1 included the "match goes black" and "molecules heat up" in Phase 1, see Appendix G).

When teachers did use these concepts, they were heavily influenced by the phase of the task. Generally, teachers' science content knowledge was idiosyncratic in that they tended not to apply concepts across similar situations. For example, when explaining about the wax melting, 33% of teachers referred to molecules, this dropped to 16% when explaining how the match lit up (e.g., "friction excites the molecules"), then to 10% for the wick burning, and to none when teachers were explaining the wax burning.

Similar differences were found involving heat (as temperature, heat or heat energy). Teachers brought more sophisticated understandings to situations involving heat and melting wax (Phase 2, 100% for melting wax), than they did about heat and ignition (Phase 1, 56% when lighting the match), with lowest understandings demonstrated for heat in incomplete combustion (Phase 3, 23% when explaining why the candle went out, only 3% for why there was smoke and none for the wick burning). Concepts of chemical change was also irregularly involved by teachers in their explanations, for example, 46% demonstrated some level of understanding of this idea for the wick burning, but none mentioned it to explain the smoke.

## 4.2 Scores for Science Knowledge

The next focus for analysis of the data about science content knowledge was to compare the scores of individual teachers. Teachers' responses were assigned a value (of 0, 1, 2, 3 or 4) that best described the level of sophistication for each concept. The total score for each teacher was the sum of the levels demonstrated for each concept. Table 11 shows scores for each phase and a total score for each teacher (e.g., Teacher 1 had scores of 8, 10 and 9 with a total of 27).

Table 11

*Teachers' Scores for Phases, by Groups*

| Teacher | Score | | | |
|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 3 | Total |
| | | Group 1, Extensive Year 11 | | |
| 1 | 8 | 10 | 9 | 27 |
| 2 | 15 | 19 | 8 | 42 |
| 3 | 12 | 19 | 14 | 45 |
| 4 | 18 | 24 | 17 | 59 |
| 5 | 25 | 13 | 12 | 50 |
| 6 | 26 | 27 | 14 | 67 |
| | | Group 2, Extensive Year 7 | | |
| 7 | 16 | 18 | 15 | 49 |
| 8 | 14 | 21 | 4 | 39 |
| 9 | 11 | 26 | 21 | 58 |
| 10 | 11 | 13 | 11 | 35 |
| 11 | 15 | 20 | 8 | 43 |
| 12 | 11 | 20 | 13 | 44 |
| | | Group 3, Limited Year 7 | | |
| 13 | 15 | 8 | 6 | 29 |
| 14 | 14 | 13 | 5 | 32 |
| 15 | 13 | 12 | 10 | 35 |
| 16 | 12 | 13 | 4 | 29 |
| 17 | 12 | 12 | 4 | 28 |
| 18 | 23 | 18 | 8 | 49 |

Table continues.

Table 11

*Teachers' Scores for Phases, by Groups (continued)*

| | | | | |
|---|---|---|---|---|
| | | Group 4, Extensive Year 3 | | |
| 19 | 19 | 10 | 7 | 36 |
| 20 | 9 | 9 | 9 | 27 |
| 21 | 19 | 20 | 17 | 56 |
| 22 | 7 | 17 | 7 | 31 |
| 23 | 14 | 17 | 14 | 45 |
| 24 | 3 | 13 | 6 | 22 |
| | | Group 5, Limited Year 3 | | |
| 25 | 7 | 12 | 6 | 25 |
| 26 | 7 | 13 | 7 | 27 |
| 27 | 12 | 14 | 6 | 32 |
| 28 | 12 | 17 | 7 | 36 |
| 29 | 16 | 17 | 7 | 40 |
| 30 | 4 | 10 | 7 | 21 |

The results in Table 11 show that teachers demonstrated a range of science knowledge. The range of total scores was 21 (Teacher 30) to 67 (Teacher 6). This establishes that selection of teachers by their science background (i.e., initial allocation to a group depended on the teachers' extensive or limited science education history and the ages of students they usually taught) resulted in a range of science knowledge, which was an aspect of the research design.

The extent of variation of some teachers' scores from others in their group was unexpected. For example, Teacher 1's total score was not consistent with others in the Extensive Year 11 group, while Teacher 9 from Extensive Year 7 and Teacher 21 from Extensive Year 3 were uncharacteristically high and both close to the highest score of 67. This variation within groups is indicative of the wide range of science knowledge teachers as individuals hold, and how teachers' levels of knowledge should not be assumed on the basis of their science background. These differences are partially explained by teachers' comments during the interviews of other factors that were influential on their science knowledge: their ability to recall high school science,

their specialisation in physical or biological sciences, and even personal opportunity to engage in science through their partner's career (e.g., Teacher 10 remarked that her partner was an engineer and that this had helped her science understanding).

The extent that some individual teachers' science content knowledge varied between the three phases of the candle task indicates that some applied their knowledge inconsistently. Table 12 shows the average scores for each phase, and is useful as a way to compare individual teachers scores against the average, for example, Teacher 16 (scores of 12, 13 and 4, see Table 11) was close to the average score for Phases 1 and 2 but well below the average score for understandings about blowing out the candle (see Table 12). Not all teachers followed this pattern, for example, Teacher 20 was below average for Phases 1 and 2, but performed relatively well in Phase 3.

Table 12 also shows that the range of scores within each phase was similar, with the minimum score for Phase 2 slightly higher. Because the three concept grids were derived from students' and teachers' responses, each scores for a different numbers of concepts (e.g., Phase 1 scores for 10 concepts and Phase 2 for 16 concepts) and has different levels for each of the concepts (e.g., from one to four), it is not valid to compare the average scores across the three phases, nor to conclude that teachers performed, on average, better in Phase 2 than in Phase 3.

Table 12

*Teachers' Scores for All Three Phases*

| | Score | | | |
|---|---|---|---|---|
| | Phase 1 | Phase 2 | Phase 3 | Total |
| Total | 400 | 475 | 278 | 1158 |
| Average | 13.3 | 15.8 | 9.2 | 38.6 |
| Range | 3 - 25 | 8 - 27 | 1 - 21 | 19 - 60 |

Teachers' science knowledge of the task reflected, to some extent, their science education history (see Table 13). All three groups with an extensive science education history had higher average scores than did the two groups with limited histories.

Table 13

*Summary of Scores for Groups for All Three Phases*

| | Score | | | | | |
|---|---|---|---|---|---|---|
| Group | Phase 1 | Phase 2 | Phase 3 | Total | Average | Range |
| Ext. Year 11 | 104 | 112 | 74 | 290 | 48.3 | 27 - 67 |
| Ext. Year 7 | 78 | 118 | 72 | 268 | 44.6 | 35 - 58 |
| Lim. Year 7 | 89 | 76 | 37 | 202 | 33.6 | 28 - 49 |
| Ext. Year 3 | 71 | 86 | 60 | 217 | 36.1 | 22 - 56 |
| Lim. Year 3 | 58 | 83 | 40 | 181 | 30.1 | 21 - 40 |

Note: Lim. refers to limited, and Ext. to extensive science education background.

The age of students usually taught (see Table 14) reflected differences in teachers' science knowledge. Year 11 teachers had a higher average score for all three phases than did Year 7 teachers. The lowest average score was held by Year 3 teachers. Appendix J has full details of these results.

Table 14

*Summary of Scores by Ages of Students Usually Taught*

| | Score | | | | | |
|---|---|---|---|---|---|---|
| Student | Phase 1 | Phase 2 | Phase 3 | Total | Average | Range |
| Year 11 | 104 | 112 | 74 | 290 | 47.3 | 27 - 67 |
| Year 7 | 167 | 194 | 109 | 470 | 39.1 | 28 - 58 |
| Year 3 | 129 | 169 | 100 | 398 | 33.1 | 21 - 56 |

This decrease in the average score from the Year 11 to Year 3 teachers suggests that teachers' science knowledge of the task was less sophisticated when the teachers' experience was with younger students. This was probably due to the differences in demands on teachers' science knowledge (the higher conceptual level of the upper secondary curriculum and the non-specialisation of the science curriculum in primary) and education history (secondary science teachers must hold a degree in science).

While this trend is not unexpected, teaching Year 3 or Year 7 did not exclude individual teachers from demonstrating high science knowledge about the candle.

Teachers with the highest and lowest scores demonstrated similar knowledge (see Appendix J) irrespective of the age of students they usually taught: highest scores for Year 3, 7 and 11 (scores of 56, 58 and 67) were similar as were the lowest scores for Year 3, 7 and 11 (scores of 21, 28 and 27). This is not necessarily true for other science tasks which require different knowledge (e.g., the draw-an-atom type of task mentioned in Chapter 3).

### 4.3 High, Midrange and Low Science Knowledge

The categorisation of teachers as having high, midrange and low science knowledge provided further answers for the research question of what teachers understood about the candle task: how their explanations varied, how they used specific science terminology, how they referred to and used key concepts, and their confidence and fluency.

Teachers were ranked by their total score for the three phases. Cut-off points were set to allow ten teachers in each category as high (44-54), midrange (32-43), or low science knowledge (19-31). Results in Tables 15, 16 and 17 summarise Appendix K (for Phase 1), Appendix L (Phase 2) and Appendix M (Phase 3).

Similarities and differences of science content knowledge for teachers with high, midrange or low science knowledge were extracted from the interview data, guided by the patterns in Appendixes K, L and M. These captured what was typical of teachers' different levels of sophistication of knowledge of the candle, irrespective of their science background, as categories on a limited number of variables. This was appropriate as teachers with the same reported science background demonstrated highly divergent scores, and some individuals varied widely in their science knowledge for each phase. For example, Teacher 18 (Limited Year 7, with a score of 49, ranked equal 6th, see Table 15) was categorised as having high science knowledge; Teacher 17 (also in the Limited Year 7 group, with a score of 28, ranked 24th, see Table 17) was categorised as having low science knowledge. Most of the teachers with high science knowledge had an extensive science education history (four of the six who taught Year 11 were in this group) and those with low science knowledge typically had a limited science education.

Table 15

*Scores and Ranking for Teachers With High Science Knowledge*

| | | | High Science Knowledge | | | |
|---|---|---|---|---|---|---|
| Teacher | Phase 1 | Phase 2 | Phase 3 | Total | Ranking | Group |
| 6 | 26 | 27 | 14 | 67 | 1 | Ext. 11 |
| 4 | 18 | 24 | 17 | 59 | 2 | Ext. 11 |
| 9 | 11 | 26 | 21 | 58 | 3 | Ext. 7 |
| 21 | 19 | 20 | 17 | 56 | 4 | Ext. 3 |
| 5 | 25 | 13 | 12 | 50 | 5 | Ext. 11 |
| 18 | 23 | 18 | 8 | 49 | = 6 | Lim. 7 |
| 7 | 16 | 18 | 15 | 49 | = 6 | Ext. 7 |
| 3 | 12 | 19 | 14 | 45 | = 8 | Ext. 11 |
| 23 | 14 | 17 | 14 | 45 | = 8 | Ext. 3 |
| 12 | 11 | 20 | 13 | 44 | 10 | Ext. 7 |
| Total | 175 | 202 | 145 | 522 | | |

Note: = indicates equal ranking

Table 16

*Scores and Ranking for Teachers With Midrange Science Knowledge*

| | | | Midrange Science Knowledge | | | |
|---|---|---|---|---|---|---|
| Teacher | Phase 1 | Phase 2 | Phase 3 | Total | Ranking | Group |
| 11 | 15 | 20 | 8 | 43 | 11 | Ext. 7 |
| 2 | 15 | 19 | 8 | 42 | 12 | Ext. 11 |
| 29 | 16 | 17 | 7 | 40 | 13 | Lim. 3 |
| 8 | 14 | 21 | 4 | 39 | 14 | Ext. 7 |
| 19 | 19 | 10 | 7 | 36 | = 15 | Ext. 3 |
| 28 | 12 | 17 | 7 | 36 | = 15 | Lim. 3 |
| 15 | 13 | 12 | 10 | 35 | = 17 | Lim. 7 |
| 10 | 11 | 13 | 11 | 35 | = 17 | Ext. 7 |
| 14 | 14 | 13 | 5 | 32 | = 20 | Lim. 7 |
| 27 | 12 | 14 | 6 | 32 | = 20 | Lim. 3 |
| Total | 141 | 156 | 73 | 370 | | |

Note: Ranking is continued from Table 15; = indicates equal ranking

Table 17

*Scores and Ranking for Teachers With Low Science Knowledge*

| | | | Low Science Knowledge | | | |
|---|---|---|---|---|---|---|
| Teacher | Phase 1 | Phase 2 | Phase 3 | Total | Ranking | Group |
| 22 | 7 | 17 | 7 | 31 | 21 | Ext. 3 |
| 13 | 15 | 8 | 6 | 29 | = 22 | Lim. 7 |
| 16 | 12 | 13 | 4 | 29 | = 22 | Lim. 7 |
| 17 | 12 | 12 | 4 | 28 | 24 | Lim. 7 |
| 1 | 8 | 10 | 9 | 27 | = 25 | Ext. 11 |
| 20 | 9 | 9 | 9 | 27 | = 25 | Ext. 3 |
| 26 | 7 | 13 | 7 | 27 | = 25 | Lim. 3 |
| 25 | 7 | 12 | 6 | 25 | 28 | Lim. 3 |
| 24 | 3 | 13 | 6 | 22 | 29 | Ext. 3 |
| 30 | 4 | 10 | 7 | 21 | 30 | Lim. 3 |
| Total | 84 | 117 | 65 | 266 | | |

Note: Ranking is continued from Table 16; = indicates equal ranking

A comparison of total scores (within the same phase) for teachers with high, midrange and low science knowledge (see Table 18) suggests that the ideas in Phase 3 (about extinguishing a flame and what smoke is) proved equally difficult for teachers with midrange and low science knowledge.

Table 18

*Total and Average Scores for Teachers With High, Midrange and Low Science Knowledge, by Phase*

| | Science Knowledge | | |
|---|---|---|---|
| Phase | High | Midrange | Low |
| Phase 1 | 175 | 141 | 84 |
| Phase 2 | 202 | 156 | 117 |
| Phase 3 | 145 | 73 | 65 |
| Total (Average) | 522 (174.0) | 370 (123.3) | 266 (88.66) |

A key interpretation of these results was that science knowledge was less a case of teachers having or not having concepts, but more about the level of sophistication with which they used these concepts. Teachers often held concepts about the same aspect of the candle task (e.g., friction) but the level of sophistication of understanding for that concept varied (e.g., some just used the term friction, others linked it to heat, still others to a system of transfers of heat energy). Teachers who scored highly usually used some concepts in all three phases, for example, concepts about molecules.

Generalisations about teachers' science content knowledge on the basis of their science education history or ages of students usually taught, or their score during a science interview, must be made cautiously. Trends and similarities can be described, and terms such as high or low science content knowledge convey a sense of what is common or typical, but teachers demonstrated their science concepts in idiosyncratic ways. For example, some individuals recognised the wood of a match as fuel but insisted the wax was there only to stop the wick from burning too fast. Some employed an effective molecular model in one phase (e.g., when explaining wax melting) but relied on gross observations in another (e.g., to explain smoke).

### *4.3.1 High Science Knowledge*

What were the characteristics of teachers ranked with the highest scores for science knowledge? These teachers used more sophisticated, complex and abstract ideas and more specialised science terminology than did teachers with lower scores. They were more likely to provide scientifically acceptable explanations of events (they held fewer misconceptions and were less inaccurate) and made causal links more competently. One distinguishing characteristic was the high incidence of awareness of transfers, for example, they involved temperature, heat or heat energy consistently in their explanations and often specified the mechanism of transfer. They were more confident in their understanding, for example, they risked suggesting the names of chemicals rather than using less specific options such as "chemical" or "substance." They did not consistently refer to concepts of gases or chemical change.

*Lighting the Match*

In the first phase the key characteristic was the idea of sufficient heat energy being available to ignite the match head. Teachers used both simpler terms (e.g.,

"enough heat") or more specific terms like activation energy or ignition point. Some, whose knowledge was practised, were succinct, linking multiple concepts such as heat, friction, ignition temperature, ignition point, chemical properties neatly (although including an inaccuracy on the location of the chemical):

> The angle of strike was just right to produce enough friction and enough heat to reach the ignition temperature and for the phosphorous and, um, potassium chloride material in the match head to light up. So you reached the ignition point when you were striking with the right force. (Teacher 4)

Others were familiar enough with concepts and terminology to provide a correct, although hesitant account that was less cohesive. Although lacking some of the terminology, Teacher 21 alluded to many sophisticated concepts:

> Right, um, you took a match out of the box. Then you, um struck it on the side which obviously, um there was a chemical, chemical reaction between the match head and this stuff on the side of the box. Um, there was friction involved which ignited the end of the match—where there's obviously some sort of chemical in there. Um, heat was formed, um heat was then given off—intense heat was given off. Um, the wood—the heat was so intense that the wood actually started to burn and the heat was then transferred from the match from the burning wood to the wick of the, um candle, which is now burning. Heat from the actual striking that the friction would heat caused the [unfinished]. Obviously you need a heat source to ignite a chemical. (Teacher 21)

*Burning the Candle*

Teachers with high science knowledge were likely to recognise that both the wick and the wax burn (six of the ten did so). Most referred to ideas of carbon (as an indication, or product, of chemical change) to describe the wick blackening. One teacher's explanation was outstanding and specified that wax vaporised before burning:

> The wick is in fact relatively unimportant. Um, the important part in terms of the burning of the candle is the wax bowl which has formed there. It's the actual wax which is burning ... The wick is burning but very, very slowly, and in fact the wick only burns down when the wax level falls. Once the wax level falls then a proportion of the wick burns to actually take the flame back to the surface ... It's the hydrocarbon which makes up the wax which is actually being vaporised and then burning. So 99% of the ... energy which is involved in the heat and the light is coming from the wax, less than 1% is coming from the wick. So the wick is just a place to localise where the flame will actually burn. (Teacher 6)

Teachers with high science knowledge were not always so certain. For Teacher 5, strong visual evidence versus book learning led to uncertainty (e.g., "it doesn't look like it, does it? But I know the wax at the top of the wick [burns]. No, that doesn't make sense, does it?"), vacillation and use of competing ideas of the wax as fuel (e.g., "the wick burns but also some of the wax burns ... they combine with oxygen to produce $CO_2$ and $H_2O$") or that it just coated the wick ("well the wax doesn't actually [burn]. The wick's coated with wax ... so it would be, so that's the string, so it would be the string burning and some wax that was probably impregnated in the wick"). This classic mismatch between what she had learned and what she could see stimulated her to use observation and reasoning skills to try and work out this frustration she felt to explain events in a reasonable manner:

> There's a nagging doubt because I think I've read somewhere that the wax actually burns. But now that I'm observing it that doesn't match up with my preconceived idea ... I know that if you have a great big bowl of a candle it [the flame] can actually drown in the melted wax. And you'd think that if the wax is going to burn that it would actually catch on fire in here [indicates melted wax reservoir] wouldn't you? (Teacher 5)

Teachers with high science knowledge consistently used ideas of heat transfer to explain the wax heating, melting, burning and setting. They used terms such as solid

and liquid. Most were comfortable with multiple transfers of heat and energy between the parts of the candle system. Some provided specific temperatures:

> The specific temperature being involved in melting or re-solidifying, for example, the temperature the wax melts at about 54 degrees Celsius and the temperature of the flame is about 80 degrees Celsius ... sufficient to keep the wax melting. And when the flame has gone out the wick starts cooling off. The temperature goes below the melting point of wax and so the wax cannot receive latent heat. (Teacher 4)

Teacher 9 consistently involved energy transfers, and like many others with high science knowledge referred to molecules only for his explanations of the wax melting, where he was fluent, although not all of his ideas are scientifically correct views:

> The transfer of the heat energy to the wax it's causing ... the molecules to move ... out from a solid state into a more fluid state. So as the energy is being applied to it the molecules are moving faster and faster until it gets to a point where it becomes free fluid. It's actually because the molecules are no longer compact, as in a solid state. As the heat's supplied to it the molecules are being forced to jump further and further apart to a point where it becomes a liquid mass. (Teacher 9)

Teacher 23 scored consistently in all three phases although was usually at a lower response level than, for example, Teacher 9 for similar concepts. Her presentation was less fluent and cohesive and her ideas demonstrated a broad range of science knowledge, but with misconceptions. High science knowledge did not automatically mean teachers held scientifically correct views for all aspects of the candle, for example, this teacher applied her understanding of ice as an analogy to explain the changes in melting wax and involved air spaces around the molecules getting bigger:

> The wax is melting ... because the temperature is upsetting its rigidity ... It's melting basically because ... the heat is transferring to it and it's changing state

> ... that's making the wax melt ... Um the little molecules when they're in the candle stick are actually solid and locked closely together. Now that they're being melted they're ... separating. There's more space within them and they're able to move in that forming a liquid. They're no longer rigid and closely packed together ... There's air space around them so that they're ... actually able to move ... I'm thinking like an iceblock, um when it's um solid, the ice block is actually slightly bigger than the water that goes in there. So I guess that what I'm saying is that it actually the molecules do probably get bigger ... Actually in the liquid of the ... melted wax that the air is between all those molecules. I don't know where it comes from. (Teacher 23)

*Blowing Out the Candle*

Most teachers with high science knowledge relied on heat in their reasoning for the candle blowing out, but for many, their partial understanding of burning supported only incomplete explanations of why the flame went out. They were likely to state that the flame was cooled, that the temperature was too low for combustion or there was insufficient heat energy, for example, "when I blew the thing I started to remove the heat from it so that's why we saw the white unburned carbon and stuff that's going up." Others gave ideas of physically removing the flame, combined with supporting ideas about cooling and continuance of oxygen supply (Teacher 7 saw the wick as the fuel):

> Because my breath is strong enough to blow it [the flame] away from the wick it has no fuel to keep burning. It's got oxygen but it's got no fuel. And it might possibly be affecting that my breath is cooler than the wick and so it's cooling it down at the same time. Maybe that might have something to do with it. I've never thought about that. (Teacher 7)

Teachers with high science knowledge often applied scientifically correct views or terms when they tackled new situations although their conclusions were not always satisfactory. For example, Teacher 3 found it very difficult and struggled to link her ideas of moving molecules, available energy and how these made the flame go out:

Teacher: I guess you're dissipating the, um energy. You're spreading it out and you don't, you no longer have—you know [pause]

Researcher: How do you dissipate it?

Teacher: Oh, by, um moving air molecules around it. So you no longer have enough energy to support a flame I guess is one way of putting it.

Researcher: So are you blowing the energy away?

Teacher: No, no, you're not blowing the energy away. I haven't ever explained this to anyone before. I'm making this up as I go along. I'm moving the air molecules. And I mean, when you blow air out, I mean that moving air is kinetic energy. Um, I guess, um I mean dissipate is the only sort of word that I can think of. That, you're like, breathing it out ... so much that it's not blowing the energy away, but so that there's insufficient energy to support a flame. (Teacher 3)

Teacher 6's explanation was the most comprehensive; he involved all of the necessary aspects (of physical disturbance of the flame, reduction of heat, loss of fuel) which others had done, but combined them all into a coherent explanation. He also compared this to an alternative way of putting out the flame—by grabbing it to remove its "oxygen supply" and discussed "concussion" methods of explosives that both disturb the fuel and remove the oxygen. His clear idea of vaporisation of wax as the fuel supported his explanation:

> You disturb the flame which effectively causes a disturbance in the vaporisation of the wax which removes the fuel supply. So once the fuel supply is removed . it's gone .... What you're trying to do is as quickly as you can to remove the flame and disrupt the flow. Once you disrupt the flow ... of the heat energy then you lose that [flame]. (Teacher 6)

When teachers with high science knowledge commented on the smoke, it was usually to describe it as visible particles and associate it with incomplete burning,

suggesting possible gases (e.g., "evaporated wax", "unburned gases") or specified gases (e.g., carbon monoxide, carbon dioxide, water vapour).

### *4.3.2 Midrange Science Knowledge*

Teachers demonstrating mid-range science knowledge were characterised not by obviously different concepts or misconceptions when compared to teachers with high science knowledge but because their responses were more often at a lower level, so their overall score was depressed. For example, when explaining how wax melts, teachers with midrange science knowledge tended just to say that molecules were involved (Level 1) but teachers in high science knowledge specified how they were involved (i.e., by vibrating faster; Level 4). In a similar way, teachers with midrange science knowledge were just as likely as teachers with high science knowledge to involve concepts of friction, but their ideas generally focused on how it generates heat (Level 3) and they were less likely to specify it had to reach a certain temperature for it to burn (Level 4).

*Lighting the Match*

Teachers with middle rankings were less likely to use terms like chemical or energy than teachers with high science knowledge; their use of such terms was more cautious, and their suggestions were more often incorrect, for example, when hazarding a guess at what was in the match head, one suggested "phosphate" (Teacher 15); "some sort of sulfur base isn't it?" (Teacher 2); and "the match head is made out of goodness graphite, or something. No. Whatever it's made out of anyway" (Teacher 27); "it's probably something like saltpetre but I don't know" (Teacher 28). This often kept the level of their responses lower than teachers with high science knowledge.

Typical of teachers with mid-range science content knowledge were comments that were expressed without certainty (although this also happened with teachers with high science knowledge). The impression was of teachers who have not used this science knowledge perhaps since high school, and were trying to recall these memories of terms and ideas and apply them hesitantly to the candle context during the interview.

One of the key features of teachers with midrange science knowledge was their inability to fully utilise a concept in their explanations. Although Teacher 29 was

distinctive when compared to others with midrange science knowledge as he involved molecules on three occasions in his interview, on each occasion he seemed unable to apply the idea successfully: when he explained lighting the match ("um .. basically the energy in the movement is [unfinished] It needs to go somewhere and ... it, the molecules have to give off [unfinished]. So yeah, it's [unfinished]. That's my basic understanding"); explained why wax melted ("intense heat" made the wax "turn to a liquid form" and "it destabilises the molecules somehow but I am not quite sure how it would do that"); recalled that oxygen was involved in burning ("once it gets started my understanding would be that it would then [unfinished] the oxygen around would sort of re-supply, but ... I wouldn't be able to tell you yeah"); and how the wick changed ("basically it's degenerating. So as the fire burns it is, um starts off white but obviously goes to black and it's simply the molecules are burning up, and, yeah, degenerating").

*Burning the Candle*

The retrieval of relevant ideas from teachers' science education, although uncertain and without fully utilising the ideas, was stimulated and channeled by the interview situation—it supported teachers to access appropriate ideas, make connections and think through ideas of a higher response level than ones they originally made. This was one of the reasons these teachers outperformed those with low science knowledge. For example, Teacher 28 started with the idea that heat melted the wax "because it gets hot" (Level 1) which he developed to Level 3 responses about changes from solid to liquid, molecular changes, and a suggestion of an idea of melting point (see underlined phrases below):

Teacher: What's happening there is that ... the wick ... is being exposed as ... the heat from the <u>flame melts away the wax</u> which is surrounding the wick, and ... so that the wick's ... exposed so it's able to burn.

Researcher: Why does the wax melt?

Teacher: Because it gets hot.

Researcher: Why does getting hot make it melt?

Teacher: Because it's ... that's sort of the state of ... um .. It's a solid state at a particular temperature and when the temperature's too raised [*sic*] it goes into a liquid state.

Researcher: What is it about raising the temperature that makes it go into a liquid state?

Teacher: Because all the little molecules become agitated ... and they spread apart and get bigger spaces between them, I think. (Teacher 28)

Teachers with midrange science knowledge had difficulty explaining what exactly heat did to make the wax melt. What distinguished teachers from those with low science knowledge was evidence of powerful emerging ideas (e.g., "amount of heat"). For example, Teacher 15 knew that heat was essential for the wax to melt but made simplistic explanations ("because that's what wax does") then demonstrated a scientifically correct view as she compared chocolates and pencils although she could only partly remember the scientific terminology:

Teacher: But the wax is melting because it's heating up.

Researcher: Why does it melt when you heat it up?

Teacher: Because that's what wax does.

Researcher: And can you hazard a guess why that's what wax does?

Teacher: It's obviously got a low—now what do they call it? It's got a special name and it's um a low combusa' [unfinished]. No, it's not low combustibility. It's um, ah, I can't remember the exact word but the basic thing is it's got a lower melting point than something else has.

Researcher: What's melting point?

Teacher: Um, where, when something is a certain amount of heat. Um, some things can take more heat than others. For example, choccies in the sunshine can't take a great deal of heat before they start to melt. So they've got a lower melting point. Um, whereas if, I mean, you could put a pencil out in the sun for ever and ever and it would never melt because it has a higher [unfinished]. (Teacher 15)

As with high science knowledge, there were individuals who went outside the pattern: eight of the ten teachers within the middle range of science knowledge did not state the wax burned, but two (Teachers 2 and 8) did. Both these teachers scored well in some phases of the task but inappropriately applied ideas (the candle went out "partly to do with Bernoulli's principle") or inaccurate suggestions (the smoke was "evaporated wax") kept their overall scores lower than others' scores.

*Blowing Out the Candle*

Another distinguishing characteristic of teachers with a midrange science content knowledge was a strong desire to make an explanation, to try out ideas, reject and look for alternatives, more so than teachers with lower science knowledge who less frequently pursued alternatives. They were not afraid of suggesting an idea. In the case of one teacher, the decision about why the candle went out was reached after many reversals:

Teacher: Um, basically I provided too much oxygen at one time and ... it just smothered it, or removed [unfinished]. Actually my blowing probably removed the oxygen from the direct contact.

Researcher: How would your blowing remove the oxygen?

Teacher: I'm not quite sure. I, I, well basically it's altering the, the um, the amount of oxygen being burnt up around would suddenly disappear. I almost create a vacuum around it and just blows itself out. (Teacher 29)

Sometimes this led to inappropriate use of science terms and concepts to explain events. Teacher 27 suggested a smorgasbord of ideas which included inaccuracies and misconceptions, involving expanding gases, a vacuum, forces and dampness, which were tried, then discarded, in her search for a personally satisfying explanation:

When fire burns the air expands. There's no air around that burning area as it goes out. Has it got something to do with that? ... Because the force of the air that you create—the wind you create—is greater than the force of the flame that puts it out. And the wind that could carry a fire or it could blow it out—a bush

fire ... I don't really know why things smoke, but they do don't they? I know green leaves and damp things smoke more than other things. There's a certain dampness because it's melted the candle wax. (Teacher 27)

### *4.3.3 Low Science Knowledge*

Teachers categorised with low science content knowledge were likely to teach Year 3, or have a limited science education history and teach Year 7 (except Teacher 1 from Year 11). Typically, these teachers used fewer scientific terms and made fewer comments about events. These teachers were unsure of causes of phenomena and frequently said they were confused, were least likely to try out ideas, and when they used scientific terms they were usually not used to fully explain phenomena. Many would finish an attempted explanation stating that was the limit of what they knew, such as "heat makes wax melt but I don't know why" or "friction generates heat but I don't know how." They were the least likely to specify transfers in any of the phases.

*Lighting the Match*

When teachers with low science knowledge talked about lighting the match, they were less likely than teachers with high or midrange science knowledge to make a comment about the match head, and if they did, usually restricted their comments to general terms (e.g., a "special substance) and did not suggest a name for the chemical (e.g., "the chemicals on the match head, the red part on the end of the match is a mixture of some sort of chemical type thing").

They were less likely to include the matchbox as rough or abrasive in their explanations; over half did not mention the key concept of friction; and those that did generally just used the term without explanation other than to say it "makes the match hot." Linked to this omission of friction, in a follow-on effect, teachers were also less likely to mention heat or temperature involved in lighting the match (i.e., they were more likely to say the match burns and ignites, but not involve heat or heat energy). Consequently, they were very unlikely to specify that there needs to be "sufficient heat" for the match to ignite, or that the match's flame needs oxygen.

