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Primary Teachers' Particle Ideas and Explanations of Physical Phenomena: The Effect of an In-Service Training Course

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Primary Teachers' Particle Ideas and Explanations of Physical Phenomena: The Effect of an In-Service Training Course

Abstract

This paper presents a study concerning Greek primary school teachers' (n=162) ideas about the particulate nature of matter and their explanations of physical phenomena. The study took place during an in-service training course where the effectiveness of a specially designed intervention was tested. A key feature was an approach based on the concept of a substance and its states rather than 'solids, liquids and gases'. Pre-intervention, the teachers held misconceptions similar to those of pupils. Also, there seemed to be some relationship between the teachers' particle model ideas and their explanations of phenomena. Post-intervention, the teachers' descriptions and explanations were found to be significantly improved, with almost zero correlation between pre and post intervention scores. Implications for science education are discussed.

Keywords

Primary teachers, Particle ideas, Physical phenomena, In-service training

Introduction

The late 1980s saw a shift from a largely process approach to a greater emphasis on subject knowledge for primary school science in the USA, UK, Australia and New Zealand (Osborne & Simon, 1996). At that time, the Greek primary science curriculum was reconstructed to also feature content more prominently (Greek Ministry of National Education and Religion Affairs, 1985). These curricular changes placed demands on in-service primary teachers for which few were well qualified, particularly in the physical sciences. Indeed,

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3 research revealed that many primary teachers were low in their confidence to teach science
4 and held similar misconceptions to pupils (Appleton, 1995; Baker, 1994; Harlen, Holroyd &
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research revealed that many primary teachers were low in their confidence to teach science and held similar misconceptions to pupils (Appleton, 1995; Baker, 1994; Harlen, Holroyd & Byrne, 1995; Krugar, Summers & Palacio, 1990; Mant & Summers 1995; Smith & Neal, 1989; Summers, 1992; Summers & Krugar, 1992). It is difficult to see how lack of subject knowledge would not impact on the quality of teaching. Without sound understanding of the content, how could a teacher plan appropriate, imaginative lessons and engage in constructive dialogue with pupils? Instead, there is the danger of the teacher being a source of misconceptions and confusion. A robust subject content knowledge would seem to be a necessary support for pedagogical content knowledge which develops pupils' conceptual learning (Kang, 2007). Moreover, poor science teaching is likely to generate negative attitudes towards science in pupils (Harlen & Holroyd, 1997; Jurievi, Glaar, Puko & Devetak, 2008; Woolnough, 1994).

More recent studies indicate that the problem appears to persist despite greater attention to science within pre-service and in-service courses for two decades (Appleton, 2002, 2003; Author #1 et al., 2000, 2007; Jarvis, Pell & Mckee, 2003; Murphy, Neil & Beggs, 2007; Parker & Heywood, 2000; Schibeci & Hickey, 2000). There is a continuing need for in-service provision. Studies reporting interventions, both pre-service and in-service, are commonly structured upon a constructivist teaching methodology (e.g. Çalik, 2008; Jarvis & Pel, 2004; Liang & Gabel, 2005; Schibeci & Hickey, 2000; Summers, 1992). The extent to which such interventions also involve important changes in content (the ideas being taught) is not always clear. In this paper we report a study where the emphasis was on a rethinking of the content.

The nature of matter and its transformations is perhaps an especially problematic domain area because of the issues surrounding the particulate model of matter. The area has been widely investigated from the pupils' perspective across the primary and secondary age ranges. Findings indicate a large discrepancy between pupils' explanations of physical

