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RESEARCH REPORT
Concepts

Neil TAYLOR [1] and Richard K. COLL [2]
[1] *The University of New England, School of Education (Australia)*
[2] *The University of Waikato, School of Science and Technology (New Zealand)*

PRE-SERVICE PRIMARY TEACHERS' MODELS OF KINETIC THEORY: AN EXAMINATION OF THREE DIFFERENT CULTURAL GROUPS

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ABSTRACT: In this paper we describe research involving an investigation into Australian and Fiji pre-service primary teachers' mental models for Kinetic Theory. The study revealed that the teachers held a variety of mental models, some that were in agreement with the scientific models, and some that were incomplete, while a number appeared to hold no clear mental model. A constructivist-based pedagogy that was used to develop the Fiji teachers' understanding of Kinetic Theory appears to have been effective in model development. Participants reported that the most beneficial of techniques employed instruction based on the use of physical and analogical models. [*Chem. Educ. Res. Pract. Eur.*: 2002, *3*, 293-315]

KEYWORDS: *Mental model; analogy; kinetic theory; pre-service teachers*

INTRODUCTION

Research suggests that efforts to teach science are often met with rote learning of strange concepts, mere copying and a general lack of understanding on the part of students (see, e.g., Hewson, 1988). This is particularly so in the case of students in many developing countries. The lack of progress in many developing countries in relation to science and technology is claimed by some authors to be the result of the low quality of science education received by students in these countries (e.g., Mbajiorgu & Iloputaife, 2001). Science teaching is complicated by the ubiquitous use of models. Science in general, and chemistry in particular, is dominated by the use of models, and as Oversby (2000) puts it "the discipline of chemistry occupies a special place in science since few of the macroscopic observations can be understood without recourse to sub-microscopic representation or models" (p. 227).

A complication for science and chemistry instructors teaching complex chemical concepts based on models, is that sometimes the models used by scientists are being used to model other models. For example, the atomic theory from which ideas of molecules and crystals derive is itself a model of the nature of matter (Walton, 1978). A further complication arises from the verbal shorthand that is so common among experts; the scientist or competent modeller is clear on what he or she means and when communicating with another like-minded expert no confusion arises (Treagust, Chittleborough, & Mamiala, 2001; Weller, 1970). However, when scientists and teachers attempt to communicate with novices, confusion between the model and the modeled may arise. An important difference between the two is that the images possessed by experts are not of real-world objects; rather they are abstract images, that is, constructs based on the target system (Kleinman, Griffin, & Kerner, 1987).

The teaching of models and modelling is especially difficult when teachers lack pedagogical content knowledge (De Jong & Van Driel, 2001; Justi & Gilbert, 2000, 2001; Zimmermann, 2000), or when textbooks and other curriculum material reinforce or introduce alternative conceptions (Fischler & Siefert, 2001). Hawkes (1996) and others (e.g., Fensham & Kass, 1988; Taber, 1995) point out that alternative conceptions in chemistry textbooks are surprisingly commonplace. Remarkably, Hawkes stated that "after writing an article on textbook errors I received a letter from a Nobel Laureate expressing disbelief in my statement that only 2% of aqueous CdI_2 exists as $Cd^{2+}{}_{(aq.)}$" (p. 421).

The use of models and modelling in chemistry is of particular concern for pre-service primary science teachers, many of whom have been found to harbour alternative conceptions about chemical models (see, Pfundt & Duit, 1994, 1997). In this context, Kinetic Theory is especially important in chemistry in that it underpins much of chemistry, a view supported by Driver, Asoko, Leach, Mortimer, and Scott (1994) who suggest that:

> ...there are concepts which are central to students' scientific understanding in a wide range of topics and in such cases giving an appropriate amount of teaching time to them is educationally worthwhile. We would suggest that the conservation of mass and the particle theory of matter are examples of such topics. (p. 96)

Certainly, Gabel (1993) has demonstrated, albeit with a small group, that improved understanding of Kinetic Theory helps students make connections in other areas of chemistry. Thus, because Kinetic Theory underpins so many other conceptual areas of science, it has been one of the more exhaustively studied topics for conceptual understanding.

The essence of the Kinetic Theory can be encapsulated in a single sentence: *Matter consists of tiny particles, called atoms and molecules, that are constantly in motion* (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993). Despite its apparently simple nature, the Kinetic Theory can be used to explain a variety of physical properties of matter. The use of the model in this way is routine classroom practice. For example, the melting of ice can be explained by the particles of ice gaining energy from heat that in turn causes them to vibrate more vigorously breaking the bonds between them, which leads to melting. Thus in order to apply this theory effectively, students need to have a particulate view of matter, and to then understand the relationship between these particles and energy.

In this paper we report on research into pre-service primary teachers' explanations of everyday changes of phase and the extent to which they were able to apply the model of Kinetic Theory to these. We also report briefly on a sequence of instruction, which employed several different visual representations of Kinetic Theory in an attempt to move the teachers towards a better understanding of changes of in materials.

THEORETICAL CONSIDERATIONS

The study was conceptualised within a constructivist epistemology. The researchers hold a constructivist view seeing students as being purposive, and therefore constructing knowledge through social interaction and their interactions with the physical environment, as stated by Tobin, Butler Kahle and Fraser (1990):

> Within a constructivist framework learning is defined as the construction of knowledge by individuals as sensory data are given meaning in terms of prior

> knowledge. Learning is an interpretative process, involving constructions of individuals and social collaboration. (p. 411)

Thus, the central premise of the constructivist epistemology is that knowledge, whether public or private, is a human construction. A key feature of this perspective is that human beings construct mental models of their environment and new experiences are interpreted and understood in relation to existing mental models and schemes (Driver, 1988).