Typically they focused on the description of an observable sequence in preference to a science explanation for what they were seeing:

> You took the match out of the box and the match heads were that way [orients box]. You picked up the match from the dead end—the non lighting end. You struck it, um, away from you I think. I didn't notice that actually. And then [you] held the candle ... horizontally, and lit it. And you flicked the match out and put it in the box like so [demonstrates]. (Teacher 16)

Those who used the terms friction and energy found it difficult or confusing to apply these ideas to explain events to their own satisfaction, for example,

> The red part on the end of the match is a mixture of some sort of chemical type thing. That the friction and the force from your hand rubbing against the corrugated part of the match box causes it to ignite somehow. Yeah, the energy, the friction really. (Teacher 22)

> If you rub something against the other it causes friction which is, um a heat, um and the more you rub it the more heat is generated. Which make the ... match light I presume. So in the chemical in the match head, um make it ignite .... I presume the molecules get excited .... molecules move and in doing so create the heat .... I don't know whether they extract something out of the atmosphere even ... to make it heat up .. I've never really thought about it much. (Teacher 16)

*Burning the Candle*

The most consistent characteristic of teachers with low science knowledge was a strong belief that

> Wax doesn't burn. The candle wick is meant to burn and it actually burns whereas when you heat the wax it just changes from a solid to a liquid and when it cools down it changes back to a solid. (Teacher 24)

All focused on the wick, explaining the wax "was there to hold the wick up straight" or that wax "makes the candle last a long time" because the wick won't burn

until it's exposed slowly by the wax melting away. Some elegantly explained this (misconception) as a useful design:

> Well it's a very clever thing a candle .... It has the candle wax melt very slowly and that's what makes candles useful .... If the wax was to melt quickly and the ... wick to burn down very quickly then the candle wouldn't be a useful piece of equipment ... and it is useful when it goes that slowly especially when the power goes out ... The wax has an effect on the wick. It stops the flame from burning it. It's not until the wax has melted away from the wick that the flame can burn. (Teacher 20)

All were familiar with changes from solid to liquid in the wax, and that this was due to heat from the flame. However, they were unlikely to specify transfers, even at the simplest level, in the observed changes. Teachers also used terms in imprecise ways, for example, the wax melts because of "the energy that's burning there" or the candle went out because "the wind reacted with the heat which was enough to put the candle out."

Others associated heat with the candle melting and used terms such as solid and liquid confidently, but were at a loss to explain this in more detail, for example,

> Heat from the flame melts wax because it's hot but I don't know how to explain it further. (Teacher 22)

> What's happening with the candle is obviously the candle—it's a solid and whatever it is—the flame it's changing its properties. It's making it go into liquid. I don't know why it does that. (Teacher 25)

> The molecules get excited ... I know nothing very much about that. I presume the molecules move and in doing so create the heat ... I don't know whether they extract something out of the atmosphere even to make the heat up. I've never really thought about it much. (Teacher 16)

The following extract demonstrates how many teachers found access to science explanations difficult, imprecise, and hesitant, and how they reached their maximum level of explanation through encouragement by the researcher. This teacher—like others—attempted explanations like a war of strength between the wax and the flame, with energy seen as something that comes from heat (rather than heat as a form of energy).

Teacher: The heat from the candle is causing the candle wax to melt because heat has this—you know the energy of heat on wax is causing it.

Researcher: How does the energy cause [this]?

Teacher: Um ... That's a good question. How does it? Well ... I'm trying to think how to put it into [words]. You can change the [unfinished] Oh, come on! [admonishes self] I'm thinking of solids, liquids and, um gases and, um I'm trying to think how to put this in a way that would easy to describe ... The energy from the heat is greater than [unfinished]. The power of that energy is greater than that of the candle wax and therefore the effect of the heat on the candle wax is to cause it to change from a solidified state ... to a liquid state. (Teacher 20)

As with teachers of high and midrange knowledge, individual teachers with low science knowledge also demonstrated isolated concepts that were of a more sophisticated level, but with misconceptions. For example, Teacher 24 attempted to explain why the wick was black, and said "its properties are being changed" because of "heat" which changed the "chemical composition ... well it's the same thing when you have electrons and that. You're just heating them up and they cause some to fly off—when it changes the properties of it." She explained that she had helped her daughter (who was recouperating from an illness) with her first year university chemistry course and had "absorbed" some of the ideas.

*Blowing Out the Candle*

This phase proved the most difficult for teachers with low science knowledge. The most consistent characteristic when talking about blowing out the candle was the lack of reference to changes in temperature, heat or heat energy, and absence of specifying the transfers involved. A few teachers were satisfied with the simplest answer, that the force of the blow made the candle go out. Others attempted an explanation that recalled a high school experiment (e.g., "The fire needs oxygen because if you put a glass over the top of it that will put it out because it won't have any more oxygen"). Others used their own knowledge to suggest (to them) plausible ideas such as an oversupply of carbon dioxide or that blowing it deprived it of oxygen:

> Just for a second I deprived the, um wick or the flame of oxygen and it went out ... When you blow on it, you've got less oxygen when you breathe out than what is surrounding it. The air around it has got 20% or 20.4 or something like that [of] oxygen. But when I breathe in, the body takes that oxygen and there's not as much when you breathe out. (Teacher 16)

The tactic, typical of teachers with midrange science knowledge, of suggesting a suite of possibilities for consideration rather than a coherent argument, was also used by teachers with low science knowledge, but while they may have the same terms or concepts (e.g. oxygen, force, carbon dioxide, snuffed) they were less secure and sophisticated in their understanding and unable to apply them convincingly or fully. For example, Teacher 25 when asked to explain what it was about her "blowing that made the flame stop" said

> Um, mm I think that, um carbon dioxide [unfinished]. Obviously it's something to do with the air and obviously, um oxygen can make the candle burn more, and obviously something that I've just breathed out, and the force of what I've breathed out must have snuffed it out. So it could be part to do with the air. (Teacher 25)

## 4.4 Summary

Analysis of data for the first research question concerning what teachers know and understand about the science concepts involved in lighting and burning a candle identified science knowledge typical for all teachers in the sample. These understandings comprised scientifically correct views, misconceptions, inaccuracies and partial explanations. The ideas most frequently held by all teachers was that wax melts due to heat, and involved friction in lighting the match. Many teachers held the misconception that wax does not burn.

Many teachers varied in the sophistication of their ideas from phase to phase of the candle task. Most inconsistently applied their ideas of gases, molecules and heat energy across the phases, for example, they involved heat more when explaining melting, and less for smoke and burning. Teachers typically had a more sophisticated knowledge if they taught older students and had an extensive science education history.

Including teachers with a range of science background was effective as it did generate diverse examples of teachers' science knowledge. However, some teacher's knowledge was highly inconsistent with others who had a similar science education history or who usually taught students of the same age. In order to describe differences in concepts and levels of understanding, individual teachers were categorised as having high, midrange or low science knowledge on the basis of their total scores for all three phases, rather than their science education background.

Characteristics of teachers with high science knowledge of the candle were that they tended to be fluent in their explanations, secure in their knowledge, familiar with the ideas, or able to work them out during the interview. They usually saw the wax as a fuel in the candle, and suggested smoke was to do with partial burning. They were likely to hold ideas of sufficient heat energy to make the match light up, and confidently use specific scientific terms such as molecules or kinetic energy.

Teachers with midrange science knowledge generally used the same ideas as teachers with high science knowledge but at a lower level. Many expressed the concept that friction generates heat, but could not explain the causal connection to the flame on the match, other than "you need heat." A common strategy was to suggest a suite of possibilities for consideration, rather than a coherent argument. Usually they

explained that the function of the wax was to preserve the wick from burning away too fast.

Teachers with low science knowledge tended to link ideas through association, for example, smoke was linked to burning through personal experience and observation, not through a scientific explanation. They often shied away from trying out ideas, and when they did use scientific terms they were not able to fully explain phenomena.

The descriptions of teachers' science content knowledge as high, midrange or low form a coherent and productive framework for the second research question: the impact of teachers' science content knowledge on the judgements they make about students' science work.

# CHAPTER 5
# MAKING JUDGEMENTS

## 5.0 Introduction

Pedagogical content knowledge in science is involved in knowing what to look for in students' work in order to make judgements about their conceptual understanding and in deciding what these judgements mean in terms of students' development. This forms the basis of the second research question: "How do teachers interpret, and how do they make their judgements about, students' work?"

In this chapter, distinct ways that teachers approached their analysis of the student work samples are described, using teachers' recognition of students' science concepts as the critical distinguishing feature. Analysis of how teachers made their judgements is continued by identification of the judgement bases teachers used as they responded to different aspects of work from six students with diverse ages and abilities.

Using the categorisation of teachers as having high, midrange and low science knowledge that was developed in Chapter 4, patterns of use in the ways that teachers used these judgement bases are described. A major part of this chapter is an examination of the relationship between teachers' science content knowledge and the successes and problems they experienced when making judgements, particularly the extent to which their science content knowledge supports a conceptual change approach to teaching and learning.

## 5.1 Reactions to Students' Work

An initial analysis of teachers' responses to the student work samples showed that all teachers made overall judgements, such as "he's quite knowledgeable", "they've got a reasonable science base", or "he's explained it, but not very scientifically." When considering the age and ability grid, teachers made comments which described achievement, such as "doing well" if the student was young, or was "below average" if older.

Teachers demonstrated a common pattern by referring to the student as "he" with only a few using the "he or she" option, and only one used "she" consistently. "They" was used in various ways: as a non-gender specific term for the student (as was "kid"

and "it"), to include other students seen as similar to teachers' current or previous classes, and to avoid the repetitive "he or she".

The initial analysis also revealed that teachers varied tremendously in the extent they took students' science concepts into consideration when making their judgements. Some teachers made minimal comments about students' concepts, others made a range of comments, and some teachers made a detailed and intensive analysis of students' concepts and misconceptions as the largest part of their judgement process. Links between teachers' science knowledge and the extent of their reaction to students' science concepts became evident during this early analysis. Characteristics of each type of reaction are explained using an example from an individual teacher as a representative of the type.

*Minimal Reaction to Students' Concepts*

This was the least sophisticated way that teachers reacted to the student work samples. Teachers made summative statements, such as "I think they're, um, they know quite a bit ... for the simple reason the terminology that's used and, um, it seems quite fluent—the whole process." However, their reasoning for their judgement was superficial, for example, Teacher 16 (who was within the range of low science knowledge) read from Student 5's work with little or no analysis of the student's understanding. This seemed to require minimal science knowledge on his part. Double quotation marks are used to indicate parts read aloud from the work sample:

Teacher: Well, I suppose he's quite knowledgeable actually [pause].

Researcher: What struck you that you said quite knowledgeable?

Teacher: [reads] "kinetic energy" is one thing, um "phase change" [pause], um "regulating the rate".

Researcher: Yes.

Teacher: [pause] "Carbon" [pause]. Actually some of these words like um "flammable" and, um "smoke was produced". (Teacher 16)

*Greater Consideration of Students' Concepts*

Some teachers took more consideration of students' science concepts. They were aware of what students knew and balanced this with what students did not seem to

understand. However, they were usually unable to detect students' misconceptions, so at times their science knowledge was insufficient to judge students' work adequately.

Teacher 10 (with midrange science knowledge) was representative as she commented on what Student 4 understood, and continued to make some distinction between science language or common language as a clue to the student's extent of understanding. She was hesitant at times, and was aware that a better understanding on her part would have improved her skills in judging the student's work:

> Oh, his description is better than mine! Well, he understands there's a chemical. He understands heat and friction I guess but ... he doesn't actually say where the heat comes from, but he understands that ... [the] match heats up, it catches fire and it was a chemical involved. He understands something's happening ... [reads] "Fire stuff", it's sort of ... not a scientific term. He's just using common language there. I don't know about his concepts. I think his understanding is not ... based on his language ... I think he's got the concept in the fact that there's a chemical on the match. So he obviously knows there's a chemical reaction of some sort. "You put the fire stuff on the match" ... well that's just observation. I don't know there's anything scientific about that. [He's] just using prior knowledge. Obviously he's seen a candle and [knows] that's just going to happen. He hasn't got any scientific basis for what he's saying. (Teacher 10)

*Intensive Focus on Science Concepts*

For some teachers, the most powerful feature about how they made their judgements was the extent of their attention to the science understandings students had, did not have, and were likely to develop. These teachers seemed to tap into their own science knowledge, and blend this with comments about pedagogical content knowledge in science, when making their judgements.

Teacher 6 (who had the highest science knowledge score) recognised Student 5's misconceptions about the wax not burning, even characterising this as a common assumption among students. He continuously compared what the student knew, to what the student had not yet "got" referring to "stage" and if certain concepts were likely or unlikely for students to have:

[reads] "kinetic energy and molecules". Now the kid has also come up with, a number of key terms, things like "kinetic energy" and "friction" and so on. Which would give me the indication that ... they've got a reasonable ... science base ... "the wick is flammable ... wax is regulating". Right now that's probably a reasonable assumption ... So they've got ... the concept that in fact kinetic energy and temperature are aligned together ... A lot of kids get into Year 11 and 12 not recognising the fact that ... temperature and kinetic energy are ... related ... They [have] obviously done the old ... "phase change" ... They've got this idea of a "plateau" ... You haven't got the stage yet that in fact the vaporisation is occurring at the burning point ... "it's a wick and it's made of string—burnt—into carbon probably". Again ... another idea not a lot of kids would come up with, the view that it in fact had carbon in it. (Teacher 6)

## 5.2 Judgement Bases

Further analysis of the data showed that teachers were regularly reacting to aspects of students' work other than science concepts. They responded to students' language, and to subtle clues that suggested students' interests, attitudes and probable school and home experiences. Teachers were like detectives, looking for clues, hints or evidence and using these as the basis for their interpretations and judgements.

Judgement bases are the aspects of students' work that teachers recognised and used to formulate their interpretations, inferences and conclusions. These bases indicate what teachers regarded as relevant and informative, and what they used when making summative or comparative judgements.

### *5.2.1 What Bases Did Teachers Recognise?*

Nineteen bases were identified and grouped into six categories. Table 19 shows the bases within each category, with examples from teachers' interviews. Three of the categories were related to students' science abilities and understandings: concept, language and skill. Two categories were linked to inferences teachers made about students: personal attribute or likely experiential background at home or school. One category related to teachers' experiences, expectations or own science knowledge.

Table 19

*Categories of Bases Teachers Recognised When Making Judgements*

| Category | Bases | Examples |
|---|---|---|
| 1. Concept | Recognised (1) a science concept the student had, or (2) had not developed, (3) a misconception; (4) when a student's explanation was unsatisfactory, or (5) referred to a hierarchy of increasingly sophisticated concepts. | "He's talked about it."<br>"He obviously doesn't understand about energy."<br>"He's wrong in that. I think it's not starved of oxygen."<br>"Can tell you the process but not understand the process." |
| 2. Language | Commented on ability with (6) general language or (7) science terminology | "Is articulate."<br>"Gave a good description."<br>"Does not know the term wick." |
| 3. Skill | Commented on the skill of (8) observation, (9) explanation, (10) inference or (11) prediction. | "Given a really good description of what they've observed."<br>"I don't think they've actually tried to explain striking." |
| 4. Personal attribute | Inferred student's (15) attitude or (16) confidence. | "His confidence—that he knows what ... he's saying is right." |
| 5. Background | Inferred student's (12) general experiential background, (13) science curriculum exposure, or (14) cultural or parental influence. | "This child obviously doesn't have a lot of background about the objects it's looking at." |
| 6. Linked to teacher | Referred to (17) own science knowledge, (18) experience with classes or own child, or (19) expectations of students at a particular age or grade. | "His description is better than mine."<br>"I'd have to refer it to the average kid I had in my class." |

*Category 1. Concept*

This category included five bases. Teachers recognised if students (a) have a concept, (b) did not have the concept, (c) have a misconception, (d) were unable to use the concept productively, or (e) referred to students' conceptual development.

*Recognised students have a science concept.* Teachers used this base in a cautious, noncommittal way to recognise that students had used a term, without commenting if it had been used appropriately or accurately (e.g., "he talked about", "has used the term", "he obviously knows about liquids and solids and gases, he knows about melting and stuff like that, he knows about flammable properties"). Some used a more sophisticated style and qualified the amount of understanding students had, for example, "he has *some* understanding of the states of matter" and "there's *quite* a good understanding there." Other teachers used rephrasing to describe understanding in more scientific terms (e.g., "he's got the concept in the fact that there's a chemical on the match, so he obviously knows there's a chemical reaction of some sort").

*Recognised students do not have the concept.* Some teachers went further by commenting on what students did not understand (e.g., "had not got" or "missed out"). Some clearly specified what it was that students did not have, for example, "obviously this child doesn't really quite understand about friction because it doesn't mention it, just saying you struck the side of the box" and "they haven't related the striking to the friction that caused it [the match to light]." Some teachers supported their observations by referring to other bases such as general language, probable age, and lack of scientific terms, rather than concepts. For example, one teacher suggested a student did not understand friction because no specific science terminology had been used: "I don't think they have a very good understanding at all ... I think they are probably an older child. Just the way they talk about [reads] 'it's got chemicals', 'like sandpaper'."

*Recognised students had an error or misconception.* Teachers also remarked on what they perceived as errors or inaccuracies (e.g., "he's ... wrong in that"), or misconceptions (e.g., "oh, so the child thinks the wick is making the flame, but not the wax"). Nearly all teachers avoided declaring students as right or wrong, instead

referring to "assumptions" students had made, or saying "he thinks that" which suggests a general willingness to accept students' ideas as formative.

*Recognised students have the concept but can't use it productively.* Teachers recognised the difference between mere use of terminology and actual understanding a concept sufficiently well to apply it productively to provide a satisfactory explanation (e.g., "He knows all the words but doesn't know why. Can tell you the process, but not understand the process").

*Recognised students' place in conceptual development.* Teachers made reference to conceptual development—how one concept is replaced by another more sophisticated one (e.g., "I doubt whether you're going to get them to the point of understanding that in fact it's not the wick that's burning but it's the wax"). They recognised key concepts that indicated limitations to present knowledge but showed the direction of conceptual progress, for example, "there is a basic understanding there but in fact they're unable to extend that understanding" or "this child is functioning in the primary school grade ... 3. I would place him at level 1 and not beyond in terms of the outcome statement matrix." This judgement base required precision, since comments were qualified by examples of the next understanding a student would probably achieve.

*Category 2. Language*

Teachers responded to quite subtle clues in students' language and interpreted these as indirect indicators of science understanding. General language and science language were the two bases identified. A widely used strategy was to comment about students' general language (e.g., "articulate" or gave "good descriptions"). Teachers also referred to students' use of science terminology (e.g., "phase change") or the absence of terms (e.g., "does not know the term wick"). This category included teachers' inferences, for example, "very few ums and ahs" was the basis for a judgement that a student was sure about phase change.

*Category 3. Skill*

Teachers commented on four bases for students' skills: observation, explanation, inference and prediction. Coding for explanation included references teachers made to description because some teachers used the terms as equivalent (e.g., "oh, they said a lot, a much better explanation, it's just more descriptive. I think it's a good

description"). Some were able to detect a difference between a student just listing a series of events and explaining those events, for example,

> Seems to be good with actually describing the things they've seen but as far as that, any scientific explanations, they seem to be a bit lacking, as far as the wax is called, why it's [the candle] burning, what happens when you blow it [the candle] out. (Teacher 1)

*Category 4. Personal Attribute*

A personal attribute of a student was seen as a relevant aspect by teachers and coded through two bases: attitude and confidence. Teachers referred to attitude (e.g., "bored", "he's had enough", "he's trying hard") if they felt this influenced students' performance. Others recognised confidence as a way to infer understanding (e.g., "he's obviously been quite comfortable with kinetic energy") or alternatively a lack of understanding (e.g., "lots of ums and ahs which means ... he or she is very unsure of what they're saying").

*Category 5. Background*

In this category, teachers referred to three judgement bases, relating to students' general, science and cultural background. Comments about science background typically referred to exposure to curriculum. These comments were either in general terms (e.g., "I don't know what the year the child is but they don't seem to have much experience") or specifically tied understanding to a school year, for example, these comments were made while using the age and ability grid:

> So he's at least done Year 8 I'd say, probably Year 9. He knows a bit about fire and things .... physical and chemical change. So I'll put 13-14 [years old] eh? Could be 15. If it's 15, I'd say average to below [average]. If it's ... 13-14, probably average. (Teacher 5)

*General background.* When teachers referred to background as a contributing factor to performance (e.g., "lack [of] prior knowledge" and "this child obviously doesn't have a lot of background about the objects it's looking at") most looked

beyond just how well students did in the work samples, and looked at what students could do with more opportunity to learn, or better home experiences.

*Science background.* Teachers also mentioned students' science curriculum or school experiences, for example, "maybe they've done a topic in class on this type of energy transfer" and "he's done some formal study in this." Teacher 6's reaction to Student 5's transcript was unusual as it extended to the type of science education this student had probably been exposed to:

> This is all stuff that they've been taught ... You get the feeling ... this particular kid has never really had to sit down and take all that stuff and explain something. ... [gestures] 'Here are the lessons and the lessons are the important thing' rather than 'Here is the concept and these lessons demonstrate aspects of them' ... They've either picked it up from somewhere or they've been isolated as being above average and have got a special course running for them ... likely to be kids who've done a little bit of chemistry or something like that. (Teacher 6)

*Cultural or parental influence.* Some teachers made reference to the effects of students' parents or cultural background on performance (e.g., "I think possibly, um ethnic, even Aboriginal child .... I think Aboriginals I knew would have called them matches"), and confirmed their thoughts by anecdotes from their own experiences with students with disadvantaged or advantaged backgrounds:

> This puts me in mind of a child who came from ... a very narrow environment because of religious reasons ... The child ... didn't seem to have any curiosity, but then hadn't been stimulated to be curious. And he was asked, 'What lives in water?' and he said, 'Cups and saucers and plates,' because the only thing he'd connect with living in water was when things were washed up. So ... who knows [he] might have been a really able child but with no enrichment or background you can't see it [ability]. (Teacher 26)

*Category 6. Linked to the teacher*

Teachers went beyond the transcript when they commented on their personal science knowledge or experiences. They often reflected on their performance during the interview as a way to gauge students' responses (e.g., Teacher 5 was unsure if the wax burned or not, and said Student 6 had her "problem too"). Teachers used their own knowledge as a benchmark to gauge students' knowledge especially when students' ideas were different to their own (e.g., "They've said that the blowing of the wind is pushing the flame out. I mean I never thought like that"). For some this was a way to verify their own ideas (e.g., "I know adults that would say that") while for others it was to remonstrate themselves (e.g., "yes, he actually did better at explaining a few of those things").

Some teachers compared the student work sample to their own children, present or past classes to gauge ability (e.g., "Some of my bright Year 2s that I've had would know that's a candle, and they would know that's wax, and they would know that it's a wick. So if this is a 7-8 year old I'd have to refer it to the average kid I had in my class"). Teachers also referred to their expectations of performance for students at a specified year of schooling (e.g., "in Year 2 [I] would expect him to know that's a candle and call it a candle").

### *5.2.2 Patterns of Use*

Teachers were interested in many aspects of students' work apart from science and this was evident in the broad variety of judgement categories they used, from students' personal attributes to misconceptions, from parental influence to skills in explanation. The approach that most teachers' adopted when making judgements was to rely on an assortment of bases. The average for all teachers was 6 bases. Table 20 shows the range from 2 (Teacher 17) to 10 (Teacher 10) and how differently five teachers used the bases. Full details are given in Appendix N.

How did teachers use such a variety? For example, Teacher 22 (see Table 20) used bases from five categories when judging Student 5, (a) concept (she identified concepts she thought the student had, and concepts she said the student was unable to use to productively to explain events), (b) skill (the quality of explanations), (c) background (both science and cultural), (d) personal attribute (student's apparent confidence) and (e) linked to her own experience (referred to junior students' ability

Table 20

*Examples of Teachers' Use of Each Judgement Base*

| | Teacher | | | | |
|---|---|---|---|---|---|
| Judgement Base | 10 | 6 | 22 | 16 | 17 |
| Concept | | | | | |
| Has concept | x | x | x | x | x |
| Has not got concept | x | x | | | |
| Misconception | | x | | | |
| Unable to use concept | x | | x | | |
| Concept development | | x | | | |
| Language | | | | | |
| Language (general) | x | | | x | |
| Language (science) | | x | | | x |
| Skill | | | | | |
| Observation | x | | | | |
| Explanation | x | | x | | |
| Inference | | | | | |
| Prediction | | | | | |
| Personal attribute | | | | | |
| Attitude | x | | | | |
| Confidence | | x | x | | |
| Background | | | | | |
| Background (general) | x | | | x | |
| Background (science) | | x | x | x | |
| Cultural or parents | | | x | x | |
| Linked to teacher | | | | | |
| Own knowledge | x | | x | | |
| Own class | x | x | | x | |
| Expectation | | x | | | |
| Individual total | 10 | 9 | 7 | 6 | 2 |

to describe and their general approach to problems). Like many teachers, Teacher 22 used categories that related to science concepts and also less academic attributes, such as honesty. In this extract, single quotation marks are used to distinguish comments she made when she suggested things her class might say and double quotations marks when she read aloud from the student work sample:

> His science knowledge and background is really very good. I'd say he's an upper primary child. He's a logical thinker. He's obviously into how the things work because he's wanting to tell you step by step and really think about it. He was a bit bored though, but everything else is, you know ... he's really thinking whereas some kids might just go 'Oh, yeah the match makes it burn' and don't think about [it]. He's honest [when he says] "I don't know what the wick's made of." (Teacher 22)

Table 21 shows the number of teachers using each base within the six categories. The most consistently used base (80%) was whether students had a science concept. Half of the teachers used the concept category in a more sophisticated way and tempered their comments about what students *had* with comments about concepts students did *not* possess. Fewer teachers identified misconceptions, or demonstrated a subtle ability to use their pedagogical content knowledge in science to detect when students were trying unsuccessfully to use a concept to make a satisfactory explanation (e.g., the student knew about phase change but did not really have a good grasp of energy transfers and was unable to use the concept productively). Very few made specific reference to how science concepts develop and change in their level of complexity. Results for this category suggest that most teachers recognised the relevance of concepts when making their judgements, as they made a simple recognition of the presence of a science concept, but far fewer supplemented this with more sophisticated judgement skills by looking for what students do not understand, hold as misconceptions, or will understand next, although these are all key factors in teaching for conceptual change.

Table 21

*Number of Teachers Using Each Judgement Base, by Science Knowledge*

| Judgement Base | Teachers' Science Knowledge | | | Total | Percent |
|---|---|---|---|---|---|
| | High | Middle | Low | | |
| Concept | | | | | |
| Has concept | 7 | 9 | 8 | 24 | 80 |
| Has not got concept | 8 | 5 | 2 | 15 | 50 |
| Misconception | 5 | 2 | 1 | 8 | 26 |
| Unable to use concept | 2 | 3 | 1 | 6 | 20 |
| Concept development | 2 | 0 | 0 | 2 | 6 |
| Language | | | | | |
| Language (general) | 4 | 6 | 7 | 17 | 56 |
| Language (science) | 6 | 4 | 5 | 15 | 50 |
| Skill | | | | | |
| Observation | 6 | 5 | 4 | 15 | 50 |
| Explanation | 4 | 4 | 4 | 12 | 40 |
| Inference | 2 | 0 | 0 | 2 | 6 |
| Prediction | 1 | 1 | 0 | 2 | 6 |
| Personal attribute | | | | | |
| Attitude | 2 | 2 | 3 | 7 | 23 |
| Confidence | 1 | 1 | 1 | 3 | 10 |
| Background | | | | | |
| Background (general) | 6 | 4 | 3 | 13 | 43 |
| Background (science) | 2 | 4 | 4 | 10 | 33 |
| Cultural or parents | 1 | 3 | 3 | 7 | 23 |
| Linked to teacher | | | | | |
| Own knowledge | 7 | 5 | 4 | 16 | 53 |
| Own class | 3 | 4 | 4 | 11 | 36 |
| Expectation | 2 | 3 | 2 | 7 | 23 |

Note: Percent refers to results only in that row.

Over half of teachers made judgements based on students' science language. General language acted as a clue to further define the child, as an indirect way of assessing science knowledge or affirming the teachers' judgements: "In my experience with more able students they do tend to use full sentences. They don't just answer one word answers, minimum answers, and the more capable they are the more information they'll tend to give you." Science communication is more prominent in current curricula so the willingness of teachers to include this broad-based aspect is appropriate.

Fifty percent of teachers commented on students' skill in observation, and fewer on explanation, but very few remarked on the more complex skills of inference and prediction although all students made either or both. It may be that teachers were not adept at recognising these skills, used the more general term "observation" instead, or thought that the candle task was a common event and prediction is better applied to unknown events. One other category was used by over half of teachers, in which teachers linked judgements to themselves. Fifty-three percent of teachers used their own knowledge as a benchmark (e.g., "Well, he or she and I think the same thing ... It's got a job of holding the wick in place"). This example demonstrated the desirability of teachers having high science knowledge of this task as the teacher has used her own misconception to gauge the student's understanding. This idea is developed later in this chapter as contributing to the problems teachers had with making judgements.

Discussion so far has looked at general patterns of use by all teachers. Table 22 summarises the results of Table 21 and reveals some similarities and differences in which bases teachers with high, midrange and low science knowledge used. Teachers with high science knowledge tended on average to use more bases (7.0 bases) than teachers with low science knowledge (5.7 bases), due to greater reliance on the concept and skill category. Teachers with high science knowledge showed a preference for these bases, perhaps as their knowledge in science supported their recognition of students' concepts and skills. Judgement categories of students' personal attributes and background were used equally for teachers in all ranges of science content knowledge; there was a slight tendency for teachers with low science knowledge to rely more on language and less on their own science knowledge.

Table 22

*Number of Times Teachers Used Each Base in Each Judgement Category, by Science Knowledge*

| | Teachers' Science Knowledge | | |
|---|---|---|---|
| Judgement category | High | Midrange | Low |
| Concept | 24 | 20 | 8 |
| Language | 10 | 10 | 12 |
| Skill | 13 | 10 | 8 |
| Personal attribute | 3 | 3 | 4 |
| Background | 9 | 11 | 10 |
| Linked to teacher | 12 | 10 | 9 |
| Average | 7.0 | 6.5 | 5.7 |

Note: Numerals in each cell indicate the total number of times teachers used the bases in that category.

Although very few teachers made direct reference to concept development in their judgements (see Table 21), results suggest that teachers with high rather than low science knowledge were more likely to base their judgements on aspects of students' work that could support a conceptual change orientation—they were more aware of what concepts students do not have, of misconceptions, and difficulties students had in using concepts to explain productively or convincingly. While teachers with low science knowledge made as many and as diverse judgements, they either did not see the value of using the concepts category to such a marked extent, or were unable to do so. For either reason, these findings suggest the supportive relationship between teachers' high science content knowledge and their ability to use a conceptual change approach when making judgements about students' work.

### 5.3 Science Content Knowledge and Judgements

Some of the judgement bases teachers used were not dependent on their science content knowledge, for example, taking students' personal attributes into consideration is appropriate to all school subjects. Other bases were linked strongly to teachers' science content knowledge, for example, recognising when a student is

unable to use a concept productively is based on the teacher knowing how to use it in that way.

Building on results from the previous section, this section describes the ways that teachers' science knowledge affected the accuracy and appropriateness of judgements they made: how it supported judgements and also how it led to problems.