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3 phenomena (melting, boiling, evaporation, condensation and dissolving) and the science view
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5 (e.g. Andersson, 1990; Author #1 & #3, 2005; Author #3, 1998b,c; Bar & Galili, 1994; Bar &
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7 Travis, 1991; Costu & Ayas, 2005; Lee, Eichinger, Anderson, Berkheimer & Blakeslee, 1993;
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9 Osborne & Cosgrove, 1983; Paik, Kim, Cho & Park, 2004; Russell, Harlen & Watt, 1989;
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11 Stavey, 1990; Tytler, 2000). This work also reveals widespread difficulties with the
12
13 particulate theory of matter (e.g. see Andersson, 1986; Author #3, 1998a; Barker, 2002;
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15 Driver, Squires, Rushworth & Wood-Robinson, 1994; Gabel & Bunce, 1994; Garnett, Garnett
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17 & Hackling, 1995; Gomez, Benarroch & Marin (2006); Hatzinikita, Koulaidis & Hatzinikitas,
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19 2005; Krnel, Watson & Glazar, 1998; Liu, 2001; Smith, Anderson, Krajck & Coppola, 2004).
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21 Similar findings are reported in studies with pre-service teachers (e.g. Çalik & Ayas, 2005;
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23 Jarvis, Pell & Mckeon, 2003; Kokkotas, Vlachos & Koulaidis, 1998; Schoon & Boone, 1998;
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25 Tekkaya, Cakiroglu & Ozkan, 2004).

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32 Given the research on pupils' difficulties, there is debate as to when the particle model
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34 should be introduced. At present, it is found in the early secondary curriculum in most
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36 countries (Martin, Mullis, Gonzales & Chrostowski, 2004) and there is an argument for
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38 postponement (Harrison & Treagust, 2002). Certainly, in the UK and Greece, it is not part of
39
40 the official primary curriculum. However, one's position on the introduction of the particle
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42 model depends on one's belief in the reasons for pupils' difficulties. We contend that the
43
44 conceptual accuracy of the particle model on offer, rather than pupils' capabilities (or
45
46 teachers' pedagogical abilities) is the prevailing limiting factor (Author#3 & #1, 2008).
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48 Without first distinguishing between substances and mixtures of substances, the model is
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50 usually introduced to explain 'solids', 'liquids' and 'gases'. Differences in melting and
51
52 boiling points are not addressed. In all, this could be confusing and therefore have little utility.
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54 Scientifically, there are no such things as 'solids', 'liquids' and 'gases': there are substances
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56 and their states (with mixtures of substances often having complex behaviour). Talk of
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58 'solids', 'liquids' and 'gases' may lead pupils to think that these are three separate kinds of
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3 matter (Author#3, 1996) and hence there must be three types of particle which carry the
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matter (Author#3, 1996) and hence there must be three types of particle which carry the
respective macroscopic properties, a common misconception (e.g. Andersson, 1990; Ben-Zvi,
Eylon, & Silberstein,1986; Gabel & Sumuel 1987; Griffiths & Preston, 1992; Kokkotas,
Vlachos & Koulaïdis, 1998; Pereira & Pestana, 1991). Changes of state in some instances are
then seen as perplexing anomalies. We advocate an approach which focuses on the concept of
a substance and its states. Furthermore, we would argue that particulate ideas are necessary to
sharing the scientific view of events on a macroscopic scale. For example, without identifying
a substance with a kind of particle how can one accept that the substance water can be part of
the clear air - be there to separate out on cooling the mixture? (Pupils seem to find the
appearance of condensation on a cold object one of the most difficult events to understand.).

If particle theory needs to be an integral part of teaching about physical changes one
must ask whether this package is appropriate for the primary curriculum. However, if the
standard approach to introducing the particulate view of matter is flawed we cannot say yet
what pupils could achieve otherwise at various ages. Using our new conceptual approach,
short intervention studies with primary aged pupils have yielded encouraging results (Authors
#1 & #3, 2005; Authors #1, #3 & other, 2008; Author#3 & #1, 2008). If primary pupils can
engage with particle ideas, their teachers ought to be capable. However whether this can be
realised in practice remains an empirical question, too. At older ages, teachers who have held
misconceptions throughout their school years and teaching careers may be resistant to change
– a widely noted characteristic of ‘misconceptions’.