Millar (1989) has pointed to the valuable contribution this view has made to thinking in science education:

> The constructivist approach offers an insight that is enormously valuable, in emphasising that *any* knowledge is necessarily reconstructed by the learner in the learning process. We cannot teach a body of knowledge by direct transmission; the learner is always involved in reconstructing the meaning personally. (p. 592)

Although constructivist epistemology is not universally accepted (see, e.g., Matthews, 1993), Duit (1994) argues that it has been a most powerful and fruitful driving force in research on students' and teachers' conceptions, while Summers (1992) contends that it is now widely valued as a theoretical basis for developing learners' ideas in science. Certainly, constructivist thinking is now influencing science educators' views on curriculum development and teaching and learning in the science classroom (Driver, 1989), and this influence has extended to the training of primary level teachers in science in the United Kingdom (Summers & Kruger, 1994).

METHODOLOGY

The research reported here subscribes to an interpretivist philosophy in which the role of subjective experience (of both participants and researchers) is recognized and acknowledged (Guba & Lincoln, 1989, 1994). The subjective nature of such studies proves to be both an advantage and a disadvantage. The principle advantage lies in the extra depth of understanding gained from intensive data collection methods like interviews. Interpretivist inquiries whilst recognizing the importance of context and subjectivity are prone to problems with reliability and validity. Guba and Lincoln (1989) provide some guidelines to avoid such problems. In particular they and others (e.g., Denzin & Lincoln, 1998) recommend the triangulation of data collection. That is, the gathering of data from multiple sources, particularly by the use of different methods and here we have used both interviews and focus items and activities (Denzin & Lincoln, 1998). Interviews in particular are prone to misunderstandings and we have thereby employed the notion of the translation interface in which no new terms were introduced during discourse, and only the meaning ascribed by participants was deemed to be valid (Johnson & Gott, 1994). Interpretations of data are supported by the so-called thick description (Merriam, 1988) including portions of verbatim transcript reproduced from interview transcripts.

The research reported here was intended to answer two questions:

(a) *What mental models of Kinetic Theory did pre-service primary teachers hold?*
(b) *Where these mental models were deficient, would a constructivist informed pedagogy help to provide the teachers with a more robust model?*

There were two cohorts of participants involved in this study. Australian pre-service teacher trainees who were involved in the first phase of the work (namely, the elicitation phase - see below), and Fiji pre-service teacher trainees, who were involved in both the elicitation phase and a teaching intervention which followed. The Australian participants were undertaking a Bachelor of Education degree at an Australian university. Of these 10 participants, all but one had taken at least one science subject during their final two years of secondary schooling. All 10 participants were of European descent. The Fiji participants were from the sole Government primary teachers' college in Fiji. Of the 24 participants interviewed, half were indigenous Fijians and half ethnic Indians, thus representing the two ethnic groups that comprise over 90% of Fiji's population in roughly equal proportions. All of the participants from Fiji had completed a general science course up to year 10 of their schooling, with 14 having taken at least one science subject in their final two years when science became non-compulsory.

The elicitation phase

This initial phase of the study was intended to identify the extent to which the participants could correctly apply Kinetic Theory in explanations of how materials change.

All 34 participants involved in this study were interviewed using a series of eight Interviews - About - Instances (IAI) cards (Osborne & Gilbert, 1980) (see Figure 1) and five Prediction - Observation - Explanation (POE) activities (White & Gunstone, 1992).

To begin each interview a series of focus questions were asked about the drawings on the cards. For example, the focus questions used with card 2 from Figure 1 were:

1. What has happened to the water in the puddles?
2. Where has it gone?
3. Why does this happen?

Further questions were then framed according to the participants' responses until the expression of teacher's ideas had been exhausted. In each case teachers were asked to provide the best scientific explanation they could in explaining the various phenomena.

The second part of each interview involved the use of the prediction-observation-explanation technique with five practical activities. These activities included:

1. Depressing syringes filled with air and water.
2. Submerging in water an inverted glass that contained compressed cotton wool in its inner base.
3. Using body heat to warm a gas thermometer comprising a conical flask and delivery tube containing a bead of water.
4. Inserting a heated metal ball through a ring.
5. Operating a set of model lungs.

This range of cards and activities was used to determine whether the teachers could apply Kinetic Theory consistently when explaining a variety of phenomena involving changes in matter. Thus the cards and activities provided an opportunity to probe the teachers' understanding of change of state, conservation of matter, solubility, heat and pressure, all concepts to which Kinetic Theory can be applied. Each interview lasted approximately 75 minutes and was conducted in English, which is well spoken and understood throughout Fiji.