### *5.3.1 Science Content Knowledge Supported Judgements*

From the point of view of students, an accurate and appropriate judgement by a teacher is probably one that will support their learning, interest, motivation or success. From a teacher's point of view an accurate and appropriate judgement is also one that achieves these things, plus it provides assistance in planning future lessons, tests and reports. Accurate and appropriate use of many of the judgement bases required teachers to hold a scientifically correct view and have an understanding of the terms and ideas which was sufficiently sophisticated to understand students' responses.

Examples of accurate and appropriate judgements were not confined to teachers with high science knowledge; but accurate and appropriate judgements from the point of view of a conceptual change approach occurred when teachers noted what students did not understand as well as what they did understand, suggested what they needed to understand next, identified significant indicators of misunderstanding and determined where students' ideas fit within a broad developmental framework. All of these are important aspects of supporting change in student's science concepts, and were typically the province of teachers with midrange or high science knowledge. These skills in judgement-making enabled teachers with high and midrange science content knowledge to judge a diverse range of students' ages and abilities.

How did a high science content knowledge assist teachers to make these sorts of judgements? The following examples indicate how teachers operated in two key areas, (a) recognising limited or omitted concepts, and (b) recognising misconceptions. The examples provide a detailed description of the interplay of science content knowledge and pedagogical content knowledge in science during the judgement making process.

*Identified limits or omissions in students' understanding.* When teachers held a scientifically correct view about an aspect of the candle task they were able to recognise when the student's knowledge was limited, for example, Teacher 2 (Year 11, high science knowledge) knew that the candle wax was the fuel, so she identified

Student 2's (Year 3) limited understanding that only the wick was burning (e.g., "he only knows the obvious answer") and concluded the student was operating at a visual and not an abstract level. When teachers had high science knowledge they were likely to detect omissions in students' work. This was a sophisticated aspect of the judging process, as it required the teacher to respond not just to what the student said, but to what they did not say.

Teacher 12 (Year 7, high science knowledge) took great pains to involve ideas of heat energy and energy transfers in her own explanation of the candle task, and consequently when assessing Student 6 (Year 11) she confidently noted that he had not used these ideas at all. She concluded that he knew what was happening but not why, for example, "He knows it's hot but not why due to energy."

Teacher 9 (Year 7, high science knowledge) when assessing Student 3 (Year 7) commented, "I don't think they've actually tried to explain striking. The striking of the match is actually the friction applied to it and that creates the heat." He supported his comments by outlining his own view to show what the student did not say:

> Because they're just saying you just stroked it and they haven't related the striking to the friction that's caused it to [light] and I suppose the difference in the substance. I mean both these surfaces are quite—I mean designed so that there's a lower heat, faster heating, therefore I mean the friction, strong hard friction. (Teacher 9)

Teachers with high or midrange science content knowledge did not have to have a perfect understanding of events or concepts to still recognise limits or omissions in students' explanations. Teacher 23 (Year 3, high science knowledge) was aware she had insufficient understanding of "where the heat comes from" although she had made connections between speed of striking, different amounts of heat being produced and fire resulting. Her level of understanding was sufficient for her when assessing Student 3 (Year 7) to recognise the student was unable to make this link between speed, heat and the flame:

> There's no mention of speed or anything like that. It's just, um inherent ... in the strip that will make it light. There's no combination between the match head and ... this strip ... They've got an idea ... what's causing it ... thinking it's hot because they know it ends up with a flame ... but perhaps not understanding what ... makes it hot ... Well, he or she and I think the same thing. (Teacher 23)

Teachers with midrange science content knowledge also made effective judgements relating to students' omitted or limited concepts. Teacher 29 (Year 3, midrange science knowledge) demonstrated a simple understanding of molecular changes of structure in melting. Although he could only suggest heat "destabilises the molecules somehow but I'm not quite sure how it would do that. It just alters the structure somehow. Apart from that I wouldn't know" this understanding was sufficient for him to be able to make specific analyses of Student 2's (Year 3) conceptual development and to suggest what the student could and could not quite explain. He was clear on things he'd take as significant indicators of the student's understanding: "I'd like to see the word 'change' and what's causing it to happen and what is happening and why ... Those sort of things are missing ... to me." He noted that Student 2 "know[s] it heats up and it melts but they're not quite sure as to why, other than it's just wax." He developed this perception into an argument that the student knew things changed but not how this happened:

> So my understanding is that they haven't ... actually focused much in on wax and this change of structure ... and they know it becomes, like eventually it will become soft ... but they obviously ... haven't been focused in on the how things can be changed [how] the structures of things can be changed. (Teacher 29)

*Identified misconceptions.* Some teachers relied on their own accurate science knowledge to recognise when students' ideas were at odds with scientifically correct views or had applied their ideas inappropriately. For example, Teacher 5 (Year 11 teacher, high science content knowledge) involved her pedagogical content knowledge in science about common misunderstandings of students when she assessed Student 5's ideas of the candle being blown out:

> He's saying it's a [reads] "physical change" when you blow it out and it's really ... you've stopped the chemical reaction. Oh, he just thinks his lungs are full of carbon dioxide, which is what lots of kids think. But it only goes up 4% ... whereas you're breathing in 70% oxygen. So he's just saying "starved of oxygen". I would assume probably cooled too ... he's wrong in that. It's not starved of oxygen .... He just associates smoke with heat. (Teacher 5)

Having high science content knowledge did not automatically confer the ability to make appropriate judgements, for example, Teacher 18 had stated wax was a fuel in his own explanation yet made only the simplest statements about what concepts Student 2 had, and did not comment on the student's misconception that the wax did not burn.

### *5.3.2 Problems With Judgements*

The science knowledge teachers held was helpful, but for most teachers it also let them down. When a teacher's science knowledge interfered with their judgement process this was termed a problem.

Teachers had five types of problems. These occurred when teachers:

1. were unable to recognise students' misconceptions,
2. used inappropriate or incorrect information,
3. rejected or were unable to recognise students' scientifically correct views,
4. responded to students' science terminology rather than understandings, and
5. read their own knowledge into students' work.

Problems with judgements were widespread. The number of problems teachers demonstrated ranged from none to four types. All except four teachers (Teachers 6, 21, 2 and 8) demonstrated at least one instance of a problem (see Table 23).

Not shown on Table 23 is the number of occurrences for each teacher for each type. Generally, there was one instance of each type, but a few teachers had repeated problems, for example, Teacher 14 failed to recognise three of Student 6's misconceptions and Teacher 22 rejected three different (accurate) concepts of Student 5.

Table 23

*Problems With Teachers' Judgements, by Science Knowledge*

| Problem | High Science Knowledge | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 | Total |
| Not recognise misconception | | | | | x | x | x | x | x | x | 6 |
| Inappropriate information | | | | | | | | | x | x | 2 |
| Reject correct view | | | | | | | | | | x | 1 |
| Focus on terminology | | | | | | | | | | | 0 |
| Reads-in understanding | | x | x | | x | x | x | | | | 5 |
| | Midrange Science Knowledge | | | | | | | | | | |
| | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 | Total |
| Not recognise misconception | x | | x | | x | x | x | x | x | x | 8 |
| Inappropriate information | | | | | | | x | x | x | x | 4 |
| Reject correct view | x | | | | | | | | x | | 2 |
| Focus on terminology | | | | | | | | | | x | 1 |
| Reads-in understanding | | | | | | | | x | | | 1 |
| | Low Science Knowledge | | | | | | | | | | |
| | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 | Total |
| Not recognise misconception | x | x | x | x | x | x | x | x | x | x | 10 |
| Inappropriate information | | | | | | | x | x | | | 2 |
| Reject correct view | x | | x | | | | | x | x | | 4 |
| Focus on terminology | x | | x | | | | | x | x | x | 5 |
| Reads-in understanding | | x | | x | | | | | | | 2 |

Note: Numerals other than in the Total column refer to teachers' code numbers; x indicates the teacher demonstrated the problem on at least one occasion.

*Problem 1. Not Recognising Students' Misconceptions*

The most consistent misconception held by students was that the wax did not burn, only the wick. This contributed to the problem many teachers had of accepting students' incorrect views and not recognising them as misconceptions because these views were the same as their own. For example, Teacher 1 used terms such as "chemical reaction" but did not include any suggestion that the wax burned. She held the view that the wax was "for the candle so it stands up and also so that it supports the wick that's inside the candle." Consequently, when assessing Student 1's comment that "white stuff [is] so it can hold it ... the fire" she just stated "[the student] thinks that the wax holds the fire." She focused instead on the student's limited language (e.g., "doesn't know that the white stuff's called the wax").

Alternatively, teachers sometimes commended students' scientifically incorrect views, for example, Teacher 14 was impressed with Student 6's "The flame's gone out because the increase in carbon dioxide around it and it needs oxygen to live." While it was appropriate for her to say "his knowledge is very good" when the student talked about the wax melting at a "slow even rate" and "at a high temperature the wax is turning into a liquid" she reaffirmed her own misconceptions and missed the significance of "the wick in the middle is keeping the flame alight."

Teachers' inability to recognise students' misconceptions also caused them to miss picking up on clues in students' ideas that indicated a readiness for conceptual change. When Student 6 was asked what was keeping the flame alight he stated, "Oil, I think or something flammable on the wick and the wax is just stopping it from burning all the way through." While the student did not say the wax was burning, his idea of something flammable, like oil on the wick, suggests an emerging idea that something other than just the wick was burning. When Teacher 14 read this section, she focused on language: "Well 'flammable' is ... a good describing word. This language is quite good there ... it's descriptive language ... I'd say he's got really good knowledge there." Teacher 24 also judged Student 6, and read aloud "flammable oil on the wick." When asked by the researcher what she thought of that, she paused and finally responded with "that's interesting" and did not return to the misconception. She went on to provide evidence that the interviewee was an adult because of the "expression, words like 'flammable'."

This problem has the potential in the classroom to prevent teachers from challenging students' scientifically incorrect views, to praise students for their incorrect views, or to make no comment at all which may lead the student to the conclusion that his or her views are correct, or at least acceptable to the teacher.

*Problem 2. Used Inappropriate Information*

Teachers used information which was inappropriate, incorrect or inadequate for the demands of judging. This caused problems either because they simply did not comment on students' ideas because they were themselves unsure of the scientifically correct view, or they used inappropriate analogies with the potential in the classroom to mislead, confuse, or confirm students' misconceptions.

Two teachers in their attempts to explain smoke made links between events that in a scientifically correct view are dissimilar. Teacher 27 was "not sure about the smoke ... I don't really know why things smoke, but they do don't they? I know green leaves and damp things smoke more than other things." She then transferred her ideas on dampness to the candle and suggested there was a "certain dampness because it's melted the candle wax" (i.e., melted wax is damp). Using damp things as an analogy for damp wax causing smoke is problematic, as the common factor of too low a temperature for complete combustion was not provided. There is considerable potential for Teacher 27's ideas to mislead students, as Student 1 suggested the wax was "water" and Student 3 referred to the "steam" from the candle and used a dripping water analogy to explain what was happening to the candle as it became wax. Teacher 10 also experienced difficulty with explaining smoke and responded strongly to Student 4's ideas of the wick: "when I blow it out it went to smoke and cooled off." Her inappropriate response to this student's ideas (i.e., combustion) was to see a similarity in events which are different (i.e., condensation) in the scientifically correct view. She said, "I was just thinking I've seen smoke coming out of a nitrogen bottle. I don't know if that's cooling down because it's in the air or whether it's [unfinished] I don't know maybe nitrogen's always like that. I'm just thinking is that what ... happened with the smoke? It cooled down ... it changes temperature."

Some teachers commented on this problem of inadequate knowledge and were too cautious to suggest alternative ideas. Teacher 20 qualified her overall judgement of Student 4's work by saying in effect she did not know what a "good scientific

answer" was but could recognise when the student's answer was good enough, indicating she placed more value on effort than on the accuracy of content knowledge:

> I think that the child now, like me, doesn't know, um the chemistry of burning, um so ... I don't think that's [the student's answer] a good scientific answer but I don't know what is ... I'd probably say that every time you blow out a flame smoke is the very end response of that because I've blown a few out in my time [refers to her own age]. I don't know because I don't know the chemistry of fire ... but I would be happy with that as the response from a child that I'm now teaching. (Teacher 20)

*Problem 3: Did Not Recognise or Rejected Students' Scientifically Correct Views*

Teachers, particularly those with low science knowledge, had difficulty in recognising students' scientifically correct views. Examples from three teachers (Teachers 11, 22 and 27) who evaluated Student 5's work show how his ideas were not recognised or were rejected.

Teacher 11 adopted the simple expedient of avoiding direct evaluation by restricting her comments to ones that were not evaluative, for example, "he talks about molecules" and "he uses the word carbon." The student had involved key ideas of kinetic energy and heat in lighting the match and the wax melting, but the teacher's only comment was, "We don't really talk about it [kinetic energy] in primary school."

Teacher 22 rejected some of Student 5's ideas about why the match lit as incorrect or strange. The student actually included some high level ideas: that friction as kinetic energy was due to molecules being rubbed together, which caused heat, which was needed for a chemical reaction. The teacher's alternative understanding about heat and friction became apparent when she demonstrated confusion about why the student talked about heat, and suggested an idea plausible to her that it must have been because it was a cold day when the student did the test:

> He knows something about chemicals [reads] "there'd be a chemical reaction". It isn't just a match ... He's thinking further than that ... but [reads] "you need heat". Maybe that concept is wrong. I don't know that heat is created ... Maybe

> he thinks here that we need heat from the candle because of the cold. I'm not sure why he says we need heat. Whether he means that heat is to make the match go? ... He's getting mixed up with between heat and friction. (Teacher 22)

While she had specified that heat from the candle melted the wax in her explanation of the match lighting, she did not mention heat as the link between friction and ignition, although she did mention energy and friction:

> The red part on the end of the match is a mixture of some sort of chemical type thing—that the friction and the force from your hand rubbing against the corrugated part of the match box causes it to ignite somehow. Yeah, the energy, the friction really. (Teacher 22)

The third example is from Teacher 27. Student 5 contended that "smoke was being produced all the time" even when the flame was there but that smoke was not seen before the candle was blown out because "it was hotter so maybe it was less smoke produced." Teacher 27's uncertain science knowledge led her to reject Student 5's sophisticated view of complete and incomplete combustion, saying "no, I don't think that was the reason" but without providing a specific reason. This judgement problem of rejecting scientifically correct views was compounded by another one already discussed, how she used melted wax and damp things as situations she perceived as similar.

There is a pronounced potential for teachers with similar problems to be unable to support students' science development. Teachers' lack of recognition, or rejection, of scientifically correct views could confuse or mislead students. These examples were with a Year 11 student, but some primary aged students held comparable ideas. Student 2 (Year 3) had emerging ideas of heat involved in combustion (e.g., "it might make the thing hot [the match] when you scrape it ... so you can light your candle") and Student 4 (Year 7) was quite succinct in explaining the "the red thing on the end of the match heats up and catches fire" because "it's got chemicals and stuff that burns when it's hit by something."

*Problem 4. Responded to Terminology Only*

One of the features of conceptual change is that while the understandings that people associate with a term may change and become more sophisticated, the actual term they use often remains unchanged. Teachers need to look at how, not just if, students used terms when determining their level of understanding. For example, a student can use the term kinetic energy and understand it refers to moving, or involve abstract ideas of molecules to link the energy transfers of kinetic and heat energy.

Teachers sometimes assumed that students understood the concept behind a science term just because it was used confidently, for example, Teacher 22 commented "again he's got the terminology ... he's obviously quite comfortable with kinetic energy." This teacher had explained earlier, when the student first used the term, that she was unsure what kinetic energy was: "I need to clarify in my mind again what 'kinetic energy' is before I can [explain] because I've forgotten."

Some teachers were keenly aware when students missed what to them was an essential term. For example, Teacher 30 used the word "friction" but her explanation was limited to that "rubbing something against something else" made a "spark." When judging Student 4 she said he had "got a basic understanding" but "need[ed] more work on it" because he used the term "sandpaper" to describe the side of the matchbox. This student had demonstrated an understanding of a cause and effect relationship of heat in causing fire: "the red thing on the end of the match heats up and then it catches fire." It appears the teacher did not recognise the student's attempts to involve heat in the event—which she had not included—and instead focused on the absence of a term rather than the presence of the concept behind it.

*Problem 5. Reading Too Much Into Students' Words*

Some teachers, especially those with high science knowledge, attributed their own understandings to students by reading too much into students' words. This upgraded the student's apparent understanding to a higher level than actually indicated. For example, Teacher 4 concluded that Student 4 knew the wax "was used up" which was the same as his own view of the wax as fuel, however the student had only said the wax was "getting smaller ... because it's getting hot and melting."

These effects were, at times, more subtle. Teacher 5 re-interpreted Student 6's original "oil, I think, or something flammable on the wick" into a more scientifically

correct view of "He's got the oil on the paraffin wax, on here, is actually burning." After the interview, Teacher 5 explained she had probably made this link because she used paraffin wax in conductivity experiments.

Over-attribution to students' concepts was also due to paraphrasing—re-stating students' own words in more scientific language. As teachers listed the aspects they saw in students' work they used sophisticated terminology which was at a higher level than students had used. This was made possible by the use of imprecise terms or qualifiers (e.g., "of some sort", "quite a bit of understanding" and "got some general concepts"). By using these qualifiers and paraphrasing, Teacher 9 was led to give Student 3 a higher level of understanding than was justified. He attributed to the student an understanding of "changes of state", "knows that the heat is causing the ... wax around the candle to turn into a liquid form", "the different temperature" and paraphrased the student's overall understanding with "This [the candle] can have different states of matter depending on how much heat energy is applied to it." The student did not use the words changes of state, liquid or temperature, was very limited in descriptions of the wax melting (e.g., "is like, um when something's hot it turns, drip, like water, when it's turned on it drips and when there's nothing on top of it, it doesn't drip") and once used the phrase "when it comes from the heat it like melts it." Teacher 9 also initially attributed to the student the understanding that the wax was the fuel—as was his view—but later corrected this judgement. Teacher 9 also demonstrated very astute judgements, as the student's original "the candle's turning to wax because of the heat" was successfully teased out until the teacher recognised the student believed the candle (one substance) changed into wax (a different substance) when it was heated, and back into "the proper candle again" when the flame goes out.

As teachers looked for patterns and tendencies in students' work some had difficulty in separating their own knowledge from that of the student. Regarding a student's work positively in itself is not a problem because it is likely to encourage students to repeat their perceived success. However, an inaccurate assessment has implications for the quality of feedback students receive from teachers, as it impacts on teachers' abilities to detect misunderstandings or errors students have in their

concepts (i.e., a teachers will assume a student understands and consequently does not provide opportunities for the student to develop the understanding in future lessons).

### *5.3.3 Extent of Problems*

What was the extent of these five problems? The most frequently occurring problem (see Table 24) was teachers not recognising students' misconceptions. Other problems affected fewer teachers.

Table 24

*Summary of Problems With Teachers' Judgements, by Science Knowledge*

| | Teachers' Science Knowledge | | | | |
|---|---|---|---|---|---|
| Problem | High | Midrange | Low | Total | Percent |
| Not recognise misconception | 6 | 8 | 10 | 24 | 80 |
| Inappropriate information | 2 | 4 | 2 | 8 | 26 |
| Reject correct view | 1 | 2 | 4 | 7 | 23 |
| Focus on terminology | 0 | 1 | 5 | 6 | 20 |
| Reads-in understanding | 5 | 1 | 2 | 8 | 26 |
| Total | 14 | 16 | 23 | | |

Note: Percent refers only to results in that row.

This result is influenced by the nature of the candle task, since only a few teachers who knew the wax burned recognised the limited understanding common to all six student work samples (i.e., the wax did not burn, it only melted, or was there to hold up the wick). While other tasks may lead to a different ratio of problems, results indicate the potential for widespread problems with judgements.

The most important conclusion from these results is that teachers with high science knowledge generally had fewer problems, as they were less likely to reject students' correct views, were less likely to focus on terminology rather than the understandings behind the terms, and were more likely to recognise a misconception, than were teachers with low science knowledge. However, they were more likely to "read-into" students' work concepts or understandings that students did not actually demonstrate than were teachers with low science knowledge.

This result confirms the positive value of teachers' science knowledge in making their judgements of students' science work for the candle task less problematic, more appropriate and accurate.

## 5.4 Other Differences Between Teachers' Judgements

To conclude this chapter, brief observations are made about differences in teachers' judgements associated with the (a) age of students usually taught, and (b) the individual student work sample.

*Ages of Students Usually Taught*

Teachers who usually taught Year 3, 7 or 11 showed a similar reliance on using a variety of bases (see Table 25). Full details are given in Appendix O and summarised in Appendix P.

Table 25

*Teachers' Use of Judgement Categories, by Age of Students Usually Taught*

| | Age of Students Usually Taught | | |
|---|---|---|---|
| Judgement Category | Year 11 n = 6 | Year 7 n = 12 | Year 3 n = 12 |
| Concept | 14 | 24 | 16 |
| Language | 4 | 15 | 13 |
| Skill | 9 | 8 | 14 |
| Background | 6 | 10 | 15 |
| Personal attribute | 1 | 3 | 6 |
| Linked to teacher | 4 | 15 | 15 |

Note: Each category consisted of more than one base. The number in each cell is the number of times the bases in that category were used by teachers (e.g., the six Year 11 teachers used the bases in the concept category a total of 14 times).

Most primary teachers made judgements by using bases closely linked to science concepts, and other bases less directly linked, in equal partnership. Primary teachers did not use fewer science bases than secondary teachers, but were generally more prepared to consider a broader range of other aspects that affect learning: students' attitude, general language ability, personality, home life and culture. Support for this

practice can be found in *Primary Investigations* which included aspects such as cooperative behaviour in science assessment checklists. Primary teachers were more likely to refer directly to their own knowledge, gauging or comparing the students' ideas to their own, than were secondary teachers. Year 3 teachers were less likely to refer to science concepts and more likely to refer to students' skills, background and personal attributes. Year 11 teachers were less likely to use categories related to students' language or personal attributes or make stated links to their own experience or knowledge.

*Student Work Samples*

Each teacher judged the work of one student, so individual teacher's judgement processes may have been influenced by the nature of the particular student work sample they were allocated. Some support for this is provided by results in Table 26 which indicate that when judging Students 4, 5 and 6, teachers made more judgements about concepts, more often linked their judgements to themselves, and made fewer comments about students' skills.

Table 26
*Number of Times Bases Were Used in Each Judgement Category, for Each Student*

| | Student | | | | | |
|---|---|---|---|---|---|---|
| Judgement Category | 1 | 2 | 3 | 4 | 5 | 6 |
| Concept | 6 | 7 | 11 | 11 | 10 | 10 |
| Language | 6 | 1 | 6 | 7 | 5 | 7 |
| Skill | 7 | 8 | 7 | 4 | 2 | 3 |
| Background | 4 | 6 | 4 | 4 | 9 | 4 |
| Personal attribute | 2 | 0 | 0 | 3 | 3 | 2 |
| Linked to teacher | 4 | 5 | 3 | 7 | 7 | 8 |
| Total for student | 29 | 27 | 31 | 36 | 36 | 34 |

Notes: The number in each cell is the total number of times the bases in that category were used by the five teachers who judged that student's work (e.g., for Student 1, teachers used the bases in the concept category a total of 6 times). Students 1 and 2 = Year 3, Students 3 and 4 = Year 7, and Students 5 and 6 = Year 11.

Teachers probably responded to the increased complexity of conceptual knowledge, and longer transcripts, of these three work samples. Teachers appeared to compensate for less evidence of conceptual development in work samples for Students 1 and 2 in particular, by focusing more on the skills category. Similarly, few teachers commented on attitude for Students 2 and 3 (possibly because the students' attitude or confidence was not as forthcoming as other students who said they found the task easy, difficult, or said they were not sure). Student 5's work attracted many comments about background, because the student stated he had not studied candles.

However, three findings from the analysis suggest that teachers were not unduly influenced by the individual student work sample they judged (i.e., to the extent teachers' judgements for different students should not be compared). Firstly, teachers often judged the same student with markedly different overall reactions, for example, when Teacher 16 (who made a minimal reaction to the student's concepts) and Teacher 6 (who focused intensively on the student's concepts) both judged Student 5, as discussed at the beginning of this chapter. Other instances, for example, Student 6's reference to "flammable oil on the wick", showed that teachers responded divergently to the same aspect of a student's work, which suggests they responded to what they chose to see, or were able to see, not only what was there for them to see. Teacher 5 interpreted this statement by the student as an indication the student knew the wax burned, Teacher 24 merely said it was "interesting", Teacher 14 made a lengthy comment about the language level, and Teachers 12 and 25 both briefly commented that "flammable" was a "good word" so the child was of high school age, but did not comment specifically on the use of "oil."

Secondly, teachers were equally diligent in making comments about some aspects of students' work, for example, language was a frequently used judgement category for five of the six students (see Table 26). This suggests that language is one of a preferred set of detective tools applied for science judgements for all students, even when the complexity of language varied tremendously (as evident in the work samples of Students 1 and 6 in Appendix B). Student 2 was the exception, with one teacher using the language base, possibly because this work sample was not distinguished by unusual terms, low fluency, or complex terminology.

Finally, the total number of times bases in each category were used for each student was within a narrow range (of 27-36, see Table 26). While there were exceptions (i.e., the teachers who used few bases), on the whole, teachers responded to a rich variety of aspects in students' work irrespective of the sophistication or complexity of the individual work sample.

The individual student work sample did influence the frequency of problems teachers experienced with their judgements. Results shown on Table 27 suggest that as students' science work became more sophisticated (for Students 4, 5 and 6), teachers experienced increasing problems making judgements. This was due mainly to teachers being more likely to reject students' correct views and focus only on terminology.

Table 27

*Number of Teachers who Demonstrated Each Problem, for Each Student.*

| Problem | Student | | | | | |
|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 |
| Not recognise misconception | 5 | 3 | 3 | 4 | 4 | 5 |
| Inappropriate information | 1 | 1 | 0 | 2 | 1 | 3 |
| Reject correct view | 0 | 0 | 0 | 0 | 3 | 4 |
| Focus on terminology | 0 | 0 | 0 | 1 | 3 | 2 |
| Reads-in understanding | 2 | 1 | 2 | 2 | 1 | 1 |

Notes: Students 1 and 2 = Year 3, Students 3 and 4 = Year 7, and Students 5 and 6 = Year 11. The numeral in each cell indicates the number of teachers who demonstrated that problem (i.e., all 5 teachers did not recognise a misconception held by Student 1).

## 5.5 Summary

Teachers in the sample used a rich variety of aspects of students' work to make judgements, their interpretations typically included reference to science concepts, general and science language and the skill of observation, with less frequent reference to other categories such as student background or personal attributes. Teachers also took their own knowledge, expectations and experiences into consideration. They often interpreted subtle clues and combined these to draw conclusions that went

beyond the text of the transcript, which they considered pertinent to their judgements, often looking for reasons behind the student's performance, such as social background.

Many teachers demonstrated skill at interpreting students' often poorly expressed or contradictory ideas, and took trouble to interpret evidence to present students in a positive light (e.g., "has the general idea" or "has some idea"). Some teachers had said of themselves that they "had no idea" about the candle task, but this was rarely said about students' work. The majority gave the impression of a willingness to examine students' work in detail and seemed concerned to make a fair judgement.

The use teachers made of judgement bases in the concepts category varied from cautious and noncommittal, through simple recognition of concepts students have and do not yet have, to an astute awareness of students' misconceptions and, for a few teachers, an appropriate sense of conceptual development. Differences in teachers' use of these conceptual bases were linked to their own science knowledge: those with high science knowledge relied more on judgements based on students' concepts and skills, related to themselves, whereas teachers with low science knowledge were more likely to use students' language and background and make fewer comments about students' concepts, skills or their own knowledge or expectations.

A major contribution of high levels of teachers' science knowledge was the ability it seemed to bestow on teachers to see beyond students' mere use of a science term, to gauge the accuracy of students' understanding of the concept, to decide when students were limited in their ability to make satisfactory explanations, and to compare this to the next more sophisticated understanding, to determine what students do not yet understand. However, not all teachers with high science content knowledge employed it to make these more complex judgements about students' understandings.

The chief concern about teachers' abilities to support student learning resulting from this analysis was the problems teachers had when making judgements, such as using inappropriate information to judge students' work. Some problems were experienced largely by teachers with low and midrange science knowledge, for example, rejecting scientifically correct views held by students, or making a superficial reaction that confused terminology with understanding, and not recognising students'

misconceptions. One problem usually associated with teachers with high science knowledge was reading too much into students' work.

The majority of teachers experienced two problems and some had three or four problems, with one sample of a student's work. This suggests that making judgements of students' work is challenging, and beset with traps for teachers, particularly those with insufficient science knowledge.

The identification of ways in which teachers' inaccurate or insufficient knowledge interfered with the judgements they made of students' work has important implications for the impact of a conceptual change approach to teaching, because of increased demand on teachers' own science knowledge as a frame of reference for gauging the extent, direction and rate of students' development. While many teachers used similar bases, the level of their own science knowledge influenced the accuracy and appropriateness of the judgements they were able to make using these bases. If conceptual change is to become part of teachers' pedagogy and orientation to science teaching, then a case can be made for assistance to be provided for teachers to utilise their science content knowledge more appropriately in order to better support students' conceptual development.

The ways that teachers translated their judgements into suggestions for practical, follow-up strategies of a conceptual change approach is the focus of Chapter 6.

# CHAPTER 6
# FOLLOW-UP ACTIVITIES

## 6.0 Introduction

After teachers had judged one of the six student work samples, they were asked to suggest two follow-up activities which they felt would support that student's progress in science. Teachers' responses provided the data for the research question: "What strategies do teachers suggest to support students' further learning?"

Identifying students' understandings and choosing follow-up activities are important pedagogical decisions teachers make which influence students' future development. Follow-up activities are devised by teachers to follow a lesson or student learning experience. These activities or strategies may relate to their judgements, for example, a teacher may notice a student has difficulty with ideas of heat and friction and consequently plan activities to deal with this.

In this chapter, some of the different ways that teachers took students' concepts into account as part of their decision-making are described. Also examined are teachers' orientations to school science which were evident in their suggestions: discovery, processes, content mastery, conceptual change and integrated language. Comparisons are made between the patterns of recognition of students' concepts that teachers with high, midrange and low science knowledge made, and these patterns are linked to the follow-up activities they suggested. Lastly, the effect of the age of students usually taught, and the effect of the individual student work sample, on what teachers suggested are briefly discussed. A summary concludes the chapter.

## 6.1 Recognising Students' Concepts in Follow-Up

Teachers suggested a broad variety of activities. These included having students talking about and playing with the candle to develop appropriate terminology or improve explanations, comparing solid and liquid fuels to develop ideas of differences in fuels, or experimenting with different situations such as melting margarine to develop more generalisable concepts such as changes of state. Some activities were repeatedly mentioned (e.g., putting a jar over the candle), others only once (e.g., putting ice in the sunshine and in a cupboard and comparing what happened).

An important difference between teachers' suggestions was the extent to which they referred to the science concepts evident in the student work sample when devising their suggestions. This varied from minimal to extensive.

### *6.1.1 Referring to Students' Concepts*

Based on the interview data, it seemed that teachers made use of students' concepts in three ways when deciding on follow-up activities: (a) an indirect reference to concepts, (b) a general reference that linked to comments or judgements they had made earlier in their interview, and (c) a precise use of students' concepts based extensively on their earlier judgements. Examples from teachers' transcripts are used to illustrate these differences.