In this paper we report the outcome of an in-service course, which adopted a substance
approach to the particle model and physical changes, for Greek primary teachers. In this
context the following two research questions were addressed:

- What was the affect of the course on teachers' understanding of the particle model and
their explanations of physical phenomena during this course?

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- What is the relationship between the degree of teachers' understanding of the particle model and their explanations of physical phenomena?

In both questions, commonalities with pupils' thinking were also examined.

The content and structure of the training course

The study took place during an in-service teachers' professional development program. Under central control from the Greek Ministry of National Education and Religion Affairs each Primary Educational Department of Greek Universities had the responsibility for planning and implementing a particular training program. These were open to Greek primary teachers with up to 25 years teaching experience, on a voluntary basis. In this context, Democritus University of Thrace launched a two-year program, where, among other courses, participants attended a five week (six hours per week) training course on basic concepts of chemistry. The conceptual structure and content of the course had been developed by two of the authors (the 1st and the 3rd).

Table 1 outlines the content covered by the course with respect to physical changes (further work on chemical change is not reported here). Similar content has been used with Greek primary pupils (Authors #1 & #3, 2005; Authors #1, #3 & other, 2008). The rationale behind the scheme is discussed in full elsewhere (Author#3 & #1, 2008) and we give just a brief overview here.

[Insert Table 1 about here.]

Given the expected weaknesses in the teachers' background knowledge, the scheme starts by identifying properties which depend on the material only. Here material means any recognizable kind of 'stuff' be it a substance (element or compound) or a mixture of substances. Next, melting behaviour is used to give an operational definition of a substance: a sample of stuff which has a precise melting point (there is a sharp change between solid and liquid) as opposed to a mixture which melts over a temperature range. The particulate view of

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3 matter is then introduced to explain why a substance can change between the solid and liquid
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5 states. At the outset, the intention is to counter any suggestions that 'solids' and 'liquids' are
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7 two types of matter. A simple model is presented which talks about the 'particles of a
8
9 substance', where the identity of the substance rests with the particles: different substances
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11 are different particles (there is no distinction between molecules, atoms or ions). These
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13 particles have an 'ability to hold' on to each other (which is different for different substances)
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15 and an energy of movement (which depends on the temperature). The 'ability to hold' is a
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17 characteristic of a substance and does not change on change of state. Melting is explained by
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19 increased energy of movement which partially overcomes the hold so the particles can move
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21 around from place to place, but are still kept close together. The particles themselves,
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23 whatever their physical nature, do not change. Following on, the change to the gas state
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25 (boiling) is explained by the particles having enough energy to completely overcome the
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27 'hold'. Crucially, the coexistence of different substances in different states at the same
28
29 temperature is explained by differences in the 'ability to hold' (which give different melting
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31 and boiling points). Substances in the gas state at room temperature have a very weak hold
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33 between their particles – they are not a different kind of matter. (NB: We prefer to use 'hold'
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35 rather than attraction since 'hold' anticipates later refinement into the idea of a bond as a
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37 balance between attraction and repulsion.) Finally, the idea of a distribution of energy
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39 amongst particles at a particular temperature is introduced to explain evaporation of water into
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41 the air at room temperature, and the separation of water from the air on cooling.
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52 **Methodology**

53 *Sample*

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55 One hundred and sixty two primary school teachers (68 male and 94 female)
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57 participated in the present study. All were working in primary schools in the area of East
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59 Macedonia and Thrace, Greece, and their teaching experience ranged from 2 to 21 years
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3 (mean 12.7 and SD=4.5). The teachers had not participated in any similar in-service training
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5 programs previously. Their undergraduate studies on general science had been the only
6
7 formal education on this matter. During their in-service teaching they would have acquired
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9 similar experiences, since all would have been using the same mandated textbook and
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11 guidance (Greek Pedagogical Institute, 2003). It should be stressed here that teaching
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13 experience does not necessarily enhance conceptual learning or bring expertise in science
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15 teaching (Morrison & Lederman, 2003).
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22 *Teaching*