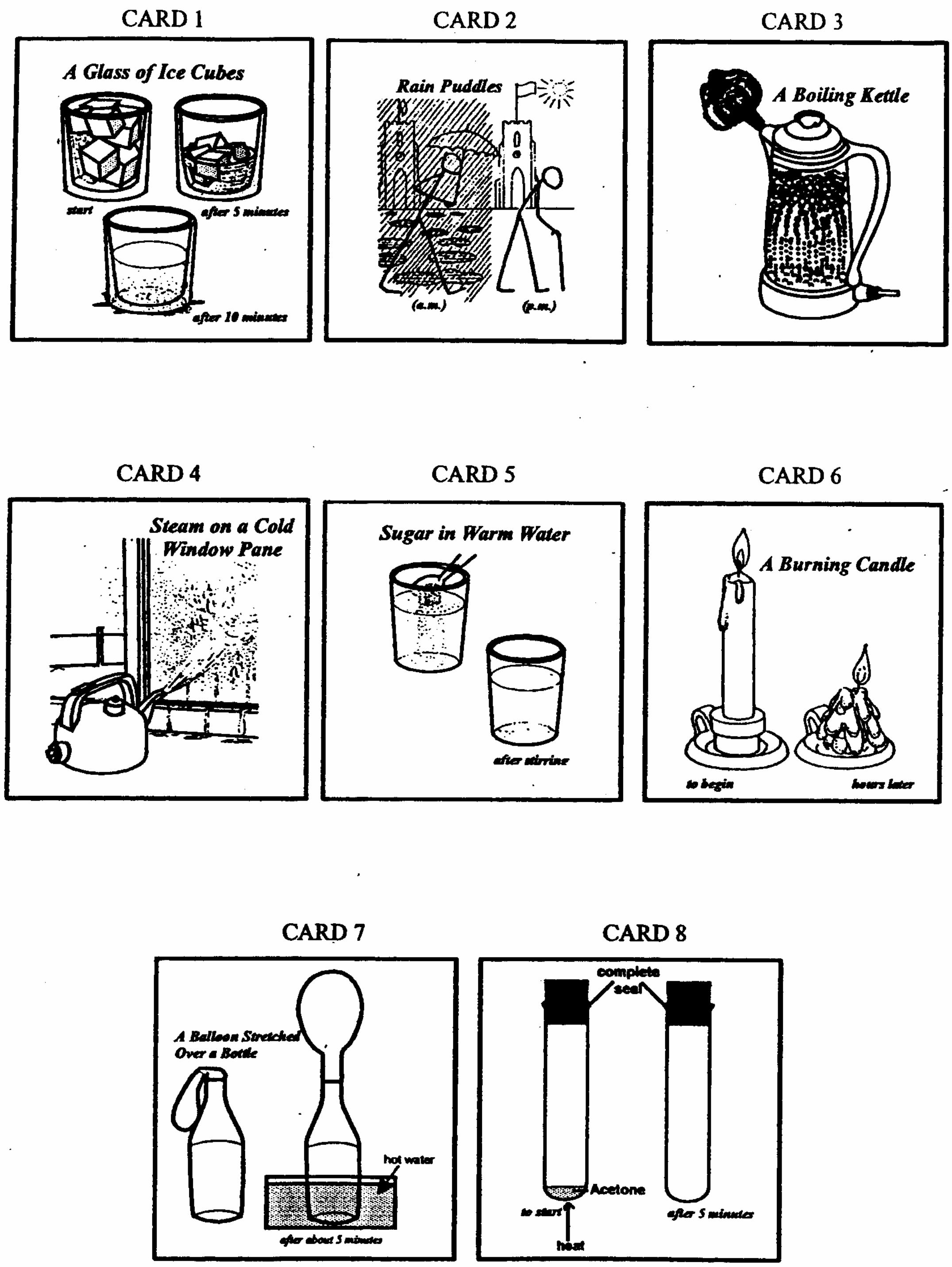

FIGURE 1. *Cards used in the elicitation phase interviews with the pre-service teachers.*

All interviews were audio-taped, transcribed and analysed for teachers' scientific and alternative conceptions. The outcomes of the interview analysis were validated by six judges, all of whom were experienced science educators (Rollnick & Rutherford, 1990). The judges were asked to analyse the transcripts of two sample interviews and identify those conceptions they believed were represented in each. The results from the judges were compared with the analysis of the researchers and the percentage agreement for each concept calculated. An averaged agreement of 89% was obtained and this was considered a satisfactory indication of the validity of the analysis.

The analysis was used to develop Concept Profile Inventories (CPI) for the each of the three ethnic groups; European, Fijian and Indian represented within the overall group of 34 interviewed teachers. A CPI is one way of representing the pattern of beliefs about a certain phenomenon expressed by a particular participant or group of participants (Erikson, 1980). In this instance the CPI was compiled from the teachers' scientific and alternative conceptions obtained from the interview transcripts which were grouped into 4 categories: Change of Phase, Conservation of Matter, Solubility and Gaseous Pressure. An example of a segment of the Fijian teachers' CPI (for Change of Phase) is provided in the appendix. The development of the CPIs for each ethnic group allowed for easy comparison of their scientific and alternative conceptions.

The intervention

This elicitation phase informed the development of a 6-week constructivist-based teaching intervention about changes in materials which was undertaken with the Fiji teachers. A total of 26 teachers, representing a single second year class at the government teachers' college, took part in the program. The components of this program, including the extensive use of analogies, physical models and collaborative group work, are described in detail elsewhere (Lucas & Taylor, 1997) and Figure 2 shows the sequence of strategies typically employed in presenting a particular session.

Ten of the original 24 Fiji participants interviewed prior to the teaching program were again interviewed using the same protocol four weeks after its completion. Once again these interviews were transcribed and analysed for scientific and alternative conceptions and compared to the pre-instruction transcripts for any changes in conceptions.

FINDINGS AND DISCUSSION

In addition to identifying and classifying teachers' conceptions about changes in matter, the researchers attempted to categorise the extent to which the teachers applied a molecular model to their explanations of the phenomena provided. To this end each teacher's explanation of the cards and activities presented was carefully examined and coded according to the following scheme:

1. Energy = Teacher makes either explicit or implicit reference to energy during the explanation or reference to any form of energy such as heat or movement.
2. Particles = The teacher makes implicit or explicit reference to atoms, molecules or simply the term particles during the explanation.
3. Partial Molecular Model = The teacher makes reference to both energy and particles during the explanation, but fails to make explicit the link between them, for example, "the particles move apart."
4. Complete Molecular Model = The teacher makes explicit reference to the relationship between energy and particles during the explanation, for example, "the particles gain energy when they are heated", and has applied a Kinetic Theory of matter.