*Indirect Reference*

Some teachers listed things that students could do. By implication, their "do this activity" suggestions referred indirectly to students' conceptual development needs, but teachers neither specified nor justified such links, for example,

> Oh, I'd do the vinegar and bicarb[onate] with the carbon dioxide. They've probably done it before ... I'd look at um, things which are flammable and things which aren't flammable, and I'd look at melting points of different objects. (Teacher 24)

Some teachers responded to concepts within the candle task rather than to students' ability with these concepts. For example, Teacher 16 recognised only friction and heat as part of the task. While his suggested assortment of activities may have been appropriate, he made no comment on if, when or why they were appropriate to his judgements or the student's ability:

> You could even, um, oh, as far as substances, as far as friction goes, using, um different substances—rubbing them together to see which produces, um heat and so on like that. I suppose even you could have, um like some sort of thermometer or something like that ... Put it on the bottle and see if the temperature ... goes up. (Teacher 16)

*General Reference*

Other teachers referred to at least one concept students did not have, or needed to develop, but only in general terms, usually with a "needs more of this" comment, for example, the student needed to "be more specific in their explanations, for example, talk about gases, if it's a physical or chemical change—more observation skills" (Teacher 1). These teachers often focused on aspects of students' work they saw as insufficient, for example, the students' language or use of science terminology, but without specifying what aspects of language were appropriate:

Teacher: Obviously the language would need work—to build that up.
Researcher: How would you do that?
Teacher: I'd just really talk a lot and just keep repeating the same things and get them to pick up ... the candle. (Teacher 13)

*Extensive and Precise Linkage*

Other teachers focused extensively on students' concepts when planning their follow-up activities. They explicitly and precisely stated a concept students did not have or needed to develop, then linked specific activities attuned to developing that concept. There was often an element of "fix this", for example, Teacher 5's content knowledge was sufficient to recognise that Student 6's ideas on exhaled gases were inaccurate, so she suggested "Fix up the ideas of lungs and carbon dioxide. Let a balloon out over a Bunsen flame to help them understand why it goes out." Often teachers justified their selection by describing the understanding students would achieve from that activity, for example,

Teacher: Well, I might do a little bit of work on friction because that's something he didn't understand.
Researcher: What sort of work might you do?
Teacher: Well, friction causes heat, and various ways that, um, heat is caused ... you've got your match but you might just use rubbing ropes [pretends to draw rope through hands] ... all the different ways that

you can feel heat from friction and get the concept of friction. (Teacher 14)

### *6.1.2 Patterns of Use*

Table 28 shows that overall, most teachers made references in general terms to one or more concepts students did not have or needed to develop, and suggested follow-up activities that provided for increased opportunity to learn or practice. Less frequently, teachers made either indirect references or precise linkages to follow-up activities when they referred to students' concepts.

Table 28

*Summary of Teachers' References to Concepts in Suggested Follow-Up, by Science Knowledge*

| | Teachers' Science Knowledge | | | | |
|---|---|---|---|---|---|
| Reference | High | Midrange | Low | Total | Percent |
| Indirect reference | 1 | 4 | 4 | 9 | 30 |
| General reference | 6 | 8 | 7 | 21 | 70 |
| Precise linkage | 6 | 4 | 0 | 10 | 33 |

Notes: Numerals in columns other than Percent refer to the number of teachers who made references in that way. The Total number of references (40) is greater than the number of teachers in the sample, as some teachers made references in two ways. Percent refers to results only in that row.

More details of the reference patterns for teachers with high, midrange and low science knowledge are reported in Table 29. Most teachers used students' concepts in only one way. But ten teachers recognised and used students' concepts in two ways. This was typical of teachers with midrange science knowledge who primarily made general references to students' concepts, accompanied by either a precise linkage or an indirect reference. For example, Teacher 10 responded to Student 4's use of the word chemicals ("the match catches fire because it's got chemicals") with an indirect reference which did not link to the student's concepts (e.g., "I might ask him what he'd like to know based on what the class would like to know and then set up some sort of investigation. Have lots of discussions"). Teacher 10 also proposed additional

activities about chemical change although she did not specify what it was the student understood already or why he needed that particular activity (e.g., "Look at how things change—reverse and irreversible changes—that sort of thing. You could do some sorting things with paper and that sort of thing. You could mix powders and water and that sort of stuff").

Table 29

*Teachers' References to Students' Concepts in Suggested Follow-Up, by Science Knowledge*

| Reference | | | | High Science Knowledge | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 | Total |
| Indirect reference | | | | | | | x | | | | 1 |
| General reference | | x | x | | | | x | x | x | x | 6 |
| Precise linkage | x | | | x | x | x | | | x | x | 6 |
| | | | | Midrange Science Knowledge | | | | | | | |
| | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 | Total |
| Indirect reference | | x | x | | | | | x | | x | 4 |
| General reference | x | x | x | | x | x | x | x | | x | 8 |
| Precise linkage | | | | x | x | | x | | x | | 4 |
| | | | | Low Science Knowledge | | | | | | | |
| | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 | Total |
| Indirect reference | | | x | | | | | x | x | x | 4 |
| General reference | x | x | | x | x | x | x | | | x | 7 |
| Precise linkage | | | | | | | | | | | 0 |

Notes: Numerals other than in the Total column refer to teachers' code numbers; x indicates the teacher demonstrated that extent of reference. The Total for each range of science content knowledge exceeds the number of teachers with that science content knowledge (10) because some teachers referred to students' concepts in more than one way.

One of the most important results was the absence of teachers with low science knowledge who based their follow-up activities on precise links to students' concepts.

These teachers were aware of students' concepts (7 of the 10 made a general reference to concepts when suggesting students needed more of a particular activity) but they did not make explicit the links between these concepts and follow-up activities. This result advocates the value of teachers' science content knowledge to support their pedagogical knowledge—not only to recognise but to actively use students' science concepts when planning follow-up activities.

Teachers with high and midrange science knowledge were more likely to take students' concepts into consideration, and make precise links between concepts and their planned activities. Some displayed a highly developed ability to focus on students' misconceptions, for example, Teacher 8 was aware that liquid wax burned and noted that Student 2 thought only the wick burned. Her pedagogical decisions involved deciding what to help the student understand (that liquid fuels burn) and how to structure this as an activity (using multiple sources of liquid fuel). She suggested the student "Look at oil lamps, floating wicks, spirit burners, old metho' [methylated spirits] and wick burners, where fuel was obviously liquid. What's the same between the two sources?" Her suggestion was appropriate for the student she judged; but it seems likely her own partial understanding (i.e., she specified liquid wax, but did not mention it is the vaporised wax which burns) would be passed on to the student. Obviously, teachers whose science knowledge held that the wax does not burn, did not suggest follow-up activities which for them would have been inappropriate or incorrect.

As the level of teachers' science content knowledge increased, their ability to make precise links between students' concepts and follow-up, as part of their pedagogical content knowledge in science, also increased (see Table 29). Teaching for conceptual change requires teachers not only to identify students' ideas and misconceptions but actively use this identification for future planning. While making only indirect references to students' concepts when planning follow-up does not deny students the opportunity to develop conceptually, a greater accuracy with basing decisions on precise links could structure development towards more predictable outcomes.

Nevertheless, the general reference or "needs more of this" way of making suggestions was not necessarily a less developed or inappropriate way compared to

making precise linkages. Some teachers interpreted students' difficulties in broad and diverse terms, and consequently chose to deal with these from a broad base. For example, Teacher 4's main suggestion was for Student 4 to write down as many observations of the candle as possible. During his interview he did not comment on individual concepts, but gave a summative judgement of the student's overall level of conceptual development: The "science content per se is very, very elementary" and "purely based on direct observation. What is very obvious here is he's not able to bring in ... elaboration of his observation into hypothetical deductive logic. [He] uses observation and then a conclusion directly linked to that observation." Teacher 4's suggested follow-up activity was to begin with the student's limited ability with observations and extend this with more observational activities, until observations became spontaneous and more detailed. He suggested providing tools such as thermometers, rules, graph paper to stimulate both "qualitative and quantitative" observations, culminating in a "controlled or uncontrolled experimental context." Thus, on the surface Teacher 4's suggestion was just to provide more of the same, but his sophisticated reasoning was that as there were so many problems with the student's work, it was better to start again and develop the student's abilities in this basic but essential skill, as a way of working towards more complex and accurate explanations based on observations.

## 6.2 Orientations Towards School Science

A teachers' orientation to teaching science in school refers to a general approach, based on beliefs about what is relevant and important about content and pedagogy: the nature of follow-up activities is one aspect of a teacher's science orientation. Teachers' follow-up suggestions were categorised using the four science orientations developed by D. C. Smith and Neale (1991) for their research with ten kindergarten to Year 3 teachers who attended a four-week summer program in teaching primary science.

D. C. Smith and Neale (1991) described a discovery orientation as one in which the teacher is "providing materials and interesting activities, encouraging children to try things, motivating children's interest and curiosity, proposing questions, managing activities" (p. 208). In a processes orientation, the focus is on "demonstrating and

teaching steps in scientific method, providing opportunities to practice, maintaining children's correct use of method, managing activities" (p. 208). The didactic and content mastery orientation involves "presenting content clearly, showing and demonstrating, getting films, asking factual questions, correcting students' errors, giving clues and hints, providing practice, giving tests" (p. 208). A conceptual change orientation means that teachers view science as "eliciting children's ideas, providing discrepant events, challenging children to predict and explain, contrasting alternatives, presenting scientific conceptions, providing ways to apply new concepts, encouraging debate" (p. 208).

These descriptions were relevant to this research as they included detailed lists of representative activities which were based on teachers' responses. They proved appropriate to Western Australian teachers from Years 3, 7 and 11, with one additional orientation included for a few teachers whose suggestions focused primarily on whole language and integration of activities (e.g., study candles through art and literature) and science in society aspects (e.g., Aborigines making fire, use of candles and canaries as warnings to miners). An integrated approach is one in which school subjects are interdependent (Brass & Duke, 1994).

Teachers suggested a few activities which were not included in the descriptions by D. C. Smith and Neale (1991), for example, "brainstorming", or the same activity was mentioned but teachers' orientations to teaching science were clearly distinct as their intention for the activity differed, for example, to change students' existing concepts (conceptual change) or ensure students learned the proper science terms such as wick and wax (didactic and content mastery orientation). Similarly, comparing different candles or fuels was suggested by teachers within different approaches, either as a way to interest students and get them to try things (discovery), as a deliberate way to change students' existing concepts (conceptual change), as a way to demonstrate how to set up an experiment on how long different candles last (processes) or as one aspect of an integrated approach. Even teachers' use of terms, such as "teach them", "get them to understand", "talk about it", "experiment", "give them materials" or "get them to think of other examples" were not always reliable indicators of their orientations. For example, some teachers used "hands-on activity"

when their intention was for students to talk amongst themselves with minimal teacher intervention, while others used it although outlining a highly didactic approach.

Consequently, coding in this research was not a simple process of categorising solely by the activity, because an activity on its own was not necessarily representative of a teacher's particular orientation. A teacher's intention for what an activity will achieve was a better indication of his or her orientation towards science teaching.

The following outline of the five orientations details the basis for categorisation, supported by examples from teachers' interviews. In the examples, teachers often made references to students (e.g., talking of "they") instead of the one student whose work they were responding to. This probably reflected teachers' experiences with similar students, or it may suggest an extrapolation to a group or whole class, or it may also be a method to avoid an awkward "he or she" alternative.

*Discovery*

Teachers' follow-up suggestions were of a discovery science orientation when they set up situations where students could talk and play using a candle as the visual and tactile focus. The teachers' prime focus was on providing an interesting experience for students: "They need plenty of activities first where they get more time to look and think [about candles]" (Teacher 29). A guided discovery orientation was one in which teachers signaled that their intention was more than just free play. Often specifying a "hands-on" situation, teachers selected specific equipment and posed specific questions, for example, "It would be interesting to talk about other ways of putting out candles—like candle snuffers and even wet fingers" (Teacher 27); "I'd get them to do it [blow out the candle] and to watch and even maybe poke their finger—you know—that's heat [*sic*] and that's cold" (Teacher 13).

*Processes*

Teachers with a processes orientation often used words such as "experiment", "investigation" or "research", and a common characteristic was the inclusion of some type of quantitative comparison or measurement. Teachers referred to the classic "jar over the candle experiment", for example, "it would be great to do some candle experiments, put them inside different sized bottles and look at how long they burn and how when the air has been used up they just snuff out" (Teacher 27). Some suggested research activities that went beyond the candle context, to broaden a

student's view by looking at different matches or materials in the match head, or comparing blowing out other types of flames, such as gas flames. Teachers also included work on specific skills, such as "write a description of what do you see when this happens ... draw what you see ... I'd set children in groups of two or three ... [if] possible even include the jar over the top as the experiment" (Teacher 19).

Suggested follow-up activities may not have included all the methodological steps of complex experiments, but they were aimed at developing students' process skills towards that end, for example, to improve students' abilities to observe as part of reliable science experimentation procedures.

*Didactic and Content Mastery*

Teachers with a didactic and content mastery orientation were mainly concerned that students correctly understood the content. Their follow-up strategies often involved delivering the content through a focus on student errors and providing practice so students would "get it right." For example, Teacher 5 specified the point of error in factual knowledge for Student 6 who confused physical and chemical changes when describing the wax melting and the match lighting. The teacher planned for students to practise in groups to consolidate this content:

| | |
|---|---|
| Teacher: | Well what do we want to teach them? ... Do you want to teach them the structure of the match? ... I mean you might want to consolidate physical and chemical change. |
| Researcher: | Uh huh, how would you do that? |
| Teacher: | ... I think, giving them, well asking them to think of things which are physical and chemical changes and then getting them to define the difference—so a comparison and work out the difference .... get them to work out how they operationalise that definition (Teacher 5) |

Teachers suggested many ways to focus students' attention on content that had not been grasped. For example, Teacher 15 described how she would correct omissions about oxygen in students' explanations, listed follow-up activities in great detail, included sample questions she'd ask the class (shown in single quotation

marks) and saw teaching the correct terminology as a necessary requirement for better explanations:

> You'd probably want to spend time actually talking about the right sort of terminology ...Maybe saying to the children, 'Look, ok, let's explain,' and just choose one step. For example, ... using the match to light the wick—talking about how could we best explain that. 'Why would we explain it like that?' 'What's this thing burning on the top, what's it called?' ... Getting out [eradicating]... all these words like "stuff" and "little string thing"... Then maybe do the experiment again, um, something along those lines with fire and maybe ... putting like a beaker over the top or something so the kids can see how oxygen has to do with it. Because they obviously don't understand that oxygen's got anything to do with the flame burning ... 'Where's the oxygen coming from?' ... So I think terminology, explanation, you know understanding what scientific terms are .... 'Look at what's happened here?' 'Who can give me some ... explanations?' Like brainstorm little phrases and go through the little phrases ... for example, if they say "the fire stuff" [I will say] 'What do we mean by the fire stuff?' 'What's a better word for the fire stuff?' (Teacher 15)

*Conceptual Change*

Teachers with a conceptual change orientation accepted and valued students' divergent ideas. These teachers were aware of what concepts an activity or stimulus was designed to challenge, provoke or develop in students' ideas over time. For example, Teacher 6 focused on challenging Student 5 (who saw the wick as fuel) by countering the student's expectations. Teacher 6's recognition of the student's misconception meant he opted for a discrepant event activity that had been successful for him in the past (i.e., holding burning fuel won't burn your hand):

> The first thing we've got to get them to understand is what the fuel is ... You need to do some stuff on fuels in terms of what make a good fuel ... My favourite to teach kids that in fact it's not the liquid that is [burning] is just to put metho' [methylated spirits] in your hand and light it. It doesn't burn your hand. And so you ask them, 'Why, why doesn't it?' and they will say 'Well it's this and that.

> It's ... the liquid that's burning' and you'll say, 'But the liquid's in contact with my hand.' And so you just take them through and they get the idea there's vaporisation occurring. (Teacher 6)

Teachers suggested setting up situations for students to experience other events they could compare and contrast to draw out ways of applying new concepts (i.e., solid, liquid and gas fuels), for example,

> Whether you also got a kerosene lamp with a wick, or metho' [methylated spirits] rather than kerosene ... What else would I do? ... Probably looking at what other things combust. The fact that wax is a nice, combustible material, safe and stable, that sort of thing. Looking at the other forms of what we burn. And they could—perhaps if not necessarily hands-on—identify the use of gas and how mum and dad light the gas fire stove. Um, solid fuel. (Teacher 18)

Teacher 12 suggested a brainstorming technique in a "constructivist approach" (compare this to the use of brainstorm by Teacher 15 in the previous section whose intention was to rapidly correct many students' imprecise terminology) :

> Try talking, [a] lot of group work getting ideas shared ... you know where they're at, getting them to tell you—all that kind of thing... Using [a] constructivist approach, but we're brainstorming. Work in a group, write down everything we know about a candle .... make a pile of statements. Then in the group decide ... which ones we all agree with, which ones we disagree with one, and let's go from there. Because I think that's a wonderful way to get kids' [ideas] and it's not threatening (Teacher 12).

*Integrated Language*

Teachers with an integrated language orientation focused on using science as a vehicle for general language development. Science was only one aspect as they equally supported other subjects in an wholistic, cross-curricular approach with activities such as making candles, drawing birthday candles and cooking biscuits:

> More work with candles ... I'd have to look back through my books and come up with some ideas, but I would certainly integrate this. I would look at making my own candles, perhaps like with bee's wax or you know making them so that the children could understand the composition of a candle .... With little children you could relate this to birthday candles, and there are some wonderful stories—The Little Match Girl. (Teacher 20)

Teachers suggested ingenious activities. Teacher 7 planned a succession of activities into social studies, reading, writing, spelling and other subjects with the candle as the central experience for a whole language approach (notice her pedagogical decision to omit the term energy):

> Straight away I'd go into a whole language programme based on the science experiment ... Their spelling words would be like wick, wax, match box, you know things like that ... where they're actually writing about it ... Possibly do some research—instead of doing normal reading lessons. Like I do now in the classroom, I actually get out the encyclopedias and other books attributing to that topic, and, uh, we do comprehension ... or we do cloze [a fill in the missing word activity] from that, or they do summary writing. If it was a young child I probably wouldn't take energy on straight away. I'd take—well heat is energy but I'd call it heat—and look at all the different types of heat ... From then I'd probably go back in history and candle making—like in art—get them to make candles. (Teacher 7)

### *6.2.1 High, Midrange and Low Science Knowledge*

Which orientations to school science were evident from the follow-up activities suggestions teachers made? Overall, the most common orientations (see Table 30) were content mastery and discovery, with fewer teachers holding a processes, conceptual change or integrated language orientation. Nearly two-thirds of teachers in the sample held dual orientations towards teaching science (see Table 31).

Table 30

*Summary of Orientations to Teaching Science, by Science Knowledge*

| | Teachers' Science Knowledge | | | | |
|---|---|---|---|---|---|
| Orientation | High | Midrange | Low | Total | Percent |
| Discovery | 2 | 6 | 5 | 13 | 43 |
| Processes | 2 | 4 | 4 | 10 | 33 |
| Content Mastery | 6 | 4 | 5 | 15 | 50 |
| Conceptual Change | 4 | 3 | 0 | 7 | 23 |
| Integrated Language | 2 | 1 | 2 | 5 | 17 |

Notes: Numerals in columns other than Percent refer to the number of teachers whose follow-up strategies indicated the teacher held that orientation. The Total number of orientations (50) is greater than the number of teachers in the sample, as some teachers held dual orientations. Percent refers to results only in that row.

What is interesting in these results is evidence of the diversity of orientations towards school science held by the Western Australian teachers in this sample. Teachers seem to be maintaining the currency of different orientations, as 20 of the 30 teachers held dual orientations. Teachers are accessing their pedagogical content knowledge from different combinations of orientations. For example, Teacher 6 (see Table 31) suggested follow-up activities that pursued students' mastery of content (he would use a demonstration so students would learn that not only the wick burns) and conceptual change (by challenging students to work out why you don't always get burnt when you hold burning things). Ten teachers suggested activities consistent with only one orientation.

Within the Western Australian context, the orientation most recently introduced on a large scale—conceptual change—was being accessed by teachers in the sample as frequently (or infrequently) as the processes orientation which has been in curriculum documentation for far longer (especially in primary schools). The predominant orientations were not of conceptual change, and of the seven teachers (see Table 31) who made follow-up suggestions that captured a conceptual change orientation, all combined this with other approaches towards follow-up.

Table 31

*Teachers' Orientations to Teaching Science, by Science Knowledge*

| Orientation | High Science Knowledge | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 | Total |
| Discovery | | | | x | | | | | | x | 2 |
| Processes | | x | | | | x | | | | | 2 |
| Content Mastery | x | | x | x | x | | | x | x | | 6 |
| Conceptual Change | x | | | | | x | | | x | x | 4 |
| Integrated Language | | | | | | | x | x | | | 2 |
| | Midrange Science Knowledge | | | | | | | | | | |
| | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 | Total |
| Discovery | x | | x | | x | x | | x | | x | 6 |
| Processes | | x | | | x | | | x | | x | 4 |
| Content Mastery | | x | | x | | | x | | x | | 4 |
| Conceptual Change | x | | x | x | | | | | | | 3 |
| Integrated Language | | | | | | | | | x | | 1 |
| | Low Science Knowledge | | | | | | | | | | |
| | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 | Total |
| Discovery | x | x | x | | | | x | x | | | 5 |
| Processes | | | x | x | | | | x | | x | 4 |
| Content Mastery | | | | x | x | x | | | x | x | 5 |
| Conceptual Change | | | | | | | | | | | 0 |
| Integrated Language | | | | | | x | x | | | | 2 |

Notes: Numerals in columns other than Total refer to teachers' code numbers; x indicates the teacher suggested a follow-up activity consistent with that orientation.

Results in Table 31 provide some important clues to the influence of teachers' science content knowledge on their orientations to science teaching and learning. Typically, teachers with high science content knowledge held a content mastery or conceptual change orientation, those with midrange science content knowledge were more likely to use a discovery approach often in combination with other orientation, and teachers with low science content knowledge preferred a discovery or content

mastery approach. One or two teachers from each group suggested follow-up of an integrated language orientation.

In the following discussion, links are drawn between the orientation of teachers' suggestions (shown in Table 31) and the extent to which teachers made references to students' concepts when planning follow-up (shown in Table 29), described as either an indirect reference, general reference or a precise linkage.

*High Science Knowledge*

Teachers with high science knowledge tended to rely on follow-up activities of either the content mastery and conceptual change orientations, or both of these orientations. Teacher 23 was typical as she started by highlighting Student 2's skill at making predictions and challenging students to continue with this, for example, "I'm encouraging them to look ahead about what they're going to do." She suggested the direction for content development, for example, "starting to look in perhaps a little bit more of the ... content knowledge ... bringing in the vocabulary of friction ... using heat and friction." She suggested a series of activities designed to develop the student's understanding of friction in a variety of contexts, for example,

> rubbing their hands together so that there's, um so they can start to feel friction .... look at how fire perhaps begins .... rolling cars down slopes and that type of thing so you would get an idea that something was moving on a smooth surface with rough wheels ... I'd look at that type of friction as well. (Teacher 23)

She was very aware of one aspect of conceptual change teaching—the need for students to see the broader applicability of concepts and not just link them to one context, for example, "so we wouldn't get locked into thinking that friction as always being hot, as in like ... causing a flame ... I think there's always heat there but it doesn't always mean there's a flame." While sounding unsure, this teacher was using her relatively high science knowledge of heat energy to support a conceptual change and content mastery approach: a blend of telling the student and ensuring their understanding by demonstration, but also by a variety of experiences to facilitate development of a concept which she had identified the student was lacking.

Linking the finding that teachers with high science knowledge often demonstrated a conceptual change or content mastery orientation (see Table 31) to their characteristic reliance on students' concepts when planning follow-up (see Table 29), teachers with high science content knowledge can be described as demonstrating a greater facility in recognising students' concepts and using these concepts in definite ways to plan follow-up activities. This was either for students to master content they do not have, or to challenge students so they can develop more sophisticated conceptual understandings.

Teachers with high science content knowledge did not always provide follow-up activities of a conceptual change orientation. Teacher 21, who precisely linked concepts to follow-up activities (see Table 29) used a discovery orientation as a way of motivating and interesting students with activities such as cooking, within a focus on Student 3's confusion between steam and smoke. This teacher had a theoretical understanding of conceptual change, but had apparently not developed fluency in planning follow-up consistent with that orientation:

> You know, working on the basic concepts and building up to the final one I suppose, um, because there needs to be a progression of understanding before it probably gets to that stage, before you ask them ... for the child to have that transfer [of] striking [to] friction, um, you know, if they haven't had that prior knowledge. (Teacher 21)

Teacher 6, with both a conceptual change and content mastery orientation, seemed to apologise that the latter was not his first preference, "The unfortunate bit here is I'm probably ... doing here what I'm accusing [others] of—being too closely directed, but in fact you need to do some stuff on fuels, in terms of what makes a good fuel." Perhaps this signals why teachers often held dual orientations, as they found the blend of different approaches to teaching and learning effective in terms of students' progress in the classroom context, for example, balancing directed approaches with more loosely constructed orientations.

*Midrange Science Knowledge*

Six of the ten teachers with midrange science knowledge suggested follow-up activities of a discovery orientation combined with another orientation (see Table 31).

Teachers within this range of science content knowledge also made a relatively high use of general references to students' concepts (see Table 29) when planning follow-up activities.

Teacher 11 was a representative case as she used a discovery and conceptual change orientation. How did this blend work for her? She identified concepts Student 5 had about friction, phase change and molecules, and concluded the student needed more work on this area (see Table 29) by making a general reference to these concepts. This decision was then framed within a discovery orientation (e.g., she emphasised the need to keep the student interested, the provision of plenty of time for the student to try out ideas and talk about them) and conceptual change orientation (e.g., invoking the student's own concepts—what he thought rather than telling him the correct view—by asking him to apply his ideas to other contexts):

> I'd ask them to transfer the knowledge to something else that they're interested in and see if they can apply the same things, the phase change, and maybe ask them for suggestions [of] things that burn slowly, things that burn quickly. And then compare what he knows there—or she—and see if he can apply the same concept, or the same thoughts, and if there is a similarity, or do things change. (Teacher 11)

Teacher 29 also suggested follow-up activities of a discovery and conceptual change orientation, and described previous successful lessons he had used with Year 3 students, which had helped them to develop understandings about the concept of heat in other contexts. In his case, the term "hands-on" was used to indicate he would include practical materials for students so they could observe first hand what happened:

> For a good early one, water and ice is a terrific activity. Where you notice the changes, you can talk about the changes, what's affecting it, how fast it's affecting it. So, um putting [ice] out in the sun, and ice out in the cupboard, and ice everywhere else, ice in the hand ... See that's a more hands-on manner. And just looking at how other things—boiling water—what happens to steam.

> That's a good way of addressing heat. So I would do, if on this particular concept, if it's looking for cause and effect, and also looking at change in structure—that's the sort of lesson structure I'd follow up with. (Teacher 29)

Another teacher with midrange knowledge was Teacher 10. Her follow-up activities were based on either indirect references, and general references to student's concepts (see Table 29) particularly Student 4's use of the term "chemical change". She felt the student was interested in this aspect so she decided to provide additional similar activities, which were within the processes and discovery orientations (see Table 31):

> Give them materials and not say too much else, and let them go for it, and then come back to the discussion. Which means the onus is on me to have the stuff up here [taps head], you know what I mean, and try and lead it. (Teacher 10)

Teacher 10 explained how it was important for her "to have the in-head knowledge ... to do justice" to a student's questions and interest, as a strategy to maintain student learning. She recognised the demands this placed on her when following a student's lead (e.g., "Perhaps I might actually ask him what he'd like to know first. So he might say, 'Ok, what's the substance made of? Why does this happen? What is smoke?' ") as well as conducting effective, free-form, unpredictable discussion style investigations (e.g., "I might ask him what he'd like to know based on what the class would like to know and then set up some sort of investigation [and] have lots of discussions").

*Low Science Knowledge*

Teachers with low science knowledge, like those with midrange science knowledge, used the discovery, content mastery and processes orientations with nearly equal frequency but with one important difference—none showed a conceptual change orientation (see Table 31). This finding is reflected in the absence of these same teachers' precise linkage to students' concepts when planning follow-up activities (see Table 29). It appears that teachers whose science knowledge was not

well developed had difficulty in, or did not see the value in, linking their follow-up activities to changing students' concepts.

How did these teachers who made indirect or general references to students' concepts make their decisions about follow-up activities? Some presented activities in a content mastery orientation, for example, Teacher 1 suggested:

> If they could try and be more scientific in their explanations, that is, why, talk about the gases or the, whether its a chemical or physical change. Try and get them to understand so that they can recognise what sort of a change that is. (Teacher 1).

Four teachers with low science content knowledge opted for a processes orientation. Often this was not to help students with all aspects of the experimental method, but to focus on aspects such as writing down observations or recording data. Teacher 16's orientations were to provide lots of experiments which are classics in science classes, and to motivate and interest the student. He qualified all suggestions with "if they're interested in experiments":

> The next experiment I would go to would be the bell jar and the water coming up. That's always interesting ... and then you could after that, go onto the egg [in the bottle]—the actual water, the air, um pressure is actually forcing the egg in—it's not the egg being sucked in, it's being pushed in ... [rubbing] different substances together to see which produces, um, heat and so on like that. I suppose even you could have, um, like some sort of thermometer, or something like that ... put it on the bottle and see if the temperature ... goes up. (Teacher 16)

Similar to other teachers with low science content knowledge, Teacher 16 did not comment on the student's understandings when making judgements or suggesting follow-up activities, instead his follow-up ideas were ones remembered from his own experiences:

In fact I was thinking ... yesterday when I had an apricot for lunch. Now when you get the apricot seed, and as kids we used to rub them, then get a ... girl's hair clip, dig out the centre and use them as whistle. (Teacher 16)

## 6.3 Other Differences Between Teachers' Orientations

There were some clear differences in teachers' orientations which were associated with the (a) age of students usually taught, and (b) the individual student work sample.

*Ages of Students Usually Taught*

Teachers with responsibility for older students were predominantly concerned with content mastery (see Table 32). This may be a reflection of the Western Australian situation, where Year 11 is non-compulsory, preparation for tertiary admission has a high profile and there is a perceived need to support students to cover prescribed content. Both Year 7 (see Table 33) and Year 3 (see Table 34) teachers' orientations seem dislocated or at odds with their Year 11 colleagues, as they more often saw science with a discovery or processes orientation, reflected in numerous references to selecting activities that were interesting and practical.

Table 32

*Year 11 Teachers' Orientations*

| Teacher | Discovery | Processes | Content Mastery | Conceptual Change | Integrated Language |
|---|---|---|---|---|---|
| 1 | | | x | | |
| 2 | | x | x | | |
| 3 | | | x | | x |
| 4 | | x | | | |
| 5 | | | x | | |
| 6 | | | x | x | |
| Total | 0 | 2 | 5 | 1 | 1 |

Note: x indicates the teacher's suggestion was of that orientation.

Table 33

*Year 7 Teachers' Orientations*

| Teacher | Discovery | Processes | Content Mastery | Conceptual Change | Integrated Language |
|---|---|---|---|---|---|
| 7 | | | | | x |
| 8 | | | x | x | |
| 9 | | | x | | |
| 10 | x | x | | | |
| 11 | x | | | x | |
| 12 | x | | | x | |
| 13 | x | | | | |
| 14 | | | x | | x |
| 15 | | | x | | |
| 16 | x | x | | | |
| 17 | | x | x | | |
| 18 | | x | | x | |
| Total | 5 | 4 | 5 | 4 | 2 |

Note: x indicates the teacher's suggestion was of that orientation.

Year 7 teachers appeared to have an increasing concern with preparation of students for high school, as shown by a decrease in their focus on discovery (when compared to Year 3 teachers) due perhaps to their own memories of high school science. Year 3 teachers were characteristically likely to focus more on discovery than processes or experimental procedures with their students. This freer exploratory style also supported general language development through group play sessions.