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24 The teaching took place in nine independent locations, each with a class of 18
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26 participants. The whole course consisted of 30 one-hour lessons; six covered sections 1 to 3 of
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28 Table 1 (the particulate nature of substances) and nine covered sections 4 and 5 (explanations
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30 of corresponding physical phenomena). The remaining lessons covered chemical change (not
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32 reported here). *All of the teaching was carried out by the first author.*
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36 Simple demonstration experiments (e.g. melting of wax, melting of chocolate, boiling
37
38 of water) were used in the lessons. For each of these, 2-3 teachers were invited to participate
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40 (handling materials, heating etc.), while the rest observed. Overall, most of the teachers in
41
42 each class did not volunteer, saying that they didn't feel comfortable with such experiments
43
44 and preferred to watch. Only around 4-8 teachers in each class had direct involvement in one
45
46 or more these demonstrations. For more difficult or time-consuming experiments, appropriate
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48 videos were used (e.g. evaporation of alcohol or water, boiling of wax). All teachers
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50 participated in discussions on the observations and explanations. Static representations
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52 concerning the particulate nature of substances were used as aids.
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Measurements and Instruments

At the beginning of the course the teachers completed a pre-intervention written test consisting of two parts (Table 2). Part I concerns the understanding of the particle model itself and Part II concerns the application of the model to explain phenomena. In sum, Parts I and II relate to the first research question. Setting the two parts against each other addresses the second research question.

Part I contained two groups of tasks – five tasks in total. The groups correspond to two dimensions in which the degree of the development of particle ideas can be measured, namely, the *Particulate/ Continuous* dimension and the *Macroscopic/ Collective* dimension. These dimensions had emerged from a longitudinal study on pupils' understanding of the particulate view of matter (Author #3, 1998a). The former concerns the development of the notion of particles in terms of the relationship between the particles and the substance. At one end a completely continuous view of matter is held, at the other the particles are the substance. Between these two ends, the particles are embedded in the substance with varying degrees of association between the particles and the substance. The macroscopic/collective dimension relates to the association between the particles and the macroscopic properties of a state. At one end all of the macroscopic properties are carried by each individual particle. At the other end, the macroscopic properties are explained by the collective behaviour of the particles (and the physical nature of individual particles is irrelevant).

Part II consisted of four tasks, which concern measurements on the description and explanation of physical phenomena: melting, boiling, evaporation and condensation. Descriptions of all the instrument tasks for Parts I and II are given in Table 2. Figure 1 gives some of the representations used. A month after the training course, the same instrument was used as a post-intervention test. The total time period for the completion of the tests was one hour (60 min) each.

[Insert Table 2 about here] and [Insert Figure 1 about here]

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Data analysis

As the instrument was a written test applied to a large sample the data analysis is mainly quantitative. Qualitative characteristics of answers were used for categorization, but are not reported and discussed in detail. In each one of the tasks, teachers' answers were categorized according to their correctness by two of the authors (the 1st and the 2nd). The agreement percentage after discussion and negotiation became 100%. Depending on the task, a teacher's answer could be characterized as: correct (C), partially correct (PC), not entirely incorrect (NEI) and incorrect (I). The corresponding scores awarded for these categories were 3 to 0, respectively. In some tasks the categorization resulted in three levels: correct, partially correct and incorrect and the scores awarded were 2 to 0, respectively. Total scores were calculated as sums and were used as percent achievement for further statistical analysis.

The validity of the test concerns the evaluation of achievement in a specific domain and thus it refers to content validity (Mertens, 2005, p 354). Thus, the establishment of this type of validity was based on elaborated judgement and expertise. The Cronbach's alpha was 0.69 and 0.59 for pre and post intervention questionnaires, respectively. Although not very high, they are satisfactory as indicators for internal consistency. Values down to 0.55 are acceptable for statistical consideration in social science studies (Hatcher & Stepansky, 1994). However, the low Cronbach's α values in this case are not definitely related to lack of internal consistency. Kline (1999) notes that values below 0.7 can be expected in cognitive tests due to the diversity of constructs being measured.