Clearly if teachers did not incorporate the term particle into their explanation and made some reference to energy they could not be coded as using either a partial or complete molecular model. Although it was not the main purpose of the study to compare ethnic

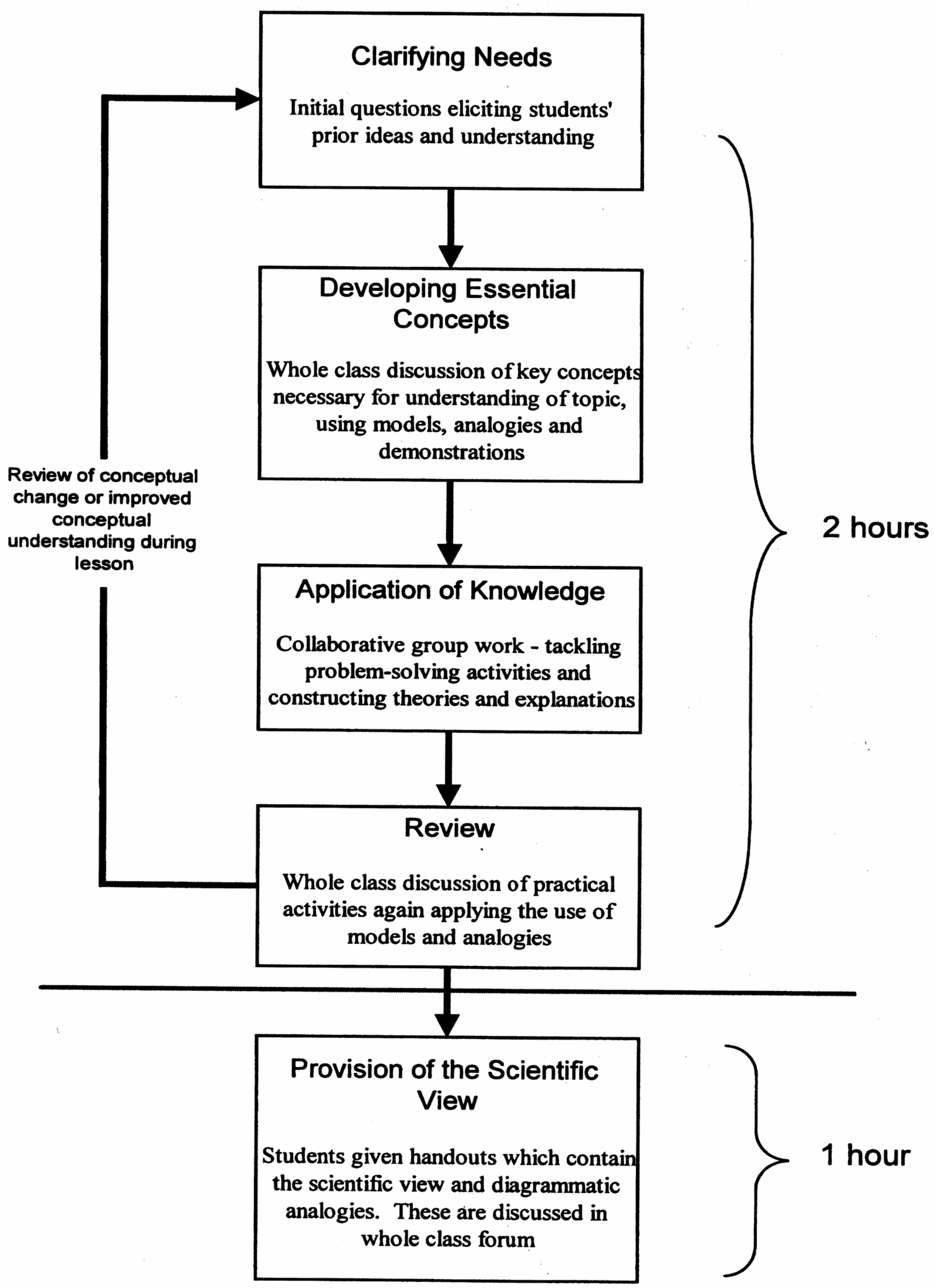

FIGURE 2. A flow chart of the sequence of a typical weekly session comprising a two hour (double) followed by a one hour (single) class.

groups, it was convenient to present the findings for Australians, Fijians and Indians separately. Thus the analysis are summarised in Tables 1-3.

The findings indicated that few participants from any group could successfully apply complete molecular models to their explanations of the presented phenomena. All of the

TABLE 1. *Australian Pre-Service Primary Teachers' use of Kinetic Theory in Explanations (n=10).*

	Ice in glass	Rain puddles	Boiling kettle	Window pane	Sugar in water	Burning candle	Bottle & balloon	Acetone in boiling tube	Syringes	Ball & ring	Inverted glass	Air thermometer	Model lungs
Reference to particles	6	3	5	4	5	2	5	5	6	6	1	3	0
Reference to energy	8	7	9	7	2	4	8	3	n/a	10	n/a	8	n/a
Partial molecular model	3	0	0	2	2	0	4	3	2	3	1	1	0
Complete molecular model	2	2	1	0	0	0	1	1	4	4	0	1	0

TABLE 2. *Fijian Pre-Service Primary Teachers' use of Kinetic Theory in Explanations (n=12).*

	Ice in glass	Rain Puddles	Boiling kettle	Window pane	Sugar in water	Burning candle	Bottle & balloon	Acetone in boiling tube	Syringes	Ball & Ring	Inverted glass	Air thermometer	Model lungs
Reference to particles	3	3	3	1	2	2	5	3	7	9	3	2	1
Reference to energy	8	11	9	8	5	6	9	7	n/a	11	n/a	5	n/a
Partial molecular model	3	3	2	0	1	0	4	1	2	7	1	2	0
Complete molecular model	0	0	0	0	0	0	0	0	3	0	0	0	0

TABLE 3. *Indian Pre-Service Primary Teachers' use of Kinetic Theory in Explanations (n=12).*

	Ice in glass	Rain Puddles	Boiling kettle	Window pane	Sugar in water	Burning candle	Bottle & balloon	Acetone in boiling tube	Syringes	Ball & ring	Inverted glass	Air thermometer	Model lungs
Reference to particles	6	9	7	3	8	1	9	7	11	12	7	8	4
Reference to energy	11	12	12	12	7	6	12	9	n/a	12	n/a	10	n/a
Partial molecular model	2	7	4	2	4	0	5	4	4	7	5	4	1
Complete molecular model	4	1	2	1	1	0	4	0	6	3	0	4	0

participants had been taught Kinetic Theory as part of their secondary science instruction, but many could only provide a partial model in their descriptions, and some were unable to apply the model at all. This was despite being asked to provide the best "scientific" explanation they could.