*Effect of the Student Work Sample*

Table 35 indicates some effect of the individuality of the student work samples on the frequency teachers chose follow-up activities of a particular orientation. Student 5 (in Year 11) had the highest number of follow-up activities related to a discovery orientation and Student 2 (in Year 3) had the highest number of conceptual change orientated follow-up activities. However, these effects appear less pronounced than the influence of the age of student usually taught on the follow-up activities teachers selected.

Table 34

*Year 3 Teachers' Orientations*

| Teacher | Discovery | Processes | Content Mastery | Conceptual Change | Integrated Language |
|---|---|---|---|---|---|
| 19 | x | x | | | |
| 20 | | | x | | x |
| 21 | x | | x | | |
| 22 | x | | | | |
| 23 | | | x | x | |
| 24 | | | x | | |
| 25 | x | x | | | |
| 26 | x | | | | x |
| 27 | x | x | | | |
| 28 | x | | | | |
| 29 | x | | | x | |
| 30 | | x | x | | |
| Total | 8 | 4 | 4 | 2 | 2 |

Note: x indicates the teacher's suggestion was of that orientation.

Table 35

*Effect of the Student Work Sample on Teachers' Orientations*

| | Student Work Sample | | | | | |
|---|---|---|---|---|---|---|
| Orientation | 1 | 2 | 3 | 4 | 5 | 6 |
| Discovery | 3 | 1 | 2 | 1 | 4 | 2 |
| Processes | 1 | 2 | 1 | 3 | 2 | 1 |
| Content Mastery | 1 | 3 | 3 | 3 | 1 | 3 |
| Conceptual Change | 0 | 4 | 1 | 0 | 2 | 1 |
| Integrated Language | 2 | 0 | 1 | 1 | 0 | 1 |
| Total | 7 | 10 | 8 | 8 | 9 | 8 |

Note: Five teachers judged each student's work, but the total number of teachers in each column exceeds 5 as most teachers had more than one orientation.

## 6.4 Summary

After teachers had judged students' work, they were asked to suggest follow up strategies they felt would be appropriate. Ten teachers in the sample made precise and explicit links to students' science concepts when planning follow-up activities. High and midrange science content knowledge appeared to support these teachers to take student' concepts into consideration when planning. However, the most frequently adopted strategy was to suggest activities that were neither justified nor linked by reference to students' concepts. This suggests that, for most teachers in the sample, to implement a conceptual change orientation would require not only an increase in the attention they pay to students' concepts, but also in how they translate this into follow-up activities which are appropriate for students' conceptual needs.

Teachers' science knowledge was linked to their orientation towards science teaching as demonstrated through the type of follow-up activities they suggested. Teachers with high science knowledge were more likely to have a concept mastery and conceptual change orientation, midrange teachers were more likely to use a discovery approach often in combination with another orientation, and teachers with a low science knowledge did not demonstrate a conceptual change orientation but were equally likely to hold a discovery or content mastery orientation.

These results echo the finding reported in Chapter 5 that teachers' science content knowledge was found to influence how they made their judgements—here it was shown to have an influence on teachers' orientations to science teaching. For example, teachers with low science content knowledge held other orientations towards ensuring students' had fun, discovered things, and learned the skills of writing in a science context. While orientations other than conceptual change are not inappropriate for good science teaching, they do not reflect the conceptual change approach present in much of the curriculum documentation described in the Literature Review.

Of concern in the Western Australian context is that 22 of the 30 teachers in the sample did not demonstrate a conceptual change orientation when making their follow-up suggestions. This concern is particularly pertinent for those with a low science content knowledge who did not make any precise reference to students' science concepts as part of their planning. Teachers who could orient their suggested

activities towards conceptual change, and who could express their intention for the activity as supporting change in the students' concepts, had high or midrange science content knowledge.

A conceptual change orientation needs to be part of all teachers' approach to be consistent with *Curriculum Framework*. For many of the teachers in this sample, adopting a conceptual change orientation requires a change in their intention for the activities they suggest, rather than a change through substitution of new activities, for example, to use a brainstorming technique for conceptual change not solely as a forum for language precision. Activities that can foster conceptual change such as predict-observe-explain, or from which conceptual change can be deduced, such as portfolios or concept maps (none of which were suggested by teachers in the sample) could also be appropriate for teachers as they develop and maintain different orientations.

These findings should not be used to suggest that teachers abandon other orientations and hold a conceptual change orientation exclusively. The aspects of the classroom situation that teachers took into consideration and which were evident in their suggestions, such as following students' interests and ensuring students have time for play and first hand experiences, ensuring that students' hold a scientifically correct view, and integrating science into a cross-curricular program, reflect appropriate alternative orientations to school science.

Some pedagogical-cultural elements need to be taken into account by teachers who are considering adopting a conceptual change orientation, since another influence on teachers' orientation to follow-up activities identified by this research was the age of students they usually taught. Teachers in Year 11 rarely involved orientations other than content mastery, teachers in Year 3 relied heavily on discovery and those in Year 7 adopted an eclectic selection of activities from the discovery, processes and concept mastery orientations.

# CHAPTER 7
# REVIEW AND DISCUSSION

## 7.0 Introduction

Key science curriculum documents in Western Australia, the *Curriculum Framework* (Curriculum Council, 1998a) and the *Outcomes and Standards Framework* (Education Department of Western Australia, 1988) specify the outcomes students should achieve and characterise science development as a progression towards increasingly sophisticated concepts and processes. The constructivist view of learning endorsed by these documents has moved the focus for pedagogical decisions away from the delivery of content by the teacher, to one in which student learning is the focus. It has placed a pronounced responsibility on teachers' skills to detect students' concepts, make valid judgements about what students' know and understand and what they are likely to understand next, in order to plan an appropriate program.

The focus of this research was to identify how content knowledge in science affects the judgements teachers make about students' science work and the follow-up strategies they suggest to support students' further learning. The quality of judgements and the appropriateness of the follow-up activities is crucial to the extent that teachers adopt a conceptual change orientation to science teaching, which, in turn, contributes to the quality of science education that students receive. Within the context of the Western Australian science curriculum, this will reflect the ability of teachers to implement the endorsed pedagogy of the *Curriculum Framework*.

In this chapter, the research questions and the research design are reviewed and set within the context which stimulated the study. Findings from the research are summarised. Limitations of the research design are examined. Finally, implications of the findings for teachers adopting a conceptual change orientation to teaching science, as well as implications for research, are discussed. Recommendations are made for the nature of professional development for teachers.

## 7.1 Overview of the Research Design

Three research questions were developed to answer the general question: What effects do teachers' science content knowledge and pedagogical content knowledge in science have on the way they make their judgements about students' science work? The first question, "What do teachers know and understand about the science concepts involved in a science-related task?", focused on describing teachers' science content knowledge about the processes and materials involved in lighting a match, burning and extinguishing a candle. The second question, "How do teachers interpret, and how do they make their judgements about, students' work?", investigated how teachers used their science content knowledge in making judgements, particularly which aspects of students' work they recognised. The third question, "What strategies do teachers suggest to support students' further learning?", examined the follow-up activities teachers suggested to support students' further learning.

The research design was built around teachers responding to a candle task, then judging student work samples about the same task. This provided the means to describe teachers' science content knowledge, how that knowledge influenced their judgements and the type of follow-up activities they planned. Figure 2 provides a diagrammatic overview of the research design.

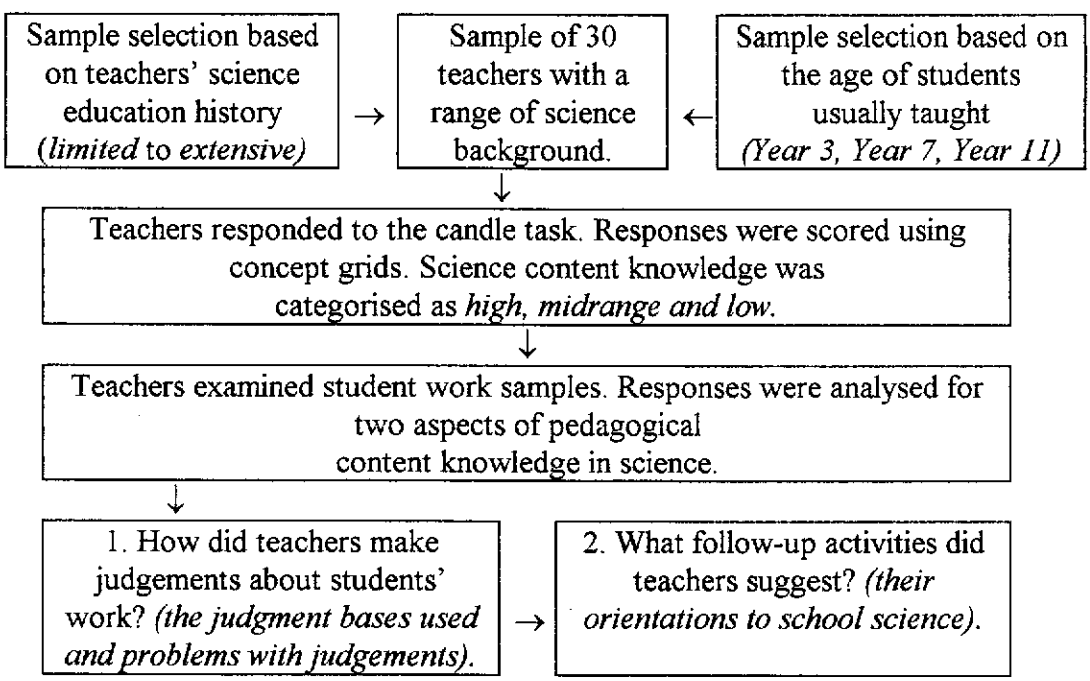


*Figure 2.* Overview of the Research Design

Teachers in the sample were selected from a range of science backgrounds. Science background was considered to be a combination of science education history and ages of students usually taught. Teachers were included as having a limited or extensive science education history, depending on factors such as what science they had studied at high school and the extent of their professional development in science. To ensure teachers were from a variety of teaching experiences, teachers were selected if they were currently teaching, and mainly taught, students at Year 3, Year 7 or Year 11.

Teachers responded to a selected science-related task, which involved describing and explaining events as a match was lit, a candle burned and then blown out. Their understandings were elicited by means of a semi-structured interview, which allowed teachers to review and expand their ideas, within the terms or concepts they themselves used. Teachers' responses were scored using three concept grids developed specifically for this purpose. These grids enabled the assignment of numerical values to represent the complexity and level of abstraction of teachers' ideas for concepts, such as burning, friction and the role of gases and molecules. Common understandings, scientifically correct views and misconceptions were described for all teachers. Teachers' scores for the three phases of the task were used to categorise them as within the high, midrange or low range of scores. These categorisations were used to describe the understandings typical of teachers within each range.

Teachers were then asked to judge one of six student work samples. Further judgements were elicited by an age and ability instrument. The extent to which teachers took into consideration students' science concepts was the major focus of analysis. This was supplemented by a description of the different bases teachers used when making their judgements, such as students' language or science skills. Teachers' use of these bases was linked to their high, midrange, or low science content knowledge.

Finally, teachers were asked to suggest follow-up activities they thought would support further learning for the student whose work they had judged. Results were described in terms of teachers' pedagogical science orientation, such as the conceptual change, discovery, processes or content mastery orientation, which was inferred from

their suggestions. Again, teachers' science content knowledge, categorised as high, midrange or low, was linked to their orientation.

## 7.2 Summary of Findings

Through the categorisation of teachers' science content knowledge as high, midrange and low, results have shown how intricately teachers' science content knowledge can influence their pedagogical content knowledge in science.

Findings have demonstrated that teachers' science content knowledge plays a part in determining which aspects of students' work they use as the basis for their judgements. Findings have also shown that teachers' science content knowledge influences their ability to make accurate and appropriate judgements of students' work, and have shown how it is associated with teachers devising follow-up activities that represent different orientations to science education.

*Science Content Knowledge*

This research has provided a detailed description of teachers' science content knowledge about the processes involved in lighting and extinguishing a candle.

Concepts such as "heat is involved when wax melts", "there is a substance on the match", "friction is involved", and "smoke is associated with flames going out" were held at an unsophisticated level by the majority of teachers in the sample. Typically, other concepts relating to gases, molecules, chemical changes and energy transfers were held by fewer teachers, even at unsophisticated levels. Some teachers were able to provide precisely worded, coherent and detailed explanations of complex events involving gas and energy transfers, while others found the task difficult and could, at best, suggest only possibilities for events.

Many maintained misconceptions about the functioning of the candle, for example, most thought that wax does not burn, many had difficulty linking concepts such as heat and friction and nearly all struggled when attempting an explanation of why a candle flame goes out. Each individual teacher's science conceptual knowledge was idiosyncratic for different phases of the candle task, for example, a teacher may have successfully used a molecular explanation for melting, but provided unsophisticated observations on visible events about burning.

*Making Judgements*

In answering the second research question, this research has described the rich and diverse variety of bases teachers used when evaluating students' science work, and has highlighted the relatively simple response to students' science concepts that most teachers made. Teachers linked their judgements to their own science content knowledge, and referred variously to other aspects of students' abilities, such as their use of language, perceived personal attributes or background. The majority of teachers examined students' work carefully, reading and re-reading parts and teasing out their ideas from often quite subtle clues.

Teachers interpreted and judged students' concepts in three general ways. The first was limited in scope, as teachers seemed to accept students' ideas without commentary. The second, and most frequently occurring, involved comments on students' concepts, but judgements were flawed because teachers' own science content knowledge was insufficient or inaccurate. The third way that teachers' responded to students' concepts characteristically involved an intense focus on the students' science concepts, and often invoked teachers' pedagogical experiences.

Students' science concepts are of central concern in conceptual change teaching, but teachers differed in the extent to which they took students' science concepts into account. A high proportion of teachers in the sample (80%) made some comment about the science concepts students had, however, fewer commented on concepts students did not have, and fewer still recognised misconceptions or detected when students were trying unsuccessfully to use a concept to make a satisfactory explanation. Very few based their judgement on a student's conceptual development by comparison to levels of increasingly sophisticated understandings.

The way all teachers included aspects of students' work not specific to science conceptual development (e.g., students' interests and background) provides them with multiple avenues which can help students. Students can grow in science understanding and develop science skills if teachers use only these aspects. But while they are relevant and may be critical to students enjoying science and doing well at it, these aspects are not the corner stone of a constructivist view of science learning. For many teachers this reliance on judgement bases not specific to science conceptual

development was linked to their own low level of science understanding and was due to their difficulty in recognising clues to science understanding.

The research has identified five problems that marred the quality and accuracy of teachers' judgements. The most pervasive problem was teachers' inability to recognise students' misconceptions, due largely to teachers holding the same misconception, or not having sufficiently highly developed science content knowledge to recognise the misconception.

Other problems encountered which were linked to teachers' low science content knowledge were: using inappropriate information to make judgements, rejecting students' scientifically correct views, and focusing on terminology rather than the level of understanding behind the term. One problem particularly recurred for teachers with high science content knowledge—reading-in more understanding than students genuinely had.

*Follow-Up Activities*

What teachers planned to do to follow on from their judgements was the focus of the third research question. Findings from this research have described how teachers varied in the extent to which they recognised students' concepts when planning follow-up, and have demonstrated how this affected their awareness of a conceptual change orientation to science teaching.

The majority of teachers in the sample made reference to students' concepts in general terms when planning activities, suggesting students needed more of a particular skill or activity, although usually they did not specify what aspects needed development. One-third of teachers made no apparent connections between concepts and follow-up activities, while another third made extensive and precise linkages.

These results were re-examined to determine the extent that teachers' suggestions represented different orientations towards school science. Each orientation carries its own pedagogical content knowledge, for example, whether teachers provide interesting activities, conduct demonstrations or teach experimental precision. A conceptual change orientation has as its prime focus the provision of learning experiences that will support students to change their ideas for ones that are more sophisticated, abstract, scientifically acceptable and generalisable to many situations. Most teachers were not familiar with this approach, instead suggesting follow-up

activities that reflected other orientations, such as discovery, content mastery and processes. A key finding is that teachers who actively use students' concepts as the basis for their judgements are in a better position to devise follow-up activities which are supportive of a conceptual change approach to teaching.

*General Research Question*

One of the most important findings of the research was that the categorisation of teachers' science content knowledge as high, midrange or low could be used successfully as a framework to describe patterns in how teachers made judgements and suggested follow-up activities linked to their judgements.

Using this categorisation, findings from the three research questions can be combined to answer the general research question: "What effects do teachers' science content knowledge and pedagogical content knowledge in science have on how they make judgements about students' science work?"

This question is answered by comparing teachers' science content knowledge, judgements and suggested follow-up activities within each of the three ranges of science content knowledge for the candle task, namely high, midrange and low.

*Teachers With High Science Content Knowledge*

Teachers with high science content knowledge used more sophisticated, complex and abstract ideas, and more specific scientific terminology to explain the candle task. They held fewer misconceptions (e.g., nearly all viewed the wax as a fuel) and were very aware of transfers of heat and energy between the different components of the match, wax and wick.

These teachers tended to base their judgements on students' concepts and misconceptions, and were more adept at making a close examination of what students understood and what they did not yet understand, what science skills students demonstrated, and related students' understanding to their own knowledge as a reference point. They had fewer problems with their judgements, as their science content knowledge supported them to make accurate comments and because they could recognise students' misconceptions. They were less likely to reject a scientifically correct view, and were not as accepting of mere use of terminology, but looked beneath this to determine whether students could "really explain" in a satisfactory way. The risk for these teachers was reading too much into students'

work, because their high level of knowledge expanded students' ideas into being at a higher level of abstraction of complexity (e.g., the student says "melt" and teacher stretches this to an understanding of "solids and liquids and change of state").

Teachers with high science content knowledge typically took more consideration of students' concepts when suggesting follow-up activities. They were the most capable at making precise and explicit links between students' existing knowledge and the type of follow-up activity needed, supplemented by activities based on general references to science concepts. Their suggestions were usually linked to a content mastery orientation or were supportive of a conceptual change orientation to school science (e.g., cognitive dissonance or applying concepts in new contexts). This suggests that teachers with high science content knowledge are either more aware of the importance of science concepts in their planning, or are more able to suggest appropriate activities.

*Teachers With Midrange Science Content Knowledge*

Teachers with midrange science content knowledge were similar to teachers with high science content knowledge, in that both referred to concepts (e.g., melting) but teachers with midrange knowledge responded at a less sophisticated conceptual level (e.g., saying that molecules were involved in melting, but not being able to specify in detail what this meant and not utilising the concept fully in an explanation). They made inaccurate statements (e.g., suggesting phosphate or graphite as the chemical on the match).

Generally, these teachers were cautious, retrieving ideas from learning completed many years ago, and grappling to bring them to bear on the problem. A strategy some used was to supply a suite of possibilities, rather than to present a coherent argument, for example, to explain why the candle went out.

When making judgements, teachers with midrange science content knowledge were able to make a broad range of comments about what students understood and what they did not seem to understand; but in their attempts to make judgements they were likely to supply inappropriate information which may, in the classroom, perpetuate students' misconceptions. Of particular effect were occasions when teachers' knowledge was at odds with students' scientifically correct views, which led them to reject students' scientifically correct views because they did not understand

the ideas themselves (e.g., the relationship of heat and friction). This also caused them to fail to recognise students' misconceptions, or to involve misleading information or inappropriate analogies in their deliberations (e.g., equating incomplete combustion and the formation of vapour). At times, teachers with midrange science content knowledge were unsure of their own concepts and had difficulty recognising clues to conceptual change in students. This led some teachers to over-reliance on the judgement bases of general language and students' cultural, or personal attributes in preference to more science-related bases.

When suggesting follow-up activities, teachers with midrange science content knowledge relied mainly on general references to students' concepts, although some individual teachers did make precise and explicit links between what students knew and needed to know. Their follow-up suggestions were largely of a discovery orientation, but also representative of content mastery and conceptual change in a strongly eclectic approach to school science.

*Teachers With Low Science Content Knowledge*

Teachers with low science content knowledge used few scientific terms and made less detailed and generally shorter comments about the candle's processes. They were more likely to omit key terms or concepts such as friction, heat or energy, and when they did use these terms, they found applying these ideas problematic, confusing and unsatisfactory. They were more likely to hold misconceptions, such as the wax melts and does not burn. They tended to restrict their observations to visible rather than abstract aspects, and usually did not specify energy transfers.

A consequence of low science content knowledge was that teachers characteristically made judgements on aspects of students' work other than science concepts and science skills, and less often used their own science content knowledge as a basis for judging students' work. These teachers in effect ignored clues to students' conceptual development, possibly because of their own science content knowledge was inadequate to the demands of making judgements of this kind.

One of the major liabilities for teachers' with low pedagogical content knowledge in science was the type and frequency of problems they had when making their judgements. For some, their low science content knowledge was insufficient for them to determine the quality of the students' ideas, for example, they responded to surface

impressions of students' use of terminology without determining the accuracy of the concept held or the precision in students' explanations. They were less likely to detect students' misconceptions. Other problems teachers with low science content knowledge had with their judgements were a lack of provision of accurate information to counter students' misconceptions, using misleading analogies or anecdotes to gauge the extent students' ideas were accurate, or rejecting students' scientifically correct views.

Teachers with low science content knowledge were less able to make the important links between students' concepts and the follow-up they suggested. Their ideas linked to the activity, or the concepts in the activity, but not to students' facility with those concepts. Their suggested follow-up activities seemed to be remembered from high school lessons (e.g., the candle and the bell jar experiment). Their suggestions were often not scientifically accurate (e.g., they suggested ideas likely to perpetuate or instill students' misconceptions). Teachers with low science content knowledge were least likely to have a conceptual change approach, but the activities they suggested for follow-up were representative of other approaches, particularly discovery (e.g., trying out other ways of putting out the candle flame) or an integrated orientation.

## 7.3 Reflections on the Research Design

The research design was effective in providing the general research focus of describing the influence of science content knowledge on how teachers made their judgements and follow-up suggestions.

Selecting teachers with a wide range of science backgrounds for the sample ensured that a range of teachers' science content knowledge was represented. The categorisation of science content knowledge (as high, midrange or low) was productive as a framework to describe patterns in the problems and strengths teachers had in making judgements about the student work samples and how they took into consideration students' concepts to a lesser or greater extent when planning follow-up activities.

The candle task proved to be a rich stimulus for students and teachers to demonstrate both simple and complex concepts. While striking a match, lighting a

candle and then blowing it out, are relatively common-place events, they provided a visually engaging focus. Used in conjunction with the semi-structured interview style, this task provided ample opportunity for teachers to demonstrate their understanding of the related science concepts.

Linking the task to concepts such as chemical change, energy transfers, heat and gases in combustion, through the three phases of the task, allowed for a rich description of science content knowledge from a range of science disciplines. Further, the candle task was appropriate to the Western Australian context, as the concepts involved, such as energy forms and transfers, the nature of materials and the changes they undergo, are representative of science concepts in the *Curriculum Framework*.

Asking teachers to respond to the candle task first was beneficial because it allowed them to become familiar with the task the students had done and gave them time to reflect on the concepts involved in the task. It also facilitated comparisons between the teachers' own science content knowledge and that of the students. These factors increased the quality and quantity of the interview data.

The concept grids developed for this research provided a means of describing in detail teachers' science content knowledge about the candle task, and distinguishing a range of science content knowledge for teachers even though they came from widely different science backgrounds. The grids reflected a conceptual change view of learning, and reinforced the notion that both teachers and students can hold the same ideas.

The presence of an interested audience (the researcher) had a positive effect on the quality of the interview data as it encouraged teachers to demonstrate their science content knowledge. The interview situation provided a context for teachers' pedagogical content knowledge in science to be accessed, and also provided ample opportunity for teachers to explore, compare and even reject their judgements and follow-up strategies. The written form of the student work samples facilitated such revisions because teachers were able to review the transcript as much as they wished.

*Limitations*

Six main limitations of the study relate to: (a) the nature of the sample, (b) the provision of limited information on which to make a judgement, (c) the inclusion of

judgements made of only one task, (d) the think-aloud aspect of the task, (e) the effect of the interview style, and (f) the presence of the researcher.

*Nature of the sample*. The chosen sample size was appropriate for the qualitative research approach needed to answer questions such as the ones of interest in this study, but the small number of teachers included means that descriptions of teachers and their judgement processes relate only to those in this sample (Simmons & Lunetta, 1993). Nevertheless, the careful selection of the sample ensured a wide range of views which is likely to be more representative of the teaching population than a random sample of similar size.

*Limited information.* Teachers had limited information (i.e., one student work sample) on which to make their judgements. Three teachers did comment about their professional preference to be able to see students in other situations because judging on the basis of one piece of work was difficult, especially with Student 1 and 2 whose transcripts were short, for example, its "hard to judge on one example" (Teacher 8). There was some evidence that the individuality of some work samples influenced how teachers responded to them.

*One task used.* Science conceptual knowledge is complex and changeable over time and context. The description of teachers' science content knowledge gained through a single interview, limited to one context, is only relevant to that context and time.

*Think aloud.* Asking "subjects to verbalize or use a think-aloud commentary" can be a limitation to research (Simmons & Lunetta, 1993, p. 170). In this research, analysis was limited to data obtained from what teachers said during their interviews. Thus, the quality of the data may have been influenced by factors such as teachers' verbal fluency, unfamiliarity with the situation of having to explain or justify their judgements, or inability to verbalise tacit understandings. Teachers may have produced quite different judgements if they had not been asked to think aloud, for example, if they had submitted a written judgement, or if they were observed in their classroom making judgements about familiar students engaged in familiar science activities. Analysis was also constrained because teachers' responses may have been misinterpreted (e.g., teachers' incomplete sentences and use of gestures to imply meaning meant their ideas were not always obvious).

*Effect of the interview style*. The semi-structured interview style was productive, in that it allowed the researcher to clarify teachers' ideas. However, it did not allow for direct questioning on aspects of students' work that teachers did not comment on. For example, Student 6 explained that blowing carbon dioxide onto the flame made the candle go out, but not all of the five teachers who read the student's work remarked on this. Thus, it was not always possible to determine if teachers thought the student held a scientifically correct view and felt no comment was needed, if they thought the student was incorrect but were unsure of what to say, if they did not regard this aspect as relevant to making a judgement, or if they were simply focusing on other aspects of the student's work. However the interview situation afforded teachers the maximum opportunity to engage with students' work, and probably represented more time than would normally be devoted to one student in the busy schedule of a teaching day.

*Presence of the researcher*. The presence of the researcher is likely to have a effect on the interviewee, and a reciprocal effect of the interviewee on the researcher (as described by Steier, 1995). For this research, the researcher may have negatively influenced the science content knowledge and the pedagogical content knowledge in science that teachers demonstrated. For example, some teachers showed uncertainty or minor discomfort when trying to explain a phenomena in scientific terms, others may have limited themselves to what they felt sure about (and thus not revealed the full extent of their understandings), and some may have been influenced by their conceptions of what the interviewer wanted to hear (e.g., the particular type of follow-up activities suggested). Interviewees also had an effect on the researcher which may have impacted on the quality of the data obtained (e.g., when teachers' science content knowledge was unexpectedly high or atypically low, or when teachers demonstrated novel misconceptions, the researcher had to be wary of showing a reaction other than one of continued encouragement and interest). Given the length of time for the interviews, and the frequent, semi-scripted interactions between the researcher and interviewees, it is unlikely that this influence did not occur. Awareness of expectations by the researcher (e.g., Year 3 teachers would have the lowest science content knowledge), and training during trialing of the interview questions and style, were effective ways to counter this influence.

## 7.4 Implications of the Findings

Evidence from this research indicates that high levels of science content knowledge by teachers have potential benefits for students through teachers making more accurate and appropriate pedagogical decisions. Results indicate that teachers with high science content knowledge more frequently utilised students' concepts as the basis for judgements, saw what students did not quite understand, were more likely to recognise misconceptions, or linked their judgements more productively to follow-up activities that were appropriate to a conceptual change orientation, than did teachers with low science content knowledge.

In this section, general implications of these findings in the Western Australian context are discussed, such as the magnitude of change required for teachers to adopt a conceptual change orientation to science teaching. Specific implications for teachers are outlined, concerning the adequacy of their science content knowledge, how they can increase the extent to which students' concepts are considered when they are making judgements, and how they can make choices based on students' concepts feature regularly in their follow-up activities.

Implications for further research are also discussed, relating to replication of the study in classroom contexts and with different tasks, determination of the extent of problems with judgements for the wider teaching population, and use of the instrumentation developed for this research to evaluate the success of teachers' professional development in science content knowledge.

### *7.4.1 Implications for Teachers*

Of concern in the Western Australian context, with an outcomes-focused curriculum and a conceptual change orientation towards science teaching and learning, is the low number of teachers in the sample who demonstrated an ability to gauge the quality of students' science concepts, recognise how these form part of a progression of increasingly sophisticated concepts, and link these concepts to follow-up activities of a conceptual change orientation. Only one teacher (Teacher 6) demonstrated consistently accurate science content knowledge, used concept development as the main basis for making judgements, and kept a precise focus on students' concepts when planning follow-up activities of a conceptual change orientation. No primary teachers were able to achieve this, even those with extensive

involvement in science education (e.g., one primary teacher had done 160 hours of science professional development in one year) or specialised science professional development in new science teaching and learning methodologies (e.g., those primary teachers in consultative, science leadership or curriculum writing roles).

This result is interpreted as indicating that developing high science content knowledge, learning to recognise students' science concepts in precise and explicit ways in order to make accurate and appropriate judgements, and plan follow-up activities of a conceptual change orientation, is a complex and demanding requirement.

Based on the patterns evident in this research, adopting a conceptual change orientation to science education, as advocated by the *Curriculum Framework*, will require for many Western Australian teachers a dramatic change in the attention they need to pay to recognising evidence of students' science conceptual knowledge, as an alternative to their present reliance on other judgement bases, such as students' general language and attitude, although these remain important. Using a variety of bases gives teachers a suite of ways to respond to students' work, however some of these bases (e.g., recognising when a student has applied a science concept incorrectly) are more likely than others to contribute to conceptual change.

For many teachers, it will require a change from well-established orientations of content mastery and discovery. This may involve changes in the types of activities offered to students to ones that are more conducive to a conceptual change approach. For some of the teachers in this research this will mean altering the way an activity is used, for example, using a brainstorm activity not just as an opportunity to practice language, but with the intention of having students air their ideas and use each other as "sounding boards" to develop more coherent and scientifically correct views. For others it may mean using group work for students to share alternative ideas and discuss their own valued interpretations, rather than just practising to get their answers to be the same as those of the teacher.

For many teachers, adopting a conceptual change orientation means a change from a focus on the activity, such as making a whistle, to a stronger focus on the concepts within the activity, such as friction. This change increases the demand on teachers' own science content knowledge to first recognise which concepts are

involved in an activity, then express them accurately to students, help students to make the links between different activities that can be discussed using the same concepts, and finally recognise how the same concept may be held at different levels of sophistication by students in the class. For many teachers, especially those in primary schools, this will require marked changes in the level of sophistication, complexity and abstraction of their own ideas, to be able to first recognise, and then support, students who have more sophisticated ideas than they do themselves.

Consequently, teacher education systems and teacher professional development providers in Western Australia which are implementing science curriculum documents that promote a constructivist view of learning and a conceptual change orientation to teaching will need to support the many teachers for whom this requires extensive development in their science content knowledge, and the way their pedagogical knowledge in science is put into practice in classrooms.

Evidence in this research is the basis for recommendations for three specific areas for both teachers and education systems to address: (a) defining teachers' science content knowledge as adequate through its pedagogical effects, (b) promoting judgements which are based on students' science concepts, and (c) assisting teachers to devise follow-up activities that are attuned to a conceptual change orientation.

*When is a Teacher's Science Content Knowledge Adequate?*

Evidence from this research can be used to make a strong case for teachers to bring a high science content knowledge to bear when making pedagogical decisions about students' science work, because teachers with high science content knowledge made judgements and suggested follow-up activities that were more precisely linked to students' conceptual change needs, than did teachers with low science content knowledge. These results echo arguments presented in Chapter 2 (e.g., Shulman, 1986; Carré & Ovens, 1994) for teachers' science content and pedagogical knowledge in science to be sophisticated enough to support students' learning.

However, while it may be desirable for all teachers to develop a high science content knowledge, in practical terms this is not a plausible solution. Researchers have warned that ineffectual "showpiece quick-fix solutions involving more in-service, better curriculum, and more research—have had limited impact on teachers' work" (Wallace & Louden, 1992, p. 518). Even an extensive 6-month inservice program for

practising teachers (Shymansky et al., 1993) reported that many teachers often regressed in their understanding, and replaced existing misconceptions by new ones until they finally showed conceptual growth.

The major difficulty with such professional development courses is that it is virtually impossible to define what science content knowledge, and to what level, is sufficient for a teacher. Science courses are successful only if they present content in a form that teachers can relate directly to their professional goals (Tobin, Roth, & Brush, 1995). However, the diversity and flexibility of outcomes-focused education mitigates against anything, other than a choice of hundreds of simultaneous courses, being immediately relevant to teachers' needs. Asking teachers to develop and maintain a high level of science content knowledge for all of the suggested concepts, topics, themes and projects included as appropriate for achievement of the Western Australian science outcomes in the *Curriculum Framework*, is not a reasonable proposition. This curriculum is too broad in scope to expect such wide-ranging expertise, for primary, as well as secondary, school teachers. Consequently, providing professional development in science content knowledge for teachers is at best a partial solution to achieving an increase in teachers' levels of science content knowledge.

An alternative approach is to define adequate or sufficient science knowledge through its pedagogical effects. Adequate, in this view, does not refer to acceptance of a "watered-down" or reduced quantity of science content knowledge (i.e., develop in-depth knowledge in one science subject as suggested by the USA's National Research Council, 1995, although this would be beneficial to teachers) but sets a teacher's science content knowledge as adequate when it supports—and does not hamper—that teacher's pedagogical skills to foster student learning in a particular outcome, topic or task. Adequacy refers to teachers' ability to recognise the consequences for student learning of their science content knowledge, rather than focusing on their ability to provide scientifically correct explanations at a high level of abstraction to students on demand.

Based on the description from this research of the different ways that teachers recognised and responded to students' concepts, teachers' science content knowledge is adequate if it supports their pedagogical content knowledge to recognise what science concepts students have, and have not got. Teachers' science content

knowledge is sufficient if it helps them recognise students' misconceptions, and when and how students' explanations are falling short of a scientifically correct view. It is ideal, rather than merely adequate, if it enables teachers to identify a student's conceptual place in a series of increasingly sophisticated science understandings and supports teachers to use this placement to plan follow-up activities that will foster further conceptual change.

What does this mean for teachers in the Western Australian context? A key aspect of this definition of adequacy is that teachers become self-aware of when their science content knowledge is no longer supportive of students' progress. Teachers with this view of the adequacy of their science knowledge recognise the limits of their knowledge, decide when they should reduce their reliance on their own knowledge, recognise when they need to find out the details of scientific events, and actively check their current understandings. Defining adequate knowledge through its pedagogical effects means teachers will continue to base their judgements or follow-up suggestions partly on their own knowledge, but will accept openly that their knowledge may be a misconception, a partial explanation, or an inaccurate view.

Some teachers in the sample demonstrated such self-awareness, developed through reflective practice. Their comments endorse the suggestion by Duke, Jobling, Rudd and Brass (1994) that teachers "need to realize that they do not have to know everything, they must learn to say, 'I don't know but let's find out together' " (p. 99). These teachers commented that the first thing they would do would be to go and "check up their books" to find out what the terms the student used meant, or if their own ideas were scientifically correct. Teacher 28 had doubts about the accuracy of the evaluation and feedback she made for Student 1, and expressed a strong concern about the risk of reinforcing incorrect understanding:

> I wouldn't want to evaluate this without making sure that my knowledge was correct because I'm absolutely, totally uncertain .. You know this really doesn't make any sense to me because I'm not sure myself of what is happening scientifically ... If I thought he was correct, I could reinforce things that were [correct] and that would stay with that child for ever-more ... If they were

incorrect and I thought they were correct, I could reinforce that sort of knowledge in the child. (Teacher 28)

The idea of adequacy through its effects on student learning was supported by the finding from this research that teachers' science content knowledge is not a static entity, but is highly variable according to both topic and context, for example, a teacher's knowledge may be high when studying a science discipline at a tertiary level, but may not be adequate to detect a student's misconception (e.g., that there is more to the wick than just holding the flame as in the case of Teacher 1). It is likely that all teachers will at some point need to reflect on the adequacy of their own science content knowledge.

Merely highlighting, during professional development courses, the problems teachers have with inadequate knowledge would have its own undesirable side effect, as many teachers are already very aware of their limitations. Indeed, lack of confidence by teachers in science was one of the factors linked to low rates of science teaching in primary schools. Appleton (1992), in a study of pre-service teachers, suggested that as they become more confident in science, they will be more likely to undertake independent science content study for themselves, or through courses. Building teachers' confidence is valuable as it encourages them to tackle science lessons, and to be life-long learners in science, but having doubts about one's own knowledge is also valuable if it leads teachers into seeking additional understanding, at their own point-of-need, before making judgements about students' knowledge and planning follow-up activities. Confidence is part of this self-awareness. Having the confidence to seek information with students—rather than feeling intimidated by lack of knowledge or avoiding a responses by accepting students' ideas without verification—is central to the idea of self-awareness.

The critical point in developing self-awareness is when teachers' confidence becomes over-confidence, and then erodes the conceptual benefits to students. This was evidenced, for example, by teachers in this sample who explained plausibly, confidently and in great detail what a clever design it was that the wax melted but did not burn, or rejected as incorrect students' emerging views of heat, friction and ignition.

When teachers are aware that their ability to support students' learning is constrained by the inadequacy of their own science knowledge, they may avoid some of the pitfalls of low science content knowledge by relying on a directed curriculum (as suggested by Aubrey, 1994). In Western Australia, this can be achieved by use of appropriate materials, such as *Primary Investigations*, to develop broad concepts applied to multiple contexts, for example, the concept of energy. It also provides background information, suggests questions and follow-up, and does not assume high levels of teacher knowledge.

*Promotion of Judgements Based on Students' Science Concepts*

The relevance of self-awareness as a pedagogical strategy can be demonstrated to teachers through professional development. A core part of courses and workshops would be to help science teachers make students' science concepts their key judgement base. For teachers to help students achieve the conceptual science outcomes, it is important for them to focus on students' science concepts in ways that are more than a superficial recognition that a student "has got" a concept. Just recognising a concept is not productive in terms of implementing a conceptual change approach—and relatively few teachers in the sample were able to do this consistently.

Instead they should consider the quality of the concept (e.g., the level of sophistication, its accuracy, whether it is based on visual or abstract ideas), use it as a marker for further development (e.g., compare it to more sophisticated concepts) and recognise its significance in terms of their pedagogical choices (e.g., which follow-up activity will be most productive in terms of conceptual change or growth). For example, teachers' transcripts from this research could be used to "create" synthesised cases of teachers' judgement processes about student work samples. These transcripts would serve as the basis for discussion, for example, of ways to take students' science concepts into account when making judgements.

Findings from this research suggest that teachers with low science content knowledge had great difficulty in recognising evidence of students' science concepts, and could benefit from exposure to powerful, broad-based concepts that are applicable to many contexts, such as forms of energy, the idea that energy is transferred between objects, recognition of molecules in contexts other than melting (especially in combustion) and explanations of changes in materials involving gases.

The focus of teachers' efforts to raise the level of sophistication of their own science content knowledge, in order to make more appropriate and accurate judgements, should be on concepts similar to those mandated in the outcomes of the *Curriculum Framework*. These powerful concepts can then be applied to the myriad tasks, topics, themes and contexts of science in the *Curriculum Framework*. For example, the concept of heat energy as a form of kinetic energy due to molecular motion would have assisted most of the teachers in this sample provide more coherent explanations of many of the events in the candle task, particularly friction, melting and ignition temperature, and would have helped them to make more accurate and appropriate judgments of students' work. Awareness of these concepts would then support teachers to recognise them in students' work, and increase their frequency of use of students' concepts as the basis for judgements.

Another implication from this research is for teachers to reduce the frequency and extent of problems experienced when making judgements. A profitable professional development course would help teachers to address the specific problems they may (unknowingly) have when making judgements, for example, perpetuating students' misconceptions when they occur, inadvertently replacing students' scientifically correct views with their own misconceptions, accepting terminology rather than understanding because their own understanding of the terms was too slight, or avoiding responding to the quality of students' concepts by the simple expedient of saying the student understands and not proceeding with further analysis. Such courses could assist teachers to recognise the impact of a conceptual change approach to teaching, and recognise its increased demand on their own science content knowledge. Teachers could develop or trial strategies to counter these problems, such as recognising the difference between mere use of terminology and evidence of understanding behind the term, employing strategies other than rejection of students' ideas when teachers recognise them as views counter to their own, or finding ways to reduce the risk of replacing students' scientifically correct views with teachers' scientifically incorrect views.

Different science education programs could be offered, based on whether teachers have high, midrange or low science content knowledge. This categorisation is not used a starting point to gauge the conceptual complexity of a science content

knowledge course (e.g., start before, or at, an understanding of molecules) but as a guide to the different pedagogical effects that findings from this research have shown are associated with these different categories. Teachers can learn how their own science content knowledge influences the form and frequency of these problems (e.g., teachers with high science content knowledge for that context were more likely to read too much into students' work).

Labeling of teachers for such courses, as having high or low science content knowledge, should not be done only on the basis of teachers' science education background. In this research, teachers with limited science education history at times demonstrated quite sophisticated reasoning while others with extensive science education found aspects of the task demanded knowledge they did not have. Thus, although science education background is important, it is only a single indicator of science content knowledge.

*Assistance to Devise Follow-Up Activities Attuned to Conceptual Change*

The third recommendation for teachers and education systems is that professional development using tasks, such as the candle, that are rich in concepts about heat, change, energy and materials could be structured to assist teachers to recognise how concepts change through increasing levels of sophistication.

The student work samples developed for this research, combined with a scoring guide in the form of the three concept grids, could be beneficial to teachers who are interested in learning how to track conceptual progress. Teachers can trace their own conceptual progression as they develop more sophisticated ideas, for example, teachers similar to those in this sample who would be developing more sophisticated concepts about molecules, gases and energy.

This appreciation of how the level of concepts changes can form the basis for further professional development in follow-up activities for teachers interested in adding a conceptual change orientation to their existing classroom practice. Teachers could investigate how activities they are currently using (e.g., brainstorm and hands-on discovery) can be restructured to promote conceptual change, as well as adopting new teaching and assessment strategies such as predict-observe-explain, concept maps and student portfolios.

Professional development needs to incorporate the experience of conceptual change teaching first hand. That is, courses must avoid adopting a transmission or discovery orientation. Teachers need to experience learning in a conceptual change way before they can use this understanding in their classes. Explicitly recognising students' and teachers' own misconceptions has been shown to be an effective approach to develop primary science teachers' understanding of electric current and is implicated as a way to help pre-service teachers adopt a conceptual change orientation (Webb, 1992).

Adopting a conceptual change orientation to teaching is not a simple matter. Work by Meyer, Tabachnick, Hewson, Lemberger, and Park (1999) with prospective elementary teachers reported uneven development, for example, these pre-service teachers accepted that teachers can follow children's ideas and interests, but they did not fully appreciate how children are making meaning in science. Their findings show clearly that adopting a conceptual change orientation requires extensive support.

Unfortunately, the provision of extensive, on-going networks to support teachers make the change to outcomes-focused teaching, assessment and reporting is currently limited in Australia, due to the paucity of teachers trained and skilled in conceptual change teaching, and the fact that teachers are still constrained by timetables and the idea that all students receive the same materials at the same time (Griffin & Smith, 1996). Further, there is a lack of practising teachers familiar with conceptual change teaching, who can assist pre-service teachers to "break the didactic teaching-learning-teaching cycle", a problem compounded because "teachers teach as they were taught" (Stoddart, Connell, Stofflett & Peck, 1993, p. 239). Marion, Hewson, Tabachnick, and Blomker (1999) reported similar findings, with new teachers finding it difficult to observe or experience teaching for conceptual change during practicum.

Support for teachers to make these changes must also acknowledge that changes involve tension as teachers' perspectives alter, as reported by Glasson and Lalik (1993) over a year long study of six science teachers, especially when teachers learn to give more credence to and time for students to develop their own understandings, rather than the more usual, and quicker, approach of presenting information.

### *7.4.2 Implications for Research*

Some of the findings of this study have implications for science education research. These relate to (a) extending the focus of the research, (b) replication in other contexts and with a larger population, (c) confirmation in the classroom, and (d) use of the research instruments in professional development.

*Extending the focus of the research.* Further research is required using tasks other than the candle, but which involve similar science concepts, in order to compare with the findings from this research. This comparison could also be extended to new tasks which involve concepts from other science disciplines to provide a sense of teachers' science content knowledge for additional outcomes in the *Curriculum Framework*. The scoring method developed for this research to identify the critical elements in teachers' science content knowledge could be used productively for other research projects, for example, parallel grids could be developed for other tasks, reflecting other outcomes of the *Curriculum Framework*.

*Replication studies.* The important finding that science content knowledge was crucial to the nature and extent of problems teachers had when making judgements should be replicated in contexts other than Western Australia, to provide information on the impact of judgements on teachers using other curricula.

Studies are also needed to determine if teachers have additional types of problems when judging students' science work for other tasks. These would identify whether some of the problem types were limited to the candle task, for example, reading too much into students' work may be a problem when teachers are dealing with some, rather than all, concepts. This would establish the generalisability of the categories of problem types developed in this research.

Studies involving larger samples are indicated to provide a description of the extent of the problems identified in this research. While data from this research showed that most teachers had difficulty with students' misconceptions are accurate for the present sample, these data suggest, rather than indicate, how pervasive these problems are for the wider teaching population. Similarly, additional research is indicated to gauge the proportion of teachers who demonstrate familiarity with follow-up activities of a conceptual change orientation. The outcomes of such research would also suggest the extent to which professional development is required.

*Confirmation in the classroom.* The findings of this study are based on interviews between the teacher and the researcher in an out-of-classroom context, so it is appropriate for further research to extend the research context, and to identify whether teachers have similar problems when making judgements in their own classrooms. Observation of teachers' decision making practices would also confirm the preferences teachers had for the different orientations to science. In this research, follow-up activities were only suggested by teachers, not actually carried out. It is important that teachers' judgement practices and follow-up are examined as they occur in classrooms because only this kind of research can check the validity of the present findings for classroom practice.

*Using the research instruments in professional development.* The student work samples and teachers' interview transcripts used in this research were prepared very carefully and whether or not they could be used successfully in teacher professional development is another fruitful avenue for research. Workshops could be built around case studies of how different teachers responded to the same student's work (e.g., differences in the extent to which teachers took students' concepts into consideration when planning follow-up). Alternatively, case studies could be trialed as a professional development strategy to demonstrate different levels of reliance on students' concepts in teachers' decision making, or to develop teachers' awareness of problems other teachers have had with science judgements.

The concept grids were an effective method to represent the level of sophistication of teachers' concepts, and a way to acknowledge and value teachers' misconceptions. They can be used to evaluate the success of professional development in science content knowledge, by tracking changes in teachers' levels of understanding of concepts about energy, chemical change, or molecules. The grids also have potential as instruments to measure the extent of change in an individual teacher's science content knowledge as a result of professional development courses, for example, as a pre-test and post-test, and in extended studies over longer time frames.

## 7.5 Conclusion

Results of this research have contributed to the science education literature by identifying the ways in which science content knowledge is a crucial determiner of two key aspects of pedagogical content knowledge in science—making judgements about students' science work, and suggesting follow-up activities to support further learning.

The first major conclusion of this research is that for over half of the teachers in this sample, making accurate and appropriate judgements about students' science concepts was not something they were able to demonstrate. They found the process of judging to be problematic and inconclusive, even when they were in quiet, supportive surroundings focusing on one student, with one task, and with ample opportunity to reflect and reassess.

Although many teachers did comment on students' concepts, which is at the heart of teaching for conceptual change, for most teachers, this was done in the simplest fashion, merely stating a student had a concept. Few teachers were able to make judgements based on the quality of the concepts, for example, if it is a misconception or if a concept has been used productively. Within the context of Western Australia, teachers were unable, or found it difficult, to make valid judgements about students' science development in the way required by the *Curriculum Framework* and *Standards and Outcomes Framework*.

The finding that teachers' level of science content knowledge was influential in determining the bases that teachers used when making judgements leads to a related conclusion: teachers should be encouraged to develop their science content knowledge because it supports their ability to gauge students' concepts within a hierarchy of increasingly sophisticated and complex ideas. This is a key aspect of their pedagogical content knowledge in science. Most teachers in the sample made a concerted effort to make fair, reasonable and broadly-based judgements, and responded to a wide variety of aspects of students' work, including students' interests, attitude, language and possible background. However, while viewing students' work from a range of judgement bases is not inappropriate, and should be encouraged, this research concludes that most teachers need to re-assess their over-

reliance on these non-science bases, and look to increase the sophistication with which they respond to students' concepts as indicators of conceptual development.

Teachers with low science content knowledge should receive the lion's share of professional development in science content knowledge, as these teachers demonstrated an inability to focus intensively on students' science concepts and skills when making their judgements. While teachers with high and midrange science content knowledge were in a better position to assess students' science concepts, few of these teachers were able to apply an understanding of concept development, consequently, teachers with these levels of science content knowledge also need to have access to professional development to develop this aspect of their pedagogical content knowledge.

Professional development workshops should make both students' and teachers' concepts, misconceptions, partial understandings and inaccuracies explicit, and involve teachers in tracking how ideas change as they become more sophisticated, complex and abstract. Professional development is needed that fosters growth in teachers' science content knowledge, particularly to help teachers recognise the effects of their knowledge on their pedagogical decisions. This recognition will be most reliably achieved through individual teachers' reflective practice and self-awareness, and the adoption of a positive outlook towards recognising the limitations of their own science content knowledge.

The second major conclusion of this research is that teachers of all levels of science content knowledge—not only teachers with low science content knowledge—demonstrated problems with the quality of their judgements. Making judgements that were accurate, in terms of scientifically correct views, and appropriate to helping students change their concepts, was influenced by teachers' science content knowledge, regardless of whether it was high or low. However, teachers' science content knowledge played an important role in reducing the severity of these problems, as the type and frequency of problems was commensurate with teachers' level of knowledge.

Teachers with low science content knowledge had the most frequent problems, particularly as they gave only minimal attention to students' concepts in their deliberations, had difficulty recognising students' misconceptions, often rejected

students' scientifically correct views, and also inappropriately corrected students' already scientifically correct views. Inadequate science content knowledge meant that teachers accepted students' efforts at face value, rather than looking at the scientific accuracy of their suggestions. The potential was also there to confuse students by providing misleading analogies and explanations.

Teachers with high science content knowledge had less frequent occurrences of these problems, because having sufficient knowledge assisted them, for example, to recognise students' misconceptions, but they were less able to guard against attributing too much understanding on the part of students. Teachers with midrange science content knowledge tended to suggest inaccurate information and misleading analogies in their attempts to judge students' work.

This research concludes that all teachers would benefit from awareness-raising professional development of the types of problems teachers have which affect the validity and quality of their judgements. Part of this professional development would aim to develop a heightened sense of self awareness of how and when teachers' science content knowledge is likely to impinge on the quality of their pedagogical decision making. In this way, teachers can avoid or reduce the negative impacts on students' science learning which were observed in the judgments of many of the teachers in this study.

A corollary of this point is that teachers' existing levels of confidence must not be eroded, but they must develop or maintain a positive view that seeking additional information is a necessary part of making accurate and appropriate judgements about students' work.

While findings from this research imply that it is desirable for all teachers to develop a high science content knowledge, since teachers with high science content knowledge had the lowest rate of problems with their judgements, such a tactic is not a plausible conclusion in the context of outcomes-focused education, in which the huge diversity of content and flexibility of topics makes it virtually impossible for teachers to develop a high science content knowledge in all conceivable science disciplines. This is particularly true for primary teachers who have other equally valid responsibilities for other subjects.

The third major conclusion of this research is that the ramifications of teachers' science content knowledge extend into the orientations they hold about school science. Part of a conceptual change orientation towards science education is not only to judge students' work with an eye to conceptual development, but to identify appropriate follow-up activities that will foster conceptual change or growth.

This research has identified that the relatively few teachers who suggested follow-up activities of a conceptual change nature were those categorised with high, or midrange, science content knowledge. Higher levels of science content knowledge were associated with teachers demonstrating the particular pedagogical content knowledge in science that supports a conceptual change orientation (i.e., they were more likely to precisely link students' concepts to follow-up activities which would move students towards the conceptual understandings they hope students will hold). Teachers with low science content knowledge did not demonstrate the ability to link—precisely and explicitly—follow-up activities to students' science concepts, and did not suggest follow-up activities of a conceptual change orientation.

The final conclusion of this research is that any practical solutions to reduce the frequency and impact on students' development of the consequences of teachers' low science content knowledge on their pedagogical decision making will require extensive, long-term attention. Those few teachers in the sample who demonstrated the ability to base their judgements largely on students' conceptual understandings, suggest follow-up strategies commensurate with a conceptual change orientation, and avoid most of the problems others had with their judgements had all been in receipt of hundreds of hours of intensive science professional development, and in some cases, years of full-time focus. An appreciation by teachers of the beneficial flow-on effects for students when they undertake to develop their science content knowledge, and in tandem, their understanding of its effects on the accuracy and appropriateness of their pedagogical decisions, is an appropriate long-term goal.

This research has reinforced Shulman's (1986) view of the centrality of science content knowledge in good teaching. It has extended his argument of the importance of science content knowledge by refining its relevance to, and clarifying its effect on, pedagogical content knowledge expressed through the quality of the judgements teachers make about students' science work and the view of science education they

hold as seen in the type of follow-up activities they suggest. Including the findings of this research in the "veritable armamentarium" (Shulman, 1986, p. 9) that teachers have in their pedagogical content knowledge in science would support teachers in Western Australia in their adoption and implementation of the *Curriculum Framework* and *Outcomes and Standards Framework*.

To implement a conceptual change orientation towards school science, teachers will need to develop their skills in making sound judgements about students' science work, in terms of reducing the type and frequency of problems experienced with judgements, and in terms of fine-tuning follow-up activities to match students' needs within a conceptual change orientation. This is a worthwhile focus for teachers and education systems.

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# APPENDIX A
# WESTERN AUSTRALIAN CURRICULUM DOCUMENTS

The extract *Working Scientifically* is taken from the *Curriculum Framework* Science Learning Outcomes (Curriculum Council, 1998a, p. 220). Full details are available on http://www.curriculum.wa.edu.au.

*Working Scientifically*

*Investigating.* Students investigate to answer questions about the natural and technological world using reflection and analysis to prepare a plan; to collect, process and interpret data; to communicate conclusions; and to evaluate their plan, procedure and findings.

*Communicating scientifically.* Students communicate scientific understandings to different audiences for a range of purposes.

*Science in daily life.* Students select and apply scientific knowledge , skills and understandings across a range of contexts in daily life.

*Acting responsibly.* Students make decisions that include ethical consideration of the impact of the processes and likely products of science on people and the environment.

*Science in society.* Students understand the nature of science as a human activity.

*Understanding Concepts*

*Earth and beyond.* Students understand how the physical environment on Earth and its position in the universe impact on the way we live.

*Energy and change.* Students understand the scientific concept of energy and explain that energy is vital to our existence and to our quality of life.

*Life and living.* Students understand their own biology and that of other living things, and recognise the interdependence of life.

*Natural and processed materials.* Students understand that the structure of materials determines their properties and that the processing of raw materials results in new materials with different properties and uses.

The extract *Energy and Change Outcome Statement* is taken from the *Outcomes and Standards Framework, Student Outcome Statements, Science* (Education Department of Western Australia, 1998, p. 52).

*Energy and Change Outcome Statement*

Students understand the scientific concept of energy and explain that energy is vital to our existence and to our quality of life.

*Energy and Change Strand Outcome Statements*

*Foundation level.* Demonstrates an awareness that energy is present in daily life.

*Level 1.* Understands that energy is required for different purposes in life.

*Level 2.* Understands ways that energy is transferred and that people use different types of energy for different purposes.

*Level 3.* Understands patterns of energy use and some types of energy transfer.

*Level 4.* Understands that energy interacts differently with different substances and that they can affect the use and transfer of energy.

*Level 5.* Understands models and concepts used to explain the transfer of energy in an energy interaction.

*Level 6.* Understands the principles and concepts used to explain the transfer of energy that occurs in energy systems.

*Level 7.* Understands the role of science in developing systems of energy transfer.

*Level 8.* Understands how to assess the role of science in helping us to explain energy systems, production and use.

The extract *Natural and Processed Materials Outcome Statement* is taken from the *Outcomes and Standards Framework, Student Outcome Statements, Science* (Education Department of Western Australia (1998, p. 92).

*Natural and Processed Materials Outcome Statement*

Students understand that the structure of materials determines their properties and that the processing of raw materials results in new materials with different properties.

*Natural and Processed Materials Strand Outcome Statements*

*Foundation level.* Demonstrates an awareness of materials and their properties.

*Level 1.* Understands that different materials are used in life and that materials can change.

*Level 2.* Understands that materials have different used, different properties an undergo different changes.

*Level 3.* Understands that properties, changes and uses of materials are related.

*Level 4.* Understands that properties, changes and uses of materials are related to their particulate structure.

*Level 5.* Understands the models and concepts that are used to explain properties from their microscopic structure.

*Level 6.* Understands the concepts and principles used to explain physical and chemical change in systems and families of chemical reactions.

*Level 7.* Understands the role of science in developing knowledge about the structure, change and use of materials.

*Level 8.* Understands how to assess the role of science in helping people describe the structure, change and use of materials.

## APPENDIX B

## WORK SAMPLES FOR STUDENT 1 AND STUDENT 6

Student 1 was in Year 3, female, of low ability; Student 6 was in Year 11, male, of high ability. The notations in brackets for phases 1, 2 and 3 have been inserted for clarity but were not included in the work samples used for the teacher interviews.

### *Student 1 Work Sample*

*[Phase 1: Striking the match]*

R tell me what I'm doing and what happens . and if you know why it happens

S you lit a match and you picked up a candle and you burnt . and you put a fire stick on the candle and you . and then you put it up on the plate

R tell me what happened here [match box] again . what did I do first? . I took out the match

S you took out the match

R and then what did I do?

S then you put it back in . you got the match and then put .. you got it .. and then you put the um . thing back in [sliding cardboard tray of match box]

R so I closed the match box

S you still had the match and then you put that on the floor [means table ] and you picked up the . then you burnt that thing and then you holded it

R how did I burn the match?

S with [point at striking strip]

R tell me . what is on the side here?

S ah ... .

R tell me what it is

S um . a fire . you . when you burn some thing you um ... [moves hands]

R what are you trying to show me with your hands?

S you um . had to ... ... you burn it with that [brown strip]

R do you know why it makes it burn?

S because its ... because its ..hard

R tell me about what happens up here [indicate flame on wick] tell me about the black part

S that [points at wick]

R yes

S um . you . lit one of them on there [a match in the box]

R so I lit a ...

S match

*[Phase 2: The candle burning]*

R on [point at candle flame] ... and what did I make up here?

S a fire

R tell me about the black part that's up here

S you um .. that went up when you put the s' [incomplete] put the match on

R anything else you can see down in here [molten pool at base of wick]

S water

R do you know what this stuff is called .. this white stuff? [wax column]

S um ... ...

R why do we have all this white stuff down here?

S because . so it can hold it

R hold what?

S fire

R hold the fire?

*[Phase 3: Blowing out the candle]*

R tell me what you can see

S um ... when I blew it .. it went out

R what went out?

S the fire

R and then what happened .. what else did you see?

S um .. I blew it or and the fire went out and then um .. .. the fire went out and then .. the black thing kind of went down a little

R so what else is happening now?

S the black things going down

[end]

*Student 6 Work Sample*

*[Phase 1: Striking the match]*

R tell me what you see and what happened

S is that it?

R yes

S you used the match because of the sulfuric head . and lit it . on the um paper what ever it's called . I don't remember . and the wick in the middle of the candle . you put it to that and that caught on fire . um . the wax around the wick makes it burn gradually but doesn't stop it from burning out . um ... that's it

R let's look at this section again, you talked about some sort of a .

S yes, it was a physical change in the match . the um matches .

R what sort of physical change?

S um . burning like . the head of the match changing

R and that stuff on the side there [brown striking strip] tell me more about that

S ... oh ...

R and you talked about how I lit the match . what happened that I was able to light the match

S um . well the . [laugh] they never taught us match lighting 101

R well use what you know

S so it was sulfur at the head of the match . and it . was it sparks or . it's not chemical . not chemical . so it was probably um . a spark or something to ignite it .

R where would the spark come from?

S the paper

R so the brown paper on the side?

S the brown paper

R gives it the

S spark

R and that makes

S fire . and the wood of the match just let's it keep burning

R tell me about the two parts of the match head and the wood

S well . the head of the match is highly flammable . and the wood isn't . so the head burnt up quickly . and the wood just stays alight um .

R how come the wood stays alight and the head burns up quickly?

S because the head's made of flammable material . it burns through quicker . and therefore it goes out quicker as well . and the wood's there because wood burns . so the flame just traveled from the head of the match to the wood . and just burned through that [unintelligible]

*[Phase 2: Burning the candle]*

R tell me about what's happening up here [point to flame on wick]

S that's a physical change in the wax . at a high temperature the wax is turning into a liquid . um . this liquid when cooled will turn back into wax . um . yes the wick in the middle is what's keeping the flame alight

R how?

S oil . I think . or something . flammable on the wick

R so you've got flammable oil on the wick that's keeping

S and the wax is just stopping it from burning all the way through

R so all this white stuff down here which you're calling wax [indicate wax column] .. what's all this stuff for ?

S that's to make sure that the . um . candle burns at a slow even rate ...

R how does it do that ?

S by collecting underneath . or around the wick . just below the flame . it makes sure the flame can't go down any further because the wax doesn't burn, it just melts . so the flame just sits on the top .. and then eventually the wax around the top melts and runs down the side of the candle and the flame moves down a bit

*[Phase 3: Blowing out the candle]*

R tell me what you see and what happens and why

S right . that's a physical change . um . the wick is smoking because its still really hot . um . the flame's gone out because of an increase in carbon dioxide around it . and it needs oxygen to live

R where did the carbon dioxide come from?

S my lungs

R why?

S gas exchange . through the alveoli

R so you're able to put out more carbon dioxide because you blew it on the flame

S it starved basically

R of

S starved of oxygen

R and that put it out

S yes

R tell me about the smoking bit again

S oh , yes . the wick was smoking because it was still hot ...

R why does it smoke because it's still hot?

S I'm not sure ... I don't know . because ... ... there's still material in it burning up . or . I don't know . I've no idea

R what about the wax stuff?

S the wax . the wax is no longer at a higher temperature and its turning back into a solid again . forming around the base of the wick

[end]

# APPENDIX C

## PROCEDURE AND PURPOSE OF THE RESEARCH

This appendix contains the explanation given to the teacher interviewee to explain the procedure and purpose of the research.