The next part of this section provides specific examples of the types of mental models offered by some of the teachers. These are presented under the categories used to develop the CPIs, namely: Change of Phase, Conservation of Matter, Solubility and Gaseous Pressure. In each section of transcript, I = Interviewer and P = Participant.

Change of phase

Commonly the Australian participants could provide only a partial molecular model of Phase Change that involved a confused conception of the relationship between energy and molecules or did not incorporate energy, for example, interviews with participants 9 and 10.

> I: What actually happens during melting? If I asked you to give a scientific explanation of what was taking place during melting, what would you say?
> P9: Is it something to do with molecules coming together or going further apart or something like that? (Australian female)
>
> I: What do you think actually happens during melting?
> P10: I'm not really sure, the water particles maybe...something to do with the particles joining together when they're frozen and then they lose their connection when they are water.
> I: Why do you think they lose their connections?
> P10: I'm not really sure of the principles, like I don't fully understand...the ice cubes come out of the freezer all icy and then they melt so maybe the reason that they aren't connected anymore is that they become invisible. Like when they're together there's a visible thing. (Australian female)

Other explanations of melting were provided at a macro level with no reference to particles. These teachers often seemed surprised when asked to elaborate on such terms as melting, for example, interview with Participant 7.

> I: What do you think actually happens during the process of melting? If you could give as scientific an answer as possible of that what would you say?
> P7: That the ice has changed form into water.
> I: Do you know why that has happened?
> P7: Because of the temperature. (Australian male)

Other participants attempted more scientific explanations but these were often very confused and appeared to comprise partially remembered information from high school, for example, interview with Participant 5.

> I: What is happening within the ice during melting?
> P5: It's changing its structure...there's a chemical reaction happening because it's changing its form. (Australian female)

A number of participants from Fiji also attempted to apply Kinetic Theory to their explanations of Phase Change but often the model they employed was incomplete, as it failed to make an appropriate link between particles and energy. This is evident, for example, in the following exchange with Participant 1.

> I: How does the heat cause melting to take place?
> P1: It causes the water particles to expand whereas when it freezes to ice it contracts and it gets together and eh when exposed to heat it eh moves far apart and it melts.
> I: Why do they move far apart...the particles?
> P1: They move far apart because eh...they get to the normal size, that means...it's far apart in the liquid form and when solid forms it gets together so that it has back to its normal size...(Indian Male)

Furthermore, the use of anthropomorphic language, such as that shown by Participant 3 below, was commonplace amongst the teachers in Fiji.

> P3: That water comes from the surroundings, because the surface of the beaker is very cold, water droplets in the surroundings, they get to the sides of the glass.
> I: Why does that happen?
> P3: They find it very suitable so they come in contact and they form water droplets (Indian Female)

While for some this was simply a means of expression, others like Participant 6 seemed to view the particles of matter as living entities.

> P6: The energy...that helps the particles to get a wider space, in other words provides the form of heat or the form of food...like we eat food so we get the strength in our bodies...the same thing here, the energy provides the strength to the particles to move and take up space.
> I: So the energy helps them to move? Do you think of the particles as living or non-living things?
> P6: They're living things (Indian Male)

The concept of condensation proved to be extremely problematic for the teachers to explain scientifically. Although half of the teachers knew that condensation forming on a cold surface was derived from the atmosphere, this being a very common phenomenon in Fiji's humid climate, other teachers believed it came directly from the ice cubes, or through the glass or attributed it to the effect of atmospheric pressure.

One teacher appeared to generate spontaneously his own alternative framework to explain condensation.

> P13: The droplets came from the air particles...which hit the cold surface and it eh when it cools it forms water.
> I: When you say air particles, can you tell me how the droplets form out of those air particles?
> P13: Maybe when the air particles get below a certain temperature they change their form (Fijian Male)

This participant proceeded to apply this framework with considerable consistency to explain other phenomena he was presented with later.

The majority of teachers could offer no explanation for the formation of condensation. Of the remainder, only two provided an acceptable explanation involving the application of Kinetic Theory.

> I: Where have those water droplets come from?
> P6: Those are from the humidity from the atmosphere...the water particles in fact are in gaseous form and when they touch the cold surface they become liquid water.
> I: Why do they become liquid?
> P6: They are losing energy there (Indian Female)

The other teachers who attempted an explanation could only do so at a macro-level.

Conservation of matter

Amongst the Australian teachers, only one participant was able to provide a comprehensive and scientific conceptual model to explain the event depicted in card 8 which was intended to probe participants' understanding of conservation of matter.

> P7: There wouldn't be a change of mass when the acetone was heated or cooled. The acetone has changed form but the same amount of molecules are present all the time (Australian Female).

However, five of the participants did not share this view, claiming that the vapour phase would have less mass than the liquid phase despite the fact that a closed system was depicted, for example, Participant 3.

> I: How would the mass of the tube be before heating and after heating?
> P3: My first instincts are to say that would be more before heating because it's got the liquid form whereas in this one it's the gaseous form and gas is lighter than the liquid state (Australian Female).

A number of responses similar to the one above indicated a lack of understanding of the concept of mass but also for weight and density.