*1. Outline of Research*

This research I am doing is about what teachers know in science. I will ask you about a science type activity, and am interested in how you would explain it, at your own level of understanding. Not how you'd teach it to you students, but what you know and understand about it. I will ask you some questions what you're saying. All of the information you give me in the interview is confidential, and I will not use your name or school in any of the material in this study.

*2. Teachers' Background*

Can I ask your age?

Your home address in case I need to contact you again? Your school address?

When did you first start teaching? So how many years have you taught?

Has most of your teaching been in the junior or upper primary, or in upper secondary classes. What have you taught in the last three years?

Did you study science at high school? Did you study any of these subjects—chemistry, physics, biology, general science, geology, human biology?

Did you study at University? Did you study any of these subjects—chemistry, physics, biology, general science, geology, botany, medicine, human biology?

Did you study at teachers college? Did you study any of these subjects—chemistry, physics, biology, general science, geology, botany, medicine, human biology? Was it as a minor or major option, compulsory unit, as extra units?

Since starting teaching, have you attended any science education classes or inservice courses? What have you been involved in? Would it be more than 5 days of full time attendance?

Since starting teaching, have you completed any formal science education courses like at TAFE (Technical And Further Education) or university ? What have you been involved in?

Do you belong to any professional groups that relate to science education. What is your involvement?

Do you have any other interests or experiences that may have contributed to your level of science education? For example, a hobby, other jobs, helping high school children, you tutor, you are a science leader, partner's job?

*3. Permission Form*

This is the permission form for this research. Please read it and if you are happy with it, then insert your name and sign it.

*4. Set Up Equipment*

[Set up audio tape, candle equipment, age and ability card, student transcript folder]

*5. Commence Interview*

[Record teacher's science content knowledge of task; judgements of student work sample; use age and ability grid; suggest follow-up activities.]

*6. Questions and Thanks*

Are there any questions you'd like to ask about the interview, the research or the tasks you have done?

[Thank the teacher for his or her participation.]

APPENDIX D

RECORDING SHEET FOR TEACHER'S PERSONAL DETAILS

| | |
|---|---|
| Name | |
| Age | |
| Year of birth | |
| Home address | |
| School address | |
| Year first started teaching | |
| Number of years taught | |
| Most teaching at Junior, Upper Primary or Upper Secondary? (e.g., in last five years mostly at or, solely at one band, primary, lower or upper secondary, middle school). | |
| Science at high school (e.g., chemistry, physics, biology, general science, geology, etc.). | |
| Science at University (e.g., chemistry, physics, biology, botany, medicine, engineering, etc.). | |
| Science at Teachers College (e.g., as minor option, compulsory, as major focus, extra units). | |
| Attended inservice in science since graduation (e.g., conferences, seminars, district courses, school based professional development). | |
| Formal study in science or other subjects since graduation (e.g., diploma, post graduate diploma, masters, fellowships). | |
| Membership of science related groups (e.g., STAWA, PriSci, Greenteach, astronomy, receive journals). | |
| Other experiences contributing to science education (e.g., hobby, other jobs, help high school children, tutor, science leader, partner's job, library) | |
| Other comments | |

# APPENDIX E

# QUESTIONS FOR TEACHER INTERVIEW

This appendix shows the general and specific questions used in the teacher interviews.

*1. Teacher's Science Knowledge of the Task*

I'd like you to watch what I'm doing, then tell me what happened, and why you think it happened. [Researcher strikes match, waves out match flame, transfers flame to candle wick, places candle upright on saucer.]

Tell me what you see and what happens and why.

Tell me about this bit up here [the flame on the wick].

What's all this white stuff here called? What's it for? [Indicate wax column].

[Blow out candle] Tell me what you see and why it happened.

What else can you see?

Why do you think that happened?

[General questions to follow from teacher's lead]

So what you're saying is ...

Tell me more about it when you said ...

How can you tell ...

What do you mean by ...

You mentioned something about the ...

Is it to do with the ...

*2. Responding to Student Work Sample*

Here is a transcript of a student who did the same activity you just did.

How would you assess this child's work or evaluate their science understanding?

Can you read the transcript, and tell me how you would assess or evaluate the student's science understandings? You can either read it all, and then tell me what you notice. Or you can make comments as you go along.

What evidence can you see that makes you make that statement?

Why do you say that about the student?

Can you see anything else about what this student knows?

Why do you say "ah" .. "laugh" .. "make that comment"?

You said "....." what did you mean by that? What made you say that?

*3. Using The Age And Ability Grid*

I'd like you to show you this grid. You can use it to show how old, or what ability, you think this student is most likely to be, based on what you noticed in the transcript. Here [indicate vertical axis] are five levels of ability and here are ages [indicate horizontal axis]. You can use one, two, three, four or five cards to show where you would locate this student. Show where you think this student would be located. Please explain your reasoning as you go along.

[Place grid in front of teacher, and place transcript above grid so it is visible and obvious].

What was your reasoning for that decision?

What was it in the transcript that you noticed that helped you make that decision about age / ability?

Tell me why you placed this card / these cards here?

*4. Follow-up Activities*

What follow-up strategies would you suggest to help this student's understanding?

What else can you suggest to help this student?

Tell me more how you'd go about doing that.

How would you arrange it?

APPENDIX F

DEVELOPMENT OF THE CONCEPT GRIDS

Table F1 Students' Conceptual and Procedural Responses

| Conceptual Knowledge | Procedural Knowledge |
|---|---|
| Description 1 | Description 1 |
| Sees the purpose of the wick as a place for flame to stay ('the black part makes the fire stand up'). Sees purpose of wax column to protect you from burning and to help you hold the candle 'so you 'don't burn yourself' or to 'hold up' the flame. Aware of melting, but not state the cause. May say molten wax is water and smoke is steam. States candle goes out 'because you blew it' or 'blow hard.' States the smoke comes when the fire goes out. May use the term 'flame' or 'fire' or as 'a light'. Recognises that part goes 'black because it's burnt.' | States a few direct and observable steps in the sequence 'you lit the match and put it on candle'; this 'makes a fire'. Uses specific verbs to describe actions: 'scraped' or 'rubbed' the match onto matchbox. Suggests causal links: 'the spark made it go on fire' or say the plate 'gives the match a light.' May focus on unimportant detail: sliding tray on matchbox. |
| Description 2 | Description 2 |
| Sees the purpose of the wax to hold the wick to localise the flame: 'to hold up the string and make sure that only the wax melts' and 'it doesn't light anything else on fire.' May view the role of the wick is to burn away 'until it shrinks.' Recognises that wax is liquid: 'goes all liquidy' or melting due to heat from flame. Tries some ideas to explain why candle goes out, suggests 'wind' from your breath makes flame go out or your breath 'just blew it away.' Unable to provide a reason for the smoke: 'it's really hot and it makes the smoke go everywhere when it goes out somehow.' Associated smoke with burning: 'smokes there because you've burned something and you always get smoke when something's burning'. | States most of key steps, with additional detail to make more links between the series of events. Links the drip of wax 'because the fire makes it hot'; the 'wax lets the candle burn because its soft'; links 'the fires really hot and it burns up on top there, and wax will probably come down' a series of causes and effects. Suggests plate makes match burn 'because it's hard' or because it 'makes the thing hot when you scrape it'. |

Note: Quotations from students are shown in single quotation marks.

Table F 1 continued.

Table F1 Students' Conceptual and Procedural Responses (Continued)

| Description 3 | Description 3 |
|---|---|
| States the wax column is there to slow the rate of the wick burning 'the wax is there so the wick just doesn't burn in two seconds because it takes time for it to heat up and turn to liquid so that more wick is exposed'. Does not recognise wax as fuel: 'it makes sure the flame can't go down any further because the wax doesn't burn, it just melts, so the flame just sits on the top and then eventually the wax around the top melts and runs down the side of the candle and the flame moves down a bit.' Links the friction of striking the rough surface, which causes sufficient heat to make the chemical in the head burn ('friction causes heat'). Connects striking plate to 'rough' surface, 'friction', 'heat' or 'special chemicals' on match head. Suggests the match has 'got chemicals in it' which is 'stuff that burns when hit by something.' Links heating to burning ('the red things on the end of the match heats up and catches fire'). May state flame gives light and heat. Tries out more ideas for candle to go out (e.g., oxygen and carbon dioxide effect, lowering temperature, physically removing flame) but unsure of which explanation is best. | Finds the steps so obvious and commonplace is unsure how detailed to specify them without further questioning. Aware of the link of causal interconnections - the 'wax is getting hot so its melts' and specifies connections 'heat from the fire' is making it melt. Able to link reversals of causes ('heat's gone and it's cooling down') when flame is blown out. May explain events that are not observable using 'heat energy'. States series of events for each major move (friction, flash point, head burns, wood reaches flash point, wood burns) using specific terminology. Can describe events in future when all the 'wax goes down and it gets smaller' then the flame will go out. |

Note: Quotations from students are shown in single quotation marks.

APPENDIX F (Continued)

DEVELOPMENT OF THE CONCEPT GRIDS

Table F2 Transitional Description

| Conceptual Knowledge | Procedural Knowledge |
|---|---|
| Description 2+ | Description 2+ |
| Specifies heat or friction is involved in match head, and there may be special chemicals in the head or the strike plate, but unable to link the two. Suggests the match has 'got chemicals in it' which is 'stuff that burns when hit by something'; aware of heating linked to burning 'the red things on the end of the match heats up and catches fire'. | Recognises causal links but unable to provide scientific explanation. Knows there are events which are not directly observable: unsure if smoke was there inside the flame and you can only see the smoke now the flame is gone. Explains that 'the wick and the wax and the flame made smoke and all come off'. |

APPENDIX F (Continued)

DEVELOPMENT OF THE CONCEPT GRIDS

Table F 3 Additional Descriptions for Phase 1

| Content Knowledge | Procedural Knowledge |
|---|---|
| Description 1<br>Match lights because you strike it on the box. There are special substances or chemical on the match. | Description 1<br>Focus on gross actions - pick up match, take it out, strike on box etc. |
| Description 2<br>Match lights because you strike it on the box, and this friction makes heat. | Description 2<br>Focus on gross actions - pick up match, take it out, strike on box etc., but with some awareness of non-visible events e.g. heat, friction. |
| Description 3<br>Match lights because you strike it on the box, and this friction makes heat. This heat raises the temperature of the chemicals on the match head sufficiently to cause them to burn. | Description 3<br>Minimal focus on gross actions, but mainly on the changes in the substances, and the chemical events. |

APPENDIX F (Continued)

DEVELOPMENT OF THE CONCEPT GRIDS

Table F 4 Additional Level Description

| Conceptual Knowledge | Procedural Knowledge |
|---|---|
| Description 4 | Description 4 |
| States the wax is the fuel for burning or vaporisation and explains heat melts wax which moves up wick and is burned. States as the wick burns it turns to 'carbon.' Mentions use of gases from the air for combustion. Aware of the need for sufficient temperature to be reached by the friction of the striking plate for the chemicals in match head to ignite: 'combustion temperature'. May use the term 'chemical reaction' but does not specify details of chemical reaction of oxygen combines with wax. Uses ideas of energy ('kinetic energy') to describe change of state. Aware that wax will absorb heat energy. Uses phase change to explain 'wax starts as a solid then becomes a liquid because of the change of kinetic energy.' Aware that there is heat loss to the atmosphere and heat exchange. To explain why candle goes out, opts for lowering of temperature combustion below that point the wax will 'burn'. States smoke may be wax as well, and may suggest the smoke is a gas. | Able to explain events that are not directly observable, and uses terms such as heat, ignition, vaporisation. |

APPENDIX G

CONCEPT GRIDS

Phase 1 Lighting the Match

| Aspect | Concept | Level of Response | | | |
|---|---|---|---|---|---|
| | | Level 1 | Level 2 | Level 3 | Level 4 |
| Why does the match light up | striking action | stroked | struck or strike | with sufficient speed | |
| | substance on the match | special substance or material or chemical | substance or material removed from head | specified incorrect chemical that ignites easily (e.g., phosphate) | specified chemical that ignites easily (e.g., phosphorus, sulfur) |
| | substance on the box | special substance or material or chemical | rough or abrasive surface | specified chemical (e.g., sulfur, phosphorus) | is rough; also specified chemical (e.g., sulfur, phosphorus) |
| | friction involved | friction | friction makes match hot | friction causes or generates heat | friction generates heat depending on speed or strength of stroke |
| | heat involved | match gets hot | match is burning or ignites | heat, heat energy sufficient for burning or flame | activation energy or ignition point reached |
| | gases involved | flame or match, needs oxygen to burn | match combines with oxygen | burning produces $CO_2$ and $H_2O$ | oxygen combines with chemicals due to heat |
| | chemical change | match goes black | match turns to carbon or carbonised | chemical reactions involved | |
| | molecules involved | molecules heat up | molecules in chemical reaction | friction excites molecules | |
| What is transferred? | involved | flame | heat | energy | specified multiple transfers |
| | mechanism | non specific terminology (e.g, moves, touches, applied) | generic term 'transfer' | specific terminology (e.g., dissipate, impart, released, converted, absorbed, gives off) | |

APPENDIX G (Continued)

CONCEPT GRIDS

Phase 2 Burning the Candle

| | | Level of Response | | | |
|---|---|---|---|---|---|
| Aspect | Concept | Level 1 | Level 2 | Level 3 | Level 4 |
| What's happening with the wick? | wick is held up | wax holds the candle | wax holds the wick | | |
| | wick burns | wick burns | material of wick burns slowly | material of wick burns readily | |
| | wax slows rate that wick burns | wax slows the wick's burning | wax melts so candle lasts long time | wick is revealed as wax melts | wax moves up wick (does not burn) |
| | heat involved | wick gets hot | | | |
| | gases involved | needs oxygen, is combustible | combines with oxygen | | |
| | chemical change | wick goes black | wick turns to carbon or carbonised | chemical change or reaction | |
| | molecules involved | molecules change | flame heats up air molecules | | |
| What's happening with the wax? (burns) | wax burns | liquid wax is fuel, solid wax is store | wax burns | wax burning is localised at the wick | wax moves up wick (does burn) |
| | heat involved | wax gets hot | heat energy sufficient for wax to burn | | |
| | gases involved | needs oxygen to burn, combustible | combines with oxygen, oxidised | burning produces $CO_2$ and $H_20$ | wax as vapour is burned |
| | chemical change | chemical change, reaction | wax is oxidised | hydrocarbon is oxidised | |
| What's happening with the wax? (melts) | wax melts | wax melts | wax melts and sets | changes solid to liquid | wax is vaporised |
| | heat involved | warm/hot wax melts, flame melts wax | heat melts wax | heat gain (melt) and heat loss (set) | a specific melting temperature |
| | molecules involved | density changes | molecules change | molecules spread out | molecules vibrate or move faster |
| What is transferred? | involved | flame | heat | energy | multiple transfers |
| | mechanism | non specific terminology (e.g., moves) | generic term 'transfer' | specific terminology (e.g., dissipate) | |

APPENDIX G (Continued)

CONCEPT GRIDS

Phase 3 Blowing Out the Candle

| | | Level of Response | | | |
|---|---|---|---|---|---|
| Aspect | Concept | Level 1 | Level 2 | Level 3 | Level 4 |
| Why does the candle go out? | flame goes out | flame goes out | flame is smothered, suffocated, choked, snuffed | | |
| | force of blow | force of blow makes flame go out | force of blow pushes flame away from wick (as the fuel) | force of blow removes air, air moves too fast, air pressure, vacuum | interrupted vaporisation, fuel vapour disturbed |
| | heat involved | flame or wick is cooled | below combustion temperature | heat energy insufficient for combustion | |
| | gases involved | deprived of oxygen | too much oxygen | too much carbon dioxide | |
| | chemical change | wick smoulders, red ember | | | |
| | molecules involved | moving air molecules | | | |
| What about the smoke? | smoke is present | see steam, condensat-ion | see or smell smoke | see or smell wax | see visible particles |
| | associated with burning | smoke occurs with burning | smoke occurs with cessation of burning or of flame | residue, left behind, waste | incomplete burning, unburnt carbon, wax or wick |
| | heat involved | heat causes wax to smell | heat causes smoke to rise | | |
| | gases involved | visible gases given off | visible or invisible gases mix with air | suggested gas was wax (e.g., evaporated wax) | unburned gases, $CO$, $CO_2$, $H_2O$, |
| | molecules involved | molecules change | | | |
| What is transferred? | involved | flame | heat | energy | specified multiple transfers |
| | mechanism | non specific terminology (e.g., moves) | generic term 'transfer' | specific terminology (e.g., dissipate, transformed) | |

APPENDIX H

TRANSCRIPT OF INTERVIEW WITH TEACHER 14

Teacher 14 was in Group 3 as she had a limited science background and taught Year 7. Punctuation has been kept at a minimum to retain the sense of the interview. The letter R refers to researcher and T to the teacher. This teacher judged Student 6 whose transcript is included in Appendix B. Short pauses are shown as (.), longer pauses as (...) and actions within brackets [ ] .

*Phase 1: Striking the Match*

R I'd like you to watch what I'm doing, then tell me what happened, and why you think it happened. [Researcher lights match, waves out match, lights candle, places candle upright on saucer]

T you struck a match . you lit the candle over the . holding the candle over the saucer I noticed maybe in case there was a drip straight off . you put the match on the tray [the saucer] so it didn't burn anything . you put the candle straight down and it's staying there. I think that's great I always put a little bit of wax on the bottom

R specially trained candle

T a specially trained candle . yes . and it's just . um just observing it . it's . just watching the wind [fans in the room move flame] flicker it around . at the moment .

R can I ask you about what we did here with the match and the matchbox

T you striked the sulfur . sulfur head is it? . against here [box] and using friction . see you use your friction to . um . ignite the match itself .

R why does friction ignite the match?

T well friction causes heat . but it's something to do with the fact that its a sulfur tip or something . the tip itself . is made so that just a minimal amount of friction . will give you . your flame

R why does a minimal amount of friction give you the flame?

T it's to do with that [indicates head] that head

R because it's to do with sulfur?

T yes I think so and that's . also . is treated with something [striking plate] I think . yes it's like a rougher surface . so you've got your rough surface helping the . build up the friction . it wouldn't work on there [points to cardboard of box] no matter what was in that [the head] so that is roughened

R so why do you have to build up friction?

T to get heat

R why?

T to burst into flame . to get that

*Phase 2: Burning The Candle*

R can you tell me more about what's happening up the top [point to top of flame]

T so while it's burning we're getting a little pool of wax . and the um . but it's uneven . one edge is quite dipped and the other's quite raised so that was with the wind direction I imagine . so . there are dribbles down the side but it hasn't started doing that yet . so we've almost got a dribble-less candle there .

R why does it dribble?

T because the way it's melting and building up . and it's becoming less um dense . it's going into like . the wax is . is solid . now it's dribbling . it's gone into a liquid form . which um needs somewhere to go . it can't just stay . it's overflowing if you like ...

R why does it go into a liquid form?

T well the heat would cause it . acting on the wax . would cause it to um . liquefy

R why does heat make the wax liquefy?

T ... eh [laughs] it's a solid state and I suppose it's going to do with its molecular structure or something like that

R tell me more about what it might be with molecular structure

T ... well I suppose it's a type of fat in a way . they used to make them from tallow . um . and so that's . just the heat . just . it's like ice and water you know really . you heat . things . back to another state . that's about all I would understand about that one

R and the black thing here can you tell me more about that [point at wick]

T the wick?

R yes

T well that's made of . of . I don't quite know . usually string . it's always been a mystery to me though why it doesn't burn . [corrects] it . I mean it actually does burn . obviously it burns at a much slower rate . than the wax itself . so therefore . therefore it um .. well I mean the wax . the wick always seems to remain the same doesn't it? [as question] as it goes down . yes so it must . just a little bit burn off . as we're going down . but . because the um string . is . the deeper density . if you like . more compact . it takes a slower time to burn . so therefore you've got enough time for it to . to light . to do it's job you know

R to give light

T yes to give light yes

R and the wax that's down here [indicate wax column] why do we have that there?

T well once it gets from that heat source it then gets into the outer air which is colder and so then it goes back to its original form because that is colder . as the warm wax dribbles down it then gets into the air again . and goes back to its original state .

R what is it about going back into the original air again that makes it go back to its original state?

T it would be the coldness of it . um

R why is it cold . or why is there coldness?

T ... well the surrounding air ... is colder . that's hot [the candle] because there's been heat applied through the flame . so there's a heat source . energy source . and

R so the wax is the energy source or the flame is the energy source?

T the flame would be

R you mentioned before and I wasn't quite sure if you meant just the wick was burning or . it sounded like you said the wax was burning but I wasn't sure

T mm yes . well I sort of did say the wax was burning . but in fact really it's the . um . the wick burning and the ca' and the wax melting isn't it [as question]

R OK

T it's a double . double action there . going on . [looks closely at flame] it doesn't even look as though the flame actually is at the real wax level . it seems maybe you can't see the base of the flame . though it just appears to be that when you get above the wax for some reason ...

*Phase 3: Blowing Out The Candle*

[Researcher blows out candle]

T OK . well as I blew it . the um . tip of the wick was quite red . a little ember . you get a lot of smell . give it a blackish smoke . then you've got a real wax smell coming through . a very strong smell . and it's almost immediately . solidified again [means wax] it's almost immediately . it's gone back to that form . probably if I touched it . it would be warm and a little bit soft . but for the appearance of it . it looks . back to you know the original state

R so when you blew it what happened

T I don't really know . I've never . it just goes out

R you mentioned the wax smell . why might there be a wax smell?

T well I would say the heat would bring it out . because the candle itself doesn't smell . until you've used the heat . it brings that smell out .

*Judging Student 6's Transcript*

R Here is a transcript of a student who responded to the same task you just did. Can you read the transcript, and tell me how you would assess or evaluate the student's science understandings? You can either read it all, and then tell me what you notice. Or you can make comments as you go along.

T [reads] mm well I think that yes . because I didn't say anything about a spark . I just said . it ignites . so I think their use of the word spark is good there

R why good . what do you mean good?

T well it just shows a bit . further thinking . further along the line . [reads] mm yes I think this person's older . and more intelligent

R because

T because . well he seems to have quite a bit of knowledge I would say . he's talking about well all the things that I'm talking about [laughs]

R for example?

T yes well he's talking about you know the higher temperature of the wax turning into a liquid and . he talks about the physical change in the wax . and "the liquid cools" the "wick's still in the middle keeping the flame alight" um he's talking about "flammable on the wick" [omits word oil in transcript] the wick . it might not be good English but it's got the language there .

R when you say language what do you mean?

T well "flammable" is a good word . a good describing word . they've used "flammable material" he's using . this language is quite good there . in itself . you know it's descriptive language ... "the candle burns to make sure that the candle burns at a slow even rate" so he's really . I'd say he's got really good knowledge there "and how does it do that? Student: By collecting underneath. Or around . just below the flame . makes sure the flame doesn't go down any further because the wax doesn't burn . it just melts . so the flame sits on top . and then eventually the wax around the top" yes oh . 'the flame's gone out because the increase in carbon dioxide around it . and it needs oxygen to live" so

R what do you think when you read that?

T well . he's really thinking about it . I hadn't . didn't even consider those sorts of things . it's sort of more like a chemical sort of knowledge I would think

R so when you were doing it why did you think the flame went out?

T I didn't [laughs] well I don't know . I don't know if I would have thought about that all that much . if I'd snuffed it [ gestures as if using a candle snuffer] used a snuffer . well I would have said yes . the oxygen has gone . but I didn't sort of relate that to blowing . strange as it may seem

R that's OK

T and he's talking about his lungs . "[reads] where did the carbon dioxide come from?" mm [laughs] "it's starved basically" yeah I think . yes

R so when you say 'yeah' what are you thinking?

T well he knows what he's talking about . or she know what she's talking about . .. mm .. yes I think this person really has got quite a good science knowledge . quite a good science knowledge I would say myself

R anything else that you notice about what this kid understands?

T "you used the match because of the sulfuric head . and lit it . the paper" . to be honest I don't know whether they still actually use sulfur for that match head . do they?

R I think it depends on the manufacturer and the country

T yes because there was a lot of um . the health um regulations . a lot of um . quite serious diseases so they may well use something else . but it's just something that's old knowledge

R mm

T something that you've picked up along the way . really

R anything else that you notice about what this kid understands?

T ... well I think he's got the idea of striking the match . it's not . he's saying that "was it sparks . or it's not chemical . not chemical" it's um . "a spark or something to ignite" I don't think he actually mentions friction as such but he knows that when you strike it . you're going to get a reaction from the side of the "brown paper" or whatever it is "on the side of the box" . he has maybe he has got the concept of friction as such . but he's got the concept of carbon dioxide and oxygen . those sort of concepts he's got quite strongly . and the idea that the head of the . the head's a "flammable material" . because "it burns quicker" but then "the wood's' a little bit slower burning so

R so what does that mean the fact that he can make that difference?

T well he's observing it and he's also looking at the different materials that are being used for fuel . other wise it would all be the same .

R OK

*Age and Ability Grid*

R I'd like you to show on this grid how old, or what ability, you think this student is most likely to be, based on what you noticed in the transcript. Here [indicate] are

five levels of ability and here are ages [indicate]. You can use one, two, three, four or five cards to show where you would locate this student. Show where you think this student would be located. Please explain your reasoning as you go along. [Place grid in front of teacher, and place transcript above grid so it visible and obvious].

T well I'd probably say we're getting into 11 and 12 here . and I'd probably say at that age . he's probably above average or . could be a 13-14 year old . of average .. if you got this age you'd be up here and it can happen [indicates younger age and higher ability]

R do you think that's possible?

T possible . yes I've had them . I have had children who would come up with that sort of stuff

R at 9 or 10?

T mm [yes]

R so in general what were you . what helped you make those decisions?

T the level of . the language used in answering . the areas that that person has covered . and there . to me there's quite a good understanding there . as I said maybe . he's one of two areas that have been missed out . but he's gone to other areas . which I didn't think of . so

R it's sort of balanced

T mm [yes] . see I would expect a 13-14 year old to know all that . that's why I say they would just be average . but then the others . I think . if it was just straight off . like if they hadn't been studying it I would say that 11-12 [X indicates teacher's placement]

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| well above average | | | X | | | | |
| above average | | | | X | | | |
| average | | | | | X | | |
| below average | | | | | | | |
| well below average | | | | | | | |
| | 5-6 | 7-8 | 9-10 | 11-12 | 13-14 | 15-16 | 17-18 |

*Follow-up Activities*

R what follow-up strategies would you suggest to help this student's understanding?

T the follow up OK ... well I might do a little bit of work on friction . because that's something he didn't understand

R what sort of work might you do?

T well friction causes heat and various . ways that um . heat is caused . you know

R for example?

T well you've got your match . but you might just use rubbing . ropes [pretends to draw rope through hands] . you know all the different ways that you can feel heat . from friction and get the concept of friction . um ... I'd don't know whether . the idea of the um . carbon dioxide and oxygen . again I might do that . the snuffing out bit . a little bit more detail and do . talk about that . the physical change of the wax I think he um is quite happy with that . you could do the old um .. like maybe have a candle in a container and then you just cut off the oxygen itself and then ...

R and the candle goes out?

T yes . and also the use that um . maybe a bit of social studies you know . they used to take the candles down into the mine . and things like that . for the bad air . like even speliologists these days . still do that . the poor old canary goes poof [head drops to one side to show bird dies] . but they still even now . people digging wells even now . I believe . mine shafts . prospectors . do the old candle trick

[end]

# APPENDIX I

# INFORMATION ON MATCHES, CANDLE FLAME, WAX AND THE WICK.

In this appendix, background information on matches, the candle flame, wax and the wick is provided. This information includes the key concepts involved in a scientifically correct explanation of the events of the science task used in this research. It also refers to ideas teachers suggested, such as tallow, cooling the flame, and different sorts of matches. The reference list appears at the end of Appendix I.

## *Matches*

Teachers referred to "safety matches", the ones in "American cowboy movies", and "poisonous" ones. There have been three main designs in matches: early designs, strike-anywhere and safety matches (Phosphorus to bismuth, 1987; see also Smith, 1996.

*Early designs.* Early matches had a white phosphorus tip, surrounded by potassium chlorate. Due to the poisonous effects of white phosphorus, these matches are now illegal. Many early designs were also dangerous (Match, 1994).

*Strike anywhere.* The next match design was "strike-anywhere" (Match, 1996, p. 250) which would ignite when drawn across any rough surface. They had a white tip of phosphorus sulfide which will burn if struck; this is also called "sesquisulfide of phosphorus" (p. 250). The tip was surrounded by a material (potassium chlorate and sulfur) that will not fire if struck, but will burn after the white centre sets it afire. This protected the matches from igniting when packed in a box. After it is lighted, the paraffin in which the match was dipped transfers the flame to the match wood. The match head contains all the chemicals to obtain ignition from heat of friction.

*Safety matches.* Recent safety matches can only be lighted by striking them across a special surface, usually on the side of the match box. In the abrasive strip is sand and non-poisonous red phosphorus. Red phosphorous is stable in air, but burns if heated. The match head is antimony sulfide and potassium dichromate (Phosphorus to bismuth, 1987) or chlorate of potash with a kindling temperature of approximately 182°C (Match, 1996, p. 250). "Book" matches are a type of safety match made from

paper and folded and bound, the striking surface is on the outside of the book (Match, 1996, p. 250).

*Candle Flame*

Becker (1997, p. 152) explained a candle as a "laminar" flame (also called a diffusion flame) and as the burning of particles or small pieces of solid organic fuels. He described a flame front as where fuel and oxidizer meet and react, usually a thin reaction zone, where the reaction rate is very fast and occurs "as fast as fuel and oxidizer can get together by diffusion." (p. 152). Another type of flame is "premixed" (such as a Bunsen burner) when fuel and oxidizer are mixed before they burn (Becker (p. 151).

Becker's (1997) explanation of a flame emphasises that wax becomes a gas which burns, that heat energy is involved, that a sufficient temperature being reached is critical, and that the charred (i.e., black) wood and wick continue to burn in a different way:

> [A flame is] an exothermic reaction front or wave in a gaseous medium .... An exothermic reaction (that liberates heat) is initiated by raising the temperature to a sufficiently high level; the reaction is started by a localized release of heat, as by a sufficiently energetic spark, and then spreads from the point of initiation .... All burning in flames associated with solid and liquid fuels remains in the gas phase. Heat from the flame melts fuels such as candle wax and magnesium metal (at least on the surface) and vaporizes the liquid. The vapor diffuses away and, at the flame front, meets oxygen diffusing toward it from the surrounding gas and burns ... In the case of wood and coal, heating at first drives off combustible gases (volatile combustible matter), which burn in a diffusion flame. The subsequent burning of the residual char, however, is exceptional and may involve no flame. The melting and boiling points of carbon are so high the vaporization is normally impossible. Instead, oxygen is usually considered to diffuse to the char surface

and there to react directly, a mode of reaction called heterogeneous combustion. (pp. 150-151)

Many teachers had difficulty with their explanations of why the candle goes out. One of the key reasons for the candle flame going out is because of a disturbance of the thin reaction zone which denies the gaseous fuel meeting with oxygen at sufficient temperature for a reaction to occur. Since reactions are very fast, even a momentary disruption, if severe enough, will cause the flame to go out. When the force of blowing (i.e., turbulence) is great enough, it will disrupt combustion which occurs only in a reaction zone localised by the wick. Becker (1997) explained this succinctly:

> The effect of turbulence ... produces a distorted and greatly convoluted reaction zone. However, turbulence affects the meeting of fuel and oxidizer quite profoundly. A crude way of explaining this is to say the turbulent diffusion is added to, and usually completely overshadows, molecular diffusion. (p. 153)

Gently blowing on the flame will increase the rate of supply of oxygen, which will speed the reaction, but this is counterbalanced to some extent by cooling the area due to removing heat at a faster rate. Ideas teachers suggested that were not supported as scientifically correct views included that flame is extinguished by too much oxygen, or blowing the flame off the candle. While teachers ideas that exhaled breath has more carbon dioxide are accurate, this increase is not sufficient to deny oxygen to the flame.

The *Science and Technology Illustrated Encyclopaedia Britannica* (Candle, 1984) explained that candle colours are due to different temperatures of the gases:

> [The] flame of a burning candle divides into several zones of different luminosity, according to the temperature of the gases undergoing combustion. The dark zone around the wick is the coolest part of the flame; the bright oxidizing flame at the tip is the hottest. (p. 545)

Cooling can also be involved in extinguishing a flame, which many teachers included in their suggestions. The *Science and Technology Illustrated Encyclopaedia Britannica* (Candle, 1984) explained that cooling burning vapours to the point where they can so longer sustain combustion will extinguish the flame, and suggested a demonstration of holding a wire screen half way up a candle flame: the metal screen reduces the temperature so that combustion is not supported.

Many teachers referred to carbon and black on the wick. Helmers (1997, p. 234) explained that smoke contains carbon black, which is formed by the "decomposition of the unburned hydrocarbon to carbon black" due to burning with insufficient air for complete combustion." This results in a smoky flame which deposits carbon black which is collected for use in rubber. Smoke contains incompletely combusted wax, as a visible vapour.

### *Wax and the Wick*

A candle is a made of a wick surrounded by solid fuel. The fuel can be wax (e.g., beeswax), or paraffin (a petroleum product). Teacher 14 (see Appendix H) referred to tallow as the material in the candle. Tallow is used in soap and candles, and is the "fatty tissue or suet of animals; the harder fat of sheep and cattle separated by melting from the fibrous and membranous matter naturally mixed with it." (Tallow, 1982, p. 1321). The wax is the fuel source for the flame. *The New Encyclopaedia Britannica* (Candle, 1994, p. 798) explained this as "heat from the flame liquefies the wax near the base of the wick. The liquid flows upward by capillary action, then is vaporized by the heat. The flame is the combustion of the wax vapour." The wick is the localisation point for combustion.

Individual teachers mentioned many of the ideas in the extract below (Candle, 1984) such as the wick curling; whale oil, paraffin, dyes, dripping and non-dripping and votive candles. The development of the candle is a story of design improvements in the wick and the type of wax:

The first candles had crudely twisted cotton wicks, and the wax was beeswax or bayberry wax or tallow, and animal fat that often had a foul odor .... Unfortunately, the twisted wick was uneven, and when burned, it tended to thicken with wax residue, enlarging the flame. As a result, the wick needed to be frequently blown out and trimmed .... Besides beeswax and bayberry wax, early candles also burned on stearic acid (from animals) and whale oil. It was not until the 1850s that petroleum wax came into use ... Petroleum wax is a mixture of hydro-carbons—atoms of carbon and hydrogen, with the carbon atoms fully saturated or bonded to the hydrogen. Some of these hydrocarbons are known as paraffins .... When a candle's wick is lit, the carbon atoms in the hydrocarbons combine with oxygen in the air (forming carbon dioxide), and the hydrogen atoms combine with the oxygen in the air to form water. The chemical reaction gives off heat and light ad turns the water into vapor .... In the early days, stearic aid was often added to paraffin to harden it and make it burn more slowly; today EVA, ethylenevinyl acetate copolymer, a white, translucent resin that is cheaper, may be used. The strengtheners work because they have a higher melting point than paraffin. Sometimes polyethylene plastic is added to harden the wax and improve the gloss, and wax-soluble dyes (colorants) and perfumes (odorants) add to the charm of the candlelit room. Today's wicks are still threaded through the length of the candle, but they no longer need to be trimmed in order to remain at the ideal burning location, which is just above the surface of the melted wax, because they are no longer twisted. Modern wicks—which may either be a woven cotton sleeve containing a metal core, a flat-plaited cotton, or square-braided cotton—have helped make candles dependable and dripless. During the 19th century, people discovered that braiding the wick would make it curl into the hot area of the flame, causing the tip to burn off and eliminating the need to trim. Unfortunately, this wick caused problems of its own: the curl moved the flame slightly off-center, which can make the candle drip. A solution is square-braided wicking ... This wick stands up straight and burns off in the tip of the flame without curling ... A metal-core wick has a wire center made of lead. In the tip of

the flame—the hottest part—beads of melted lead drop off continually, and the surrounding cotton sleeve is burned away. Thus, the wick continually trims itself. A new variation of this type is a wick with a low-melting polyethylene filament that works the same way as the lead. The metal-core wick is used mainly in candles burned in glass containers, such as ... votive candles ... To keep the wick from burning too quickly, cotton wicking is steeped in a salt solution, a process known as "pickling." (pp. 544-545)

Reference list for Appendix I

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APPENDIX J

SCORES FOR SCIENCE KNOWLEDGE, BY AGES OF STUDENTS USUALLY TAUGHT

Table J 1 Usually Teaches Year 11 or Year 7

| | Scores | | | | | |
|---|---|---|---|---|---|---|
| Teaches | Phase 1 | Phase 2 | Phase 3 | Total | Ranking | Group |
| Year 11 | | | | | | |
| 6 | 26 | 27 | 14 | 67 | 1 | E11 |
| 4 | 18 | 24 | 17 | 59 | 2 | E11 |
| 5 | 25 | 13 | 12 | 50 | 3 | E11 |
| 3 | 12 | 19 | 14 | 45 | 4 | E11 |
| 2 | 15 | 19 | 8 | 42 | 5 | E11 |
| 1 | 8 | 10 | 9 | 27 | 6 | E11 |
| Year 7 | | | | | | |
| 9 | 11 | 26 | 21 | 58 | 1 | E7 |
| 18 | 23 | 18 | 8 | 49 | = 2 | L7 |
| 7 | 16 | 18 | 15 | 49 | = 2 | E7 |
| 12 | 11 | 20 | 13 | 44 | 4 | E7 |
| 11 | 15 | 20 | 8 | 43 | 5 | E7 |
| 8 | 14 | 21 | 4 | 39 | 6 | E7 |
| 15 | 13 | 12 | 10 | 35 | = 7 | L7 |
| 10 | 11 | 13 | 11 | 35 | = 7 | E7 |
| 14 | 14 | 13 | 5 | 32 | 9 | L7 |
| 13 | 15 | 8 | 6 | 29 | = 10 | L7 |
| 16 | 12 | 13 | 4 | 29 | = 10 | L7 |
| 17 | 12 | 12 | 4 | 28 | 12 | L7 |

Table J 1 continues.

APPENDIX J (Continued)

Table J 1 Usually Teaches Year 3 (continued)

| | Scores | | | | | |
|---|---|---|---|---|---|---|
| Teaches | Phase 1 | Phase 2 | Phase 3 | Total | Ranking | Group |
| Year 3 | | | | | | |
| 21 | 19 | 20 | 17 | 56 | 1 | E3 |
| 23 | 14 | 17 | 14 | 45 | 2 | E3 |
| 29 | 16 | 17 | 7 | 40 | 3 | L3 |
| 19 | 19 | 10 | 7 | 36 | = 4 | E3 |
| 28 | 12 | 17 | 7 | 36 | = 4 | L3 |
| 27 | 12 | 14 | 6 | 32 | 6 | L3 |
| 22 | 7 | 17 | 7 | 31 | 7 | E3 |
| 20 | 9 | 9 | 9 | 27 | = 8 | E3 |
| 26 | 7 | 13 | 7 | 27 | =8 | L3 |
| 25 | 7 | 12 | 6 | 25 | 10 | L3 |
| 24 | 3 | 13 | 6 | 22 | 11 | E3 |
| 30 | 4 | 10 | 7 | 21 | 12 | L3 |

Note: = indicates equal ranking

APPENDIX K

SCORES FOR TEACHERS FOR PHASE 1

Table K 1 High Science Knowledge

| | High Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 1 | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 |
| Match lights up | | | | | | | | | | |
| Striking action | 2 | 2 | 2 | 2 | | | | | | 2 |
| Subs. on match | 4 | 4 | | 1 | 4 | 4 | 4 | 1 | 4 | 1 |
| Substance on box | 4 | | | | | 2 | | 2 | 2 | 1 |
| Friction involved | 3 | 4 | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 1 |
| Heat energy | 3 | 4 | 3 | 3 | 4 | 4 | 3 | 3 | | |
| Gases involved | | 4 | | | 4 | | | | | |
| Chemical change | | | | 3 | | | | | | |
| Molecular change | 3 | | | | 3 | 3 | | | | |
| Transfers | | | | | | | | | | |
| Involved | 4 | | 1 | 4 | 4 | 4 | 4 | 1 | 2 | 4 |
| Mechanism | 3 | | 2 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| Individual Total | 26 | 18 | 11 | 19 | 25 | 23 | 16 | 12 | 14 | 11 |

Note: Total = 175; Average = 17.5

APPENDIX K (Continued)

SCORES FOR TEACHERS FOR PHASE 1

Table K 2 Midrange Science Knowledge

| | Midrange Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 1 | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 |
| Match lights up | | | | | | | | | | |
| Striking action | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 2 | 2 | 2 |
| Subs. on match | 4 | 4 | 3 | 1 | 4 | 3 | 3 | 1 | 4 | 1 |
| Substance on box | 2 | | | | 2 | 2 | 2 | | 2 | 2 |
| Friction involved | 3 | 3 | 3 | 3 | 3 | 3 | 4 | 3 | 3 | 3 |
| Heat energy | 4 | 4 | | | 3 | 2 | | | 3 | |
| Gases involved | | | 1 | 3 | | | 1 | | | |
| Chemical change | | | | | | | | | | |
| Molecular change | | | 1 | | | | | | | |
| Transfers | | | | | | | | | | |
| Involved | | 1 | 3 | 2 | 4 | | | 3 | | 2 |
| Mechanism | | 1 | 3 | 3 | 1 | | | 2 | | 2 |
| Individual Total | 15 | 15 | 16 | 14 | 19 | 12 | 13 | 11 | 14 | 12 |

Note: Total = 141; Average = 14.1

APPENDIX K (Continued)

SCORES FOR TEACHERS FOR PHASE 1

Table K 3 Low Science Knowledge

| | Low Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 1 | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 |
| Match lights up | | | | | | | | | | |
| Striking action | | 2 | | | 2 | 2 | 2 | | 2 | 2 |
| Subs. on match | 1 | 4 | 3 | | 1 | 2 | 1 | 1 | | |
| Substance on box | | | 2 | 1 | | | 2 | 1 | 1 | |
| Friction involved | 1 | | 3 | 4 | | | 2 | 1 | | 2 |
| Heat energy | | 2 | | 3 | 2 | 2 | | | | |
| Gases involved | | | 1 | | | | | | | |
| Chemical change | | | | | 3 | | | | | |
| Molecular change | | | 3 | | | | | | | |
| Transfers | | | | | | | | | | |
| Involved | 3 | 4 | | 4 | | 3 | | 3 | | |
| Mechanism | 2 | 3 | | | | | | 1 | | |
| Individual Total | 7 | 15 | 12 | 12 | 8 | 9 | 7 | 7 | 3 | 4 |

Note: Total = 84; Average = 8.4

APPENDIX L

SCORES FOR TEACHERS FOR PHASE 2

Table L 1 High Science Knowledge

| | High Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 2 | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 |
| Wick burns | | | | | | | | | | |
| Wick is held up | | | | | | | 2 | | | |
| Wick burns | 2 | 1 | | | 1 | | 2 | 1 | 1 | 3 |
| Wax slows wick | 3 | | | 1 | | | 1 | 1 | 4 | 2 |
| Heat energy | | | | | | | | | | |
| Gases involved | | 2 | | | | | | | | |
| Chemical change | | 2 | | | 2 | | 2 | 2 | | |
| Molecules | | | | | | | | 2 | | |
| Wax burns | | | | | | | | | | |
| Wax burns | 3 | 4 | 4 | 4 | 2 | 4 | | | | |
| Heat energy | | | 2 | | | | | | | |
| Gases involved | 4 | 2 | 4 | | 3 | 1 | | | 1 | |
| Chemical change | 3 | 2 | | 1 | | | | | | |
| Wax melts | | | | | | | | | | |
| Wax melts | 4 | 3 | 4 | 3 | 1 | 3 | 1 | 2 | 3 | 3 |
| Heat energy | 3 | 4 | 2 | 3 | 4 | 3 | 3 | 4 | 1 | 2 |
| Molecules involved | | | 4 | 4 | | 4 | | | 3 | 4 |
| Transfers | | | | | | | | | | |
| Involved | 4 | 3 | 4 | 2 | | 2 | 4 | 4 | 2 | 4 |
| Mechanism | 1 | 1 | 2 | 2 | | 1 | 3 | 3 | 2 | 2 |
| Individual Total | 27 | 24 | 26 | 20 | 13 | 18 | 18 | 19 | 17 | 20 |

Note: Total = 202; Average = 20.2.

APPENDIX L (Continued)

SCORES FOR TEACHERS FOR PHASE 2

Table L 2 Midrange Science Knowledge

| | Midrange Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 2 | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 |
| Wick burns | | | | | | | | | | |
| Wick is held up | 2 | 1 | | 2 | 2 | 2 | 2 | | | |
| Wick burns | 3 | | 1 | | 1 | 1 | 1 | | 1 | 3 |
| Wax slows wick | 1 | | 1 | | 1 | 3 | 3 | 2 | 2 | 1 |
| Heat energy | | | | | | | | | | |
| Gases involved | | 2 | 1 | | | | | | | |
| Chemical change | 2 | 3 | 1 | 2 | | | | 2 | | |
| Molecules | | | 1 | | | | | | | |
| Wax burns | | | | | | | | | | |
| Wax burns | | 4 | | 4 | | | | | | |
| Heat energy | | | | | | | | | | |
| Gases involved | 1 | | | 3 | 1 | | | 1 | | |
| Chemical change | 1 | | | | | | | | | |
| Wax melts | | | | | | | | | | |
| Wax melts | 3 | 3 | 3 | 2 | 3 | 3 | 1 | 3 | 3 | 2 |
| Heat energy | 4 | 4 | 3 | 3 | 2 | 3 | 4 | 1 | 2 | 3 |
| Molecules involved | | | 2 | | | 3 | | 4 | 1 | |
| Transfers | | | | | | | | | | |
| Involved | 2 | 1 | 2 | 2 | | 1 | 1 | | 3 | 3 |
| Mechanism | 1 | 1 | 2 | 3 | | 1 | | | 1 | 2 |
| Individual Total | 20 | 19 | 17 | 21 | 10 | 17 | 12 | 13 | 13 | 14 |

Note: Total = 156; Average = 15.6

APPENDIX L (Continued)

SCORES FOR TEACHERS FOR PHASE 2

Table L 3 Low Science Knowledge

| | Low Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 2 | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 |
| Wick burns | | | | | | | | | | |
| Wick is held up | 2 | | 2 | 2 | 2 | | | 1 | | 2 |
| Wick burns | 2 | 1 | 1 | 1 | 1 | | 1 | 1 | 1 | |
| Wax slows wick | 3 | | 2 | | | 3 | 2 | | 3 | 2 |
| Heat energy | | | | | | | | | | |
| Gases involved | | | 1 | | | | 1 | | | 1 |
| Chemical change | 1 | | | | 3 | 1 | | | 2 | 2 |
| Molecules | | | | | | | | | 1 | |
| Wax burns | | | | | | | | | | |
| Wax burns | | | | | | | | | | |
| Heat energy | | | | | | | | | | |
| Gases involved | | | | | | | | | | |
| Chemical change | | | | | | | | | | |
| Wax melts | | | | | | | | | | |
| Wax melts | 3 | 3 | 3 | 3 | 2 | 3 | 2 | 3 | 3 | 1 |
| Heat energy | 3 | 4 | 4 | 2 | 2 | 2 | 3 | 2 | 3 | 2 |
| Molecules involved | | | | | | | 4 | | | |
| Transfers | | | | | | | | | | |
| Involved | 1 | | | 3 | | | | 2 | | |
| Mechanism | 2 | | | 1 | | | | 3 | | |
| Individual Total | 17 | 8 | 13 | 12 | 10 | 9 | 13 | 12 | 13 | 10 |

Note: Total = 117; Average = 11.7

APPENDIX M

SCORES FOR TEACHERS FOR PHASE 3

Table M 1 High Science Knowledge

| | High Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 3 | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 |
| Blow candle out | | | | | | | | | | |
| Flame goes out | | 2 | | 2 | 2 | 2 | | 1 | 2 | |
| Force of blow | 4 | 3 | 4 | 2 | | 3 | 2 | | 2 | 3 |
| Heat energy | 3 | | 2 | | 2 | 2 | 1 | 3 | | |
| Gases involved | | | | 3 | | | | | 1 | |
| Chemical change | | | | | | | | | | |
| Molecules involved | | | | | | | | 1 | | |
| Smoke | | | | | | | | | | |
| There's smoke | | 4 | 4 | 4 | | | 3 | 2 | 2 | 2 |
| Goes with burning | 4 | 4 | 4 | 3 | 4 | 1 | 3 | | 4 | |
| Heat energy | | | | | | | | | | |
| Gases involved | | 4 | 3 | 3 | 4 | | | | 3 | 1 |
| Molecules involved | | | 1 | | | | | | | |
| Transfers | | | | | | | | | | |
| Involved | 3 | | 2 | | | | 4 | 4 | | 4 |
| Mechanism | | | 1 | | | | 2 | 3 | | 3 |
| Individual total | 14 | 17 | 21 | 17 | 12 | 8 | 15 | 14 | 14 | 13 |

Note: Total = 145; Average = 14.5

APPENDIX M (Continued)

SCORES FOR TEACHERS FOR PHASE 3

Table M 2 Midrange Science Knowledge

| | Midrange Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 3 | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 |
| Blow candle out | | | | | | | | | | |
| Flame goes out | | 1 | 2 | 1 | 1 | | | 2 | | 1 |
| Force of blow | | | 3 | 3 | 1 | | | 3 | | 3 |
| Heat energy | | 2 | | | | | | | | |
| Gases involved | 3 | | 2 | | 3 | | | 1 | | |
| Chemical change | 1 | | | | | 1 | | | 1 | |
| Molecules involved | | | | | | | | | | |
| Smoke | | | | | | | | | | |
| There's smoke | | 2 | | | 2 | 2 | 2 | 2 | 3 | 2 |
| Goes with burning | 2 | | | | | 4 | 4 | 3 | | |
| Heat energy | | | | | | | | | 1 | |
| Gases involved | 2 | 3 | | | | | 4 | | | |
| Molecules involved | | | | | | | | | | |
| Transfers | | | | | | | | | | |
| Involved | | | | | | | | | | |
| Mechanism | | | | | | | | | | |
| Individual total | 8 | 8 | 7 | 4 | 7 | 7 | 10 | 11 | 5 | 6 |

Note: Total = 73; Average = 7.3

APPENDIX M (Continued)

SCORES FOR TEACHERS FOR PHASE 3

Table M 3 Low Science Knowledge

| | Low Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Phase 3 | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 |
| Blow candle out | | | | | | | | | | |
| Flame goes out | | | 1 | 1 | 2 | 2 | 1 | 2 | 2 | 1 |
| Force of blow | 2 | 2 | | | | 3 | 3 | 1 | 1 | 1 |
| Heat energy | | | | | | | | | | |
| Gases involved | | | 1 | 1 | 3 | | 1 | 3 | | |
| Chemical change | | | 1 | | | | | | 1 | |
| Molecules involved | | | | | | | | | | |
| Smoke | | | | | | | | | | |
| There's smoke | | 2 | | 2 | 2 | 2 | 2 | | | 2 |
| Goes with burning | 2 | | 1 | | 2 | 2 | | | 2 | 3 |
| Heat energy | | | | | | | | | | |
| Gases involved | 3 | | | | | | | | | |
| Molecules involved | | | | | | | | | | |
| Transfers | | | | | | | | | | |
| Involved | | 2 | | | | | | | | |
| Mechanism | | | | | | | | | | |
| Individual total | 7 | 6 | 4 | 4 | 9 | 9 | 7 | 6 | 6 | 7 |

Note: Total = 65; Average = 6.5.

APPENDIX N

TEACHERS' JUDGEMENT BASES, BY SCIENCE KNOWLEDGE

Table N 1 High Science Knowledge 1

| | High Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Judgement Base | 6 | 4 | 9 | 21 | 5 | 18 | 7 | 3 | 23 | 12 |
| Concept | | | | | | | | | | |
| Has concept | x | | x | x | x | x | | x | | x |
| Not got concept | x | | x | x | x | | x | x | x | x |
| Misconception | x | | x | x | x | | x | | | |
| Can't use | | | | | | | | x | | x |
| Development | x | x | | | | | | | | |
| Language | | | | | | | | | | |
| General | | | x | x | | | x | | | x |
| Science | x | | x | x | | | x | x | | x |
| Skill | | | | | | | | | | |
| Observation | | x | | x | | x | x | x | x | |
| Explanation | | | x | | | | | x | x | x |
| Inference | | x | | | | | | x | | |
| Prediction | | | | | | | | | x | |
| Personal attribute | | | | | | | | | | |
| Attitude | | | | | | | x | | | x |
| Confidence | x | | | | | | | | | |
| Background | | | | | | | | | | |
| General | | x | | x | x | | x | x | x | |
| Science | x | | | | | | | | | x |
| Cultural / parent | | | | | | | | x | | |
| Link to teacher | | | | | | | | | | |
| Own knowledge | | | x | x | x | x | x | | x | x |
| Own classes | x | | | | x | | x | | | |
| Expectation | x | | x | | | | | | | |
| Individual total | 9 | 4 | 8 | 8 | 6 | 3 | 9 | 9 | 6 | 9 |

Note: x denotes teacher used the base; Total = 71; Average = 7.10; Range 3 - 9.

APPENDIX N (Continued)

TEACHERS' JUDGEMENT BASES, BY SCIENCE KNOWLEDGE

Table N 2 Midrange Science Knowledge

| | Midrange Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Judgement Base | 11 | 2 | 29 | 8 | 19 | 28 | 15 | 10 | 14 | 27 |
| Concept | | | | | | | | | | |
| Has concept | x | x | x | | x | x | x | x | x | x |
| Not got concept | | | x | | | | x | x | x | |
| Misconception | | x | | x | | | | | | |
| Can't use | x | | | | | | x | x | | |
| Development | | | | | | | | | | |
| Language | | | | | | | | | | |
| General | x | x | | | x | | x | x | | |
| Science | x | | | | | | x | | x | x |
| Skill | | | | | | | | | | |
| Observation | | x | | | x | x | | x | x | |
| Explanation | | x | x | | | x | | x | | x |
| Inference | | | | | | | | | | |
| Prediction | | | x | | | | | | | |
| Personal attribute | | | | | | | | | | |
| Attitude | | | | | | | | x | | x |
| Confidence | | | | | x | | | | | |
| Background | | | | | | | | | | |
| General | | | x | x | | x | x | x | | |
| Science | x | x | x | | | | | | | x |
| Cultural / parent | | | x | | | | | | | x |
| Link to teacher | | | | | | | | | | |
| Own knowledge | | | | x | | | x | x | x | x |
| Own classes | x | | | x | | | x | x | | |
| Expectation | | | x | | x | | | | | x |
| Individual total | 6 | 6 | 8 | 4 | 5 | 4 | 8 | 10 | 5 | 8 |

Note: x denotes teacher used the base; Total = 65; Average = 6.50; Range 4 - 10.

APPENDIX N (Continued)

TEACHERS' JUDGEMENT BASES, BY SCIENCE KNOWLEDGE

Table N 3 Low Science Knowledge

| | Low Science Knowledge | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Judgement Base | 22 | 13 | 16 | 17 | 1 | 20 | 26 | 25 | 24 | 30 |
| Concept | | | | | | | | | | |
| Has concept | x | x | x | x | | x | | x | x | x |
| Not got concept | | x | | | | x | | | | x |
| Misconception | | | | | x | | | | | |
| Can't use | x | | | | | | | | | |
| Development | | | | | | | | | | |
| Language | | | | | | | | | | |
| General | | x | x | | x | x | x | x | x | x |
| Science | | | | x | | x | | x | x | x |
| Skill | | | | | | | | | | |
| Observation | | x | | | x | | x | x | | |
| Explanation | x | | | | x | | x | | | |
| Inference | | | | | | | | | | |
| Prediction | | | | | | | | | | |
| Personal attribute | | | | | | | | | | |
| Attitude | | | | | | x | | x | | x |
| Confidence | x | | | | | | | | | |
| Background | | | | | | | | | | |
| General | | | x | | | x | x | | | |
| Science | x | | x | | | | | x | x | |
| Cultural / parent | x | x | x | | | | x | | | |
| Link to teacher | | | | | | | | | | |
| Own knowledge | x | | | | | x | | x | x | |
| Own classes | | | x | | | x | x | | x | |
| Expectation | | | | | | x | | | x | |
| Individual total | 7 | 5 | 6 | 2 | 4 | 9 | 6 | 7 | 7 | 5 |

Note: x denotes teacher used the base; Total = 57; Average = 5.70; Range 2 - 9.

APPENDIX O

JUDGEMENT BASES, BY AGES OF STUDENTS USUALLY TAUGHT

Table O 1 Usually Teaches Year 11

| | Usually Teaches Year 11 | | | | | |
|---|---|---|---|---|---|---|
| Judgement base | 6 | 3 | 2 | 5 | 4 | 1 |
| Concept | | | | | | |
| Has concept | x | x | x | x | | |
| Not got concept | x | x | | x | | |
| Misconception | x | | x | x | | x |
| Can't use | | x | | | | |
| Development | x | | | | x | |
| Language | | | | | | |
| General | | | x | | | x |
| Science | x | x | | | | |
| Skill | | | | | | |
| Observation | | x | x | | x | x |
| Explanation | | x | x | | | x |
| Inference | | x | | | x | |
| Prediction | | | | | | |
| Personal attribute | | | | | | |
| Attitude | | | | | | |
| Confidence | x | | | | | |
| Background | | | | | | |
| General | | x | | x | x | |
| Science | x | | x | | | |
| Cultural / parent | | x | | | | |
| Link to teacher | | | | | | |
| Own knowledge | | | | x | | |
| Own classes | x | | | x | | |
| Expectation | x | | | | | |
| Individual total | 9 | 9 | 6 | 6 | 4 | 4 |

Note: x denotes teacher used the base; Total = 38; Average = 6.33; Range 4 - 9.

APPENDIX O (Continued)

JUDGEMENT BASES, BY AGES OF STUDENTS USUALLY TAUGHT

Table O 2 Usually Teaches Year 7

| | Usually Teaches Year 7 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Judgement base | 10 | 7 | 12 | 15 | 9 | 11 | 16 | 14 | 13 | 8 | 18 | 17 |
| Concept | | | | | | | | | | | | |
| Has concept | x | | x | x | x | x | x | x | x | | x | x |
| Not got concept | x | x | x | x | x | | | x | x | | | |
| Misconception | | x | | | x | | | | | x | | |
| Can't use | x | | x | x | | x | | | | | | |
| Development | | | | | | | | | | | | |
| Language | | | | | | | | | | | | |
| General | x | x | x | x | x | x | x | | x | | | |
| Science | | x | x | x | x | x | | x | | | | x |
| Skill | | | | | | | | | | | | |
| Observation | x | x | | | | | | x | x | | x | |
| Explanation | x | | x | | x | | | | | | | |
| Inference | | | | | | | | | | | | |
| Prediction | | | | | | | | | | | | |
| Personal attribute | | | | | | | | | | | | |
| Attitude | x | x | x | | | | | | | | | |
| Confidence | | | | | | | | | | | | |
| Background | | | | | | | | | | | | |
| General | x | x | | x | | | x | | | x | | |
| Science | | | x | | | x | x | | | | | |
| Cultural or parent | | | | | | | x | | x | | | |
| Link to teacher | | | | | | | | | | | | |
| Own knowledge | x | x | x | x | x | | | x | | x | x | |
| Own classes | x | x | | x | | x | x | | | x | | |
| Expectation | | | | | x | | | | | | | |
| Individual total | 10 | 9 | 9 | 8 | 8 | 6 | 6 | 5 | 5 | 4 | 3 | 2 |

Note: x denotes teacher used the base; Total = 75; Average = 6.25; Range 2 - 10.

APPENDIX O (Continued)

JUDGEMENT BASES, BY AGES OF STUDENTS USUALLY TAUGHT

Table O 3 Usually Teaches Year 3

| | Usually Teaches Year 3 | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Judgement base | 20 | 21 | 29 | 27 | 24 | 22 | 25 | 23 | 26 | 19 | 30 | 28 |
| Concept | | | | | | | | | | | | |
| Has concept | x | x | x | x | x | x | x | | | x | x | x |
| Not got concept | x | x | x | | | | | x | | | x | |
| Misconception | | x | | | | | | | | | | |
| Can't use | | | | | | x | | | | | | |
| Development | | | | | | | | | | | | |
| Language | | | | | | | | | | | | |
| General | x | x | | | x | | x | | x | x | x | |
| Science | x | x | | x | x | | x | | | | x | |
| Skill | | | | | | | | | | | | |
| Observation | | x | | | | | x | x | x | x | | x |
| Explanation | | | x | x | | x | | x | x | | | x |
| Inference | | | | | | | | | | | | |
| Prediction | | | x | | | | | x | | | | |
| Personal attribute | | | | | | | | | | | | |
| Attitude | x | | | x | | | x | | | | x | |
| Confidence | | | | | | x | | | | x | | |
| Background | | | | | | | | | | | | |
| General | x | x | x | | | | | x | x | | | x |
| Science | | | x | x | x | x | x | | | | | |
| Cultural / parent | | | x | x | | x | | | x | | | |
| Link to teacher | | | | | | | | | | | | |
| Own knowledge | x | x | | x | x | x | x | x | | | | |
| Own classes | x | | | | x | | | | x | | | |
| Expectation | x | | x | x | x | | | | | x | | |
| Individual total | 9 | 8 | 8 | 8 | 7 | 7 | 7 | 6 | 6 | 5 | 5 | 4 |

Note: x denotes teacher used the base; Total = 80; Average = 6.66; Range 4 - 9.

APPENDIX P

NUMBER OF TEACHERS USING EACH JUDGEMENT BASE, BY AGE OF STUDENTS USUALLY TAUGHT

| | Age Of Students Usually Taught | | |
|---|---|---|---|
| Judgement Base | Year 11 n = 6 | Year 7 n = 12 | Year 3 n = 12 |
| Concept | | | |
| Has concept | 4 | 10 | 10 |
| Has not got concept | 3 | 7 | 5 |
| Misconception | 4 | 3 | 0 |
| Unable to use concept | 1 | 4 | 1 |
| Concept development | 2 | 0 | 0 |
| Language | | | |
| Language (general) | 2 | 8 | 7 |
| Language (science) | 2 | 7 | 6 |
| Skill | | | |
| Observation | 4 | 5 | 6 |
| Explanation | 3 | 3 | 6 |
| Inference | 2 | 0 | 0 |
| Prediction | 0 | 0 | 2 |
| Personal attribute | | | |
| Attitude | 0 | 3 | 4 |
| Confidence | 1 | 0 | 2 |
| Background | | | |
| Background (general) | 3 | 5 | 6 |
| Background (science) | 2 | 3 | 5 |
| Cultural / parent | 1 | 2 | 4 |
| Linked to teacher | | | |
| Own knowledge | 1 | 8 | 7 |
| Own class | 2 | 6 | 3 |
| Expectation | 1 | 1 | 5 |