Subjects also provided a number of theories as to the fate of the acetone once it had been heated. These included the view that it had coated the inside of the glass, been absorbed by the rubber stopper or been absorbed by some entity between the air particles, for example, Participant 10.

> P10: Whatever is between the air particles might have absorbed the acetone, it may be something that can absorb things such as bad chemicals and pollution and that sort of thing, so maybe that's what's between the air particles (Australian Female).

In Fiji, all but three of the Indian teachers were aware that the mass of the two tubes would be the same and could readily justify this. Six Fijian teachers claimed that the mass of the substance would change during the transition from one state and two stated that they were unsure if a change would occur or not.

> P5: From the diagram I can see that due to heat the acetone particles that were in liquid form after heating they moved apart and the gap between them increased...and after five minutes of heating they change into gas particles.
> I: If you took the mass of this and the mass of this what do you think you would find?
> P5: I don't think there would be much change in mass.
> I: Would there be any change in mass?
> P5: No I don't think so...it should be same because of the complete seal.
> I: Why is that?

P5: That's stopping any gas particles or anything from getting out (Indian Male)

I: If you were to weigh both tubes what would you find?
P7: This would be lighter.
I: Why is that?
P7: Because gas is eh...you can't really see gas...and it's weightless and this is liquid and you can weigh it (Fijian Male)

This may have been, in part, attributable to fewer Fijians employing a molecular framework when thinking about this problem and concentrating instead on physical attributes.

Solubility

Of the Australian participants who attempted to explain the dissolving of sugar depicted in card 5, only half made reference to molecules or particles in their explanations. Of the five who did incorporate molecules or particles into their model of solubility, three believed that the sugar molecules were either absorbed by or attached to the water molecules, for example, Participant 1.

P1: I'd see the sugar just being attached to the outside or even being absorbed by the (water) molecule itself.

This led the same participant to a view that dissolving was an irreversible process. Most other participants, however, were able to draw on their own prior experiences to explain how this change could be reversed, for example, Participant 3

I: Could you get the sugar back out of the water?
P3: I know you could do it with salt...possibly if you evaporated the water off, the crystals the sugar crystals may come back.
I: So you've done this with salt?
P3: Yes, that's why I thought it might work with sugar even though I've never done it.

In Fiji 12 of the 24 participants teachers were able to state that dissolving involved the mixing of sugar with water. Of these, six were able to explain the processes in terms of a coherent conceptual model involving particles.

I: When you say the sugar has dissolved what does that mean?
P4: The sugar particles mix with the water particles.
I: Where do the sugar particles go?
P4: They just mix...there are gaps between the water particles and the sugar particles fill these. (Indian Male)

Only one teacher attempted to explain dissolving in terms of attraction and bonding between sugar and water molecules.

P6: So in warm water the reaction will happen faster because of the higher energy. What happens is the sugar particles are attracted to the polar water...I think the sugar particles are hydrophilic...they sort of follow the water particles and mix around with them...they get bonded...attracted to the water particles (Indian Male)

However, this view led to problems later when the same teacher attempted to explain saturation.

> P6: These crystals...these must have been eh very close hard packed crystals that hasn't got dissolved due to less energy given to them...I think there wasn't sufficient energy given to them...because the bonding in those crystals was too strong (Indian Male)

This view of saturation was also shared by two Fijian teachers, and one Indian teacher related saturation to impurities. However, half of the teachers (12) held the scientific view that saturation occurred when no more solute will dissolve in the solvent because there was no more space left between the particles of solvent. Three teachers believed that the sugar had to melt before it could dissolve and one teacher expressed the view that dissolving involved the sugar changing into water.

Gaseous pressure

Card 7 and demonstrations (1), (2), (3) and (5) were used to probe the participants' understanding of gas pressure and the nature of gases. The demonstration with the syringes, in which the participants were asked about the compressibility of liquids and gases, revealed that seven of the 10 Australian participants believed that a gas could not be compressed. Furthermore, the concept of a vacuum proved to be extremely counter-intuitive. The term vacuum, for example, was used in the wrong context as seen in Participant 1's comments,

> P1: I think the syringe with air in it will form a vacuum and you won't be able to push it closed very easily or not at all (Australian Female)

Even those participants who from their explanations appeared to have a well-established molecular model of a gas, still found the idea that there is a vacuum between the particles of a gas difficult. Generally when probed further on their understanding of the structure of gases, they revealed the belief that some form of matter must exist between the particles, for example, Participant 3

> P3:...in air there is going to be a fair bit of space and you can push the plunger down and the gas molecules will come together to a point where you can't push them any further "cause it will consume all the space.
> I: You talk about space between the particles, can you explain that further?
> P3: I want to say it's just the atmosphere, but the atmosphere has molecules in it too...I don't know what empty space would be there is no such thing in terms of molecules (Australian Female).

Amongst the teachers in Fiji, the most common alternative conception predicted was that neither substance, air nor water, could be compressed. Of the eight teachers who held this view, seven changed their explanation's upon seeing the syringes compressed.

> I: What do you think you predict will happen?
> P5: You can't push in either (plunger)
> I: OK you can try it.
> P5: Oh.
> I: So can you think why it was different from your prediction?
> P5: Maybe it's to do with the difference between air and water.
> I: How are they different?

P5: In water I would say the particles are close together but in air they are far apart...so when we press the water, because the particles are a bit together...so we can't press it...whereas this one the particles are far apart...when we press it the air particles inside here they come together so they use up the space (Fijian Male)

It appeared that this teacher had made his initial prediction without applying a mental model incorporating particles and their spatial distribution in liquids and gases, even though he clearly possessed such a model.

As with the Australian teachers, a number of Indian and Fijian teachers found the concept of a vacuum particularly difficult. A number from both groups suggested that the spaces between particles were occupied by air or water vapour, for example, Participant 4

I: You talk about the spaces between the particles, is there anything in the spaces between the particles?
P4: ...Other gases...water vapours...water vapour, yes water vapour and sometimes other gases (Indian Female)

The above data provide a "snap shot" of teachers' conceptions of certain physical changes and their ability to apply the model of Kinetic Theory in explaining these. As mentioned previously, all of the teachers had been taught Kinetic Theory during their secondary schooling but despite this only a small number could apply it effectively and consistently to their explanations. It was of interest to note that most of the alternative conceptions expressed were similar to those presented in the literature from Western studies. There was also considerable uniformity in the alternative conceptions held by teachers across the three ethnic groups involved in the study, despite their very different cultural and educational backgrounds. This finding is in keeping with Thijs and van den Berg's (1995) claim that in the domain of physical science the same alternative conceptions exist across many countries, with a variety of cultural and environmental contexts.

If teachers are to explain physical changes in matter scientifically, then it is important that they not only hold a particulate view of matter, but that they are also aware of the relationship between energy and particles. Many of the pre-service teachers in Fiji held a particulate view of matter and understood that these particles could move apart or come together, but they did not relate this to a change in energy. In some cases this appeared to be a consequence of the didactic style of teaching they received during their own schooling. In Fiji schools teachers often adhere strictly to a prescribed science course book which by its very nature can only represent the spatial change in particles during change of state and does not – demonstrate effectively that this is related to energy gain and loss. Consequently many students fail to make the connection between energy and particles.

P1: Sir like when particles gain energy...
I: Yeah?
P1: Like they move faster?
I: Yes.
P1: What if they lose energy?
I: What do you think?
P1: That means they won't move at all or something?
I: Well not that they won't move at all, but if they move faster when they gain energy...?
P1: That means they move slower when they lose energy.
P2: Yes, because what we learned (at school) was that particles...the expansion and contraction of particles but not that particles gain energy or lose energy...like.

Thus during the teaching intervention (Taylor & Lucas, 1997), much use was made of physical models and in particular a commercially produce Kinetic Theory model as well as numerous analogies in an attempt to provide the teachers with a strong visual representation of the particle/energy interaction during physical changes. Once this visual representation had been presented, the teachers then worked in small groups on simple problems to which they could apply the Kinetic Theory model, and negotiate and construct explanations to the problems. These problems covered the full range of physical changes and at the conclusion of the teaching intervention some of the teachers who had been interviewed in the elicitation phase were interviewed again using the same format to determine if their conceptions had changed. These post-intervention interviews also afforded an opportunity to determine how effectively the teachers could apply a model of kinetic theory to their explanations.

The final section of this article reports briefly on the changes in conceptions which some teachers underwent as a result of the teaching intervention and the extent to which they could identify specific pedagogy which helped improve their understanding.

What follows are sections from transcripts of interviews conducted pre- and post-instruction. Space does not permit the presentation of significant amounts of the data obtained, but examples provided are representative of the types of changes which occurred in the teachers' conceptions post-instruction.

In the first example Participant 12, a Fijian male, is explaining condensation.

	Pre-instruction explanation		*Post-instruction explanation*
I:	I see and what do you see on the outside of the glass after 10 minutes?	I:	Now this process here, what's forming on the outside of the glass?
P12:	Water spots.	P12:	Water droplets.
I:	Do you know where that water comes from?	I:	Where have they come from?
P12:	It's from the air.	P12:	They come from the atmosphere, the air.
I:	Why does that happen, that forming of water spots?	I:	Why does this process take place?
P12:	Because the outside of the container was cold so the air has liquid in it, so when the air brushes against the container it...the water particles starts...gets stuck because it's cold.	P12:	It's because of the cold surface around the container which attracts the air particles present within the…
I:	Could you say anymore about that process.	I:	Why do they change into water?
P12:	No.	P12:	Because once the air particles move closer to the cold surface they lose energy and they just get stuck onto the cold surface.

The important change in Participant 12's explanation post instruction is the inclusion of the notion that particles gain or lose energy during a change of state.

A similar learning outcome was demonstrated by Participant 15, an Indian female.

	Pre-instruction explanation		*Post-instruction explanation*
I:	And you see the final glass here after 10 minutes, what's on the outside of the glass?	I:	Can you explain as scientifically as possible what is happening in this picture.
P15:	Water droplets.	P15:	The ice cubes...when it is put in the glass it starts to melt so the particles...water vapour particles in the atmosphere when they find a cool surface they lose energy and they condense on the outside of the glass in the form of water droplets...the particles of water vapour in the atmosphere they lose energy and they...
I:	Where has that water come from?		
P15:	That water comes from the surrounding, because since the surface of the beaker is very cold water droplets in the surrounding, they get to the sides of the glass.		
I:	Why does that happen?		
P15:	They find it very suitable so they come in contact and they always form water droplets.	I:	What causes them to lose energy?
		P15:	The cold surface.

Furthermore, when explaining evaporation, Participant 18, an Indian female, moved from a very "surface level" explanation pre-instruction, towards a model which incorporated particles and energy post-instruction.

	Pre-instruction explanation		*Post-instruction explanation*
P18:	Like when we boil something the heat is there and the water evaporates in the form of vapour...it goes up. In the atmosphere it mixes up with the atmosphere.	I:	What has happened to the puddles?
		P18:	They have evaporated...they gained energy.
		I:	Where did that energy come from?
I:	And how exactly does the heat make it do that?	P18:	From the sun.
P18:	Em...like the sun's rays gets in contact with the water then it makes it warm...like the heat...as it is heated it is evaporated in the form of vapour.	I:	So how does that gain in energy actually cause the puddles to evaporate?
		P18	Like they gain energy and they move faster.
		I:	When you say they...
		P18:	The water...
I:	Could you say more about that?	I:	The water what?
P18:	No I don't think so (laughs).	P18	Like you said the water is here in the rain puddles and as they gained energy it evaporated.
		I:	You said they gain energy and they move faster but I just wondered what you meant by they...the whole puddle?
		P18:	No the water particles.

This qualitative change in which the teachers moved from a partial understanding of particle behaviour to a more complete understanding which links particles to energy gain or loss, is highly significant. Knowing that matter is composed of particles is in itself insufficient to explain changes in matter such as melting or evaporating. It is an understanding of how particles behave in different conditions which is the key to explaining these changes.

The teachers claimed that the strong visual representation provided by the Kinetic Theory model was helpful in improving their understanding of particle behaviour and in particular the relationship between particles and energy.

> I: Why did you find the particle model particularly helpful?
> P17: Because you can actually see the particles move...you can see how they lose energy.
>
> P10: Well for example like I could see...when we apply energy I can really know that the size of the particles and the number remains the same even though energy was...there's loss of energy or there's gain of energy the particles remain the same (Fijian female).
>
> I: Before you came to my lessons were you aware of the fact that particles can gain and lose energy?
> P12: No.
> I: Can you think of what helped you understand the concept better?
> P12: I'd say the use of that model.
> I: What was it about the model which you found helpful?
> P12: Because you can actually see how the particles move...you can see how they lose energy and gain energy.

The teachers claimed they also found the analogies particularly effective because they were able to link them to their everyday experiences, and a number of teachers recalled specific taught analogies when discussing this aspect of the instruction. One mentioned an analogy in which migration was linked to evaporation.

> P18: There's lots of people and then they migrate eh from for example Fiji to America, then the other poor are left so they need more money...I mean if they work hard and get more money then some more migrate...and it's the same with the acetone...it needs more energy...some of them evaporates the others are left...they need more energy.

Although not a perfect explanation, this Indian teacher had grasped the idea that energy is required for evaporation to take place. This was a particularly apt analogy for Fiji where the migration of wealthy Indians to Western countries is commonplace.

Another teacher recalled an analogy intended to help convey the idea of matter as particulate.

> I: Did you understand the analogies we used?
> P13: Yes especially the one on the beach...looking from a distance at the sand.
> I: What was that trying to do?
> P13: Looking at particles from a distance...sand from a distance is just solid, but when you look at sand pieces...particles from a few yards we can see the grains, but from a distance it will just look...we'll see it looking just white.

A number of teachers remarked that they would try to employ analogies in their own teaching where possible.

CONCLUSIONS

This study showed that despite instruction in Kinetic Theory at secondary level, few of the pre-service primary teacher participants could apply this model effectively when explaining changes in materials. Furthermore, despite coming from three quite distinct cultural groups, the participants shared many alternative conceptions about physical science. In fact as Smith and Neale (1989) suggest, it may be useful to regard primary level teachers as adult novices, in some if not all, of the science areas they teach. According to Chi, Feltovich and Glaser (1981), novices tend to dwell on the surface structures of scientific problems (i.e., the objects referred to in the problems) with which they are confronted. This contrasts with experts who appear to look at the underlying scientific principles involved. Clearly many of the participants in this study exhibited the characteristics of novices described by Chi et al. (1981), insofar as their initial response to the questions was to focus on the surface features presented. Certainly few applied the principles of Kinetic Theory to their explanations, even with considerable probing on the part of the interviewer.

However, the constructivist-based teaching intervention reported here, which drew heavily on the use of physical models and analogies appeared to have helped the teachers to construct a better mental model of Kinetic Theory, and specifically the relationship between particles and energy. Once the teachers had constructed this model they were able to apply it, albeit tentatively in many cases, to their explanations of everyday changes in matter.

CORRESPONDENCE: *Neil Taylor, School of Education, University of New England, Armidale, NSW 2351, Australia; fax: (02) 6773 5078; e-mail: ttaylor6@pobox.une.edu.au*

APPENDIX

FIJIAN CONCEPT PROFILE INVENTORY FOR CHANGE OF MATTER

(The researchers' assertion is represented in bold type, along with the number of teachers holding that conception, and an example of a teacher response).

Scientific conceptions

A.1.1 Changes of state are usually associated with the effect of temperature change on matter (7)
"Because of the heat the ice begins to melt..."
A.1.2 Changes of state are associated with the energy (velocity) of the particles which make up a substance (1)
"When you heat it the particles in the solid vibrate."
A.1.3 Intermolecular distances decrease from gases through liquids to solids (5)
"solid particles are very close together and liquid particles have a bit of space and the air much larger spaces."
A.1.4 Condensation is derived from water vapour in the atmosphere (4)
"(Condensation) its from the air around the beaker."

Alternative conceptions

A.2.1 Change of state associated with something other than temperature change (2)
"The humidity causes the ice cubes to melt."
A.2.2 Intermolecular spaces decrease from solids through liquids to gases (1)
"The particles tend to come together I mean sort of contract yes during melting they join together."
A.2.3 Condensation is due to leakage or attraction (6)
"most probably it (condensation) might have come though the glass."
A.2.4 Evaporation associated with absorption (5)
"...the liquid goes back to the sun...I think by (the sun's rays) absorbing it."
A.2.5 Particles viewed as living entities (1)
"I think the particles are living."
A.2.6 During evaporation different gas particles become bound together (1)
"here (during evaporation) it's a matter of air and the acetone being joined together, the particles bind together."
A.2.7 Condensation comes directly from ice (1)
"Maybe a little of it (condensation) comes from inside from the ice cubes here."
A.2.8 Evaporation occurs because heating makes the particles of a liquid lighter(1)
"When the particles of water is being heated up they tend to get light and rise up into the air."

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