Results and Discussion

In this section the results of the pre- and post- intervention tests are presented, discussed and compared with previous research findings. Parts I and II are considered separately and then in relation to each other through statistical analysis.

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Part I. Structure of matter

Pre- and post- intervention responses concerning the continuous/particulate dimension of substances (Table 2, tasks 1-3) are presented in Table 3.

[Insert Table 3 about here]

Pre-intervention, although the majority of the teachers had some ideas about particles (PC and NEI), few had a complete particulate picture of substances for the solid, liquid and gas states (C). The critical factor here was the idea of empty space (vacuum) between the particles. Teachers in the PC category did not provide any clarification on this. For NEI, responses indicated continuous matter around the particles. A quarter of the teachers expressed no ideas about particles. Post intervention the distribution changes and the numbers of teachers who gave correct answers increase significantly for all physical states. The numbers of incorrect views have almost disappeared.

Given the differences in age and cognitive maturity a comparison between success rates for teachers and pupils would not be reasonable. However, compared to our pupil interventions there is an interesting difference in trends. In both pre and post tests, teachers' particle ideas varied from the solid to gas states in a different way to younger pupils. The teachers' resistance in accepting particle ideas is stronger for the solid state than the gas state; the difference is statistically significant [$\chi^2 = 226$, $p < 0.000$]. The opposite seems to hold true for pupils (Authors #1 & #3, 2005; Author #3, 1998a), who have more difficulty in accepting particle ideas for the gas state. The idea of 'nothing' between particles seems to be especially challenging for pupils. Macroscopically, pupils accept the solid and the liquid states, perhaps because they can see and feel them, but not the gas state, which is invisible. Thus, possibly it is easier for them to apply new ideas to something more familiar, like the solid state. With more macro-experiences the gas state may not be so mysterious for the teachers. Due to their education, teachers are likely to be more aware of the different properties of the three states, such as the compressibility of gas state. As a result they find it easier to conceive of a vacuum

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3 between the particles when the spaces are large. Gomez, Benarroch & Marin (2006), report
4 that the understanding of the high compressibility of gas state (compared to that of liquid
5 state) increases with the conceptualization of the particulate nature of matter and is related to
6 age (for ages 9 to 22).
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12 For pupils aged 11 – 14 years old, Author #3 (1998a) found that improvement in the
13 Macroscopic/Collective dimension was more difficult than in the Continuous/Particulate
14 dimension. Tasks 4 and 5 (Table 2) explored the macroscopic- collective dimension. First,
15 teachers were asked to describe and compare particles of the same substance (water) in
16 different states (task 4). For task 5 teachers were asked to go a little further and to do the same
17 for different substances (sugar, water and oxygen) in different states (at room temperature).
18 Here, the 'size' and 'shape' of particles, in addition to 'distance between particles' and
19 'motion' of particles, should be under consideration.
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32 Table 4 shows the categories and frequencies of teachers' responses to the two tasks.
33 Pre intervention, 40.7% were in category I for both 4a and 4b. These teachers clearly ascribed
34 macroscopic characteristics to the particles; i.e. solid, liquid and gas particles for the three
35 states, respectively. Post intervention, incorrect responses dropped to 7.4% of the teachers.
36 From 7.3% pre-intervention, the percentage of teachers answering correctly (for both 4a and
37 4b) rose to 53.7%.
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46 For task 5, pre-intervention, 46.3% were in category I for both 5a and 5b. These
47 teachers did not note differences in size and shape. Again, macroscopic properties were
48 emphasised; i.e., solid particles for sugar, liquid particles for water and gas particles for
49 oxygen. Post-intervention, a significant number, 19.8%, remained in category I for both 5a
50 and 5b. At 6.2% pre and 11.7% post intervention, the number in the correct category (for
51 both 5a and 5b) was much lower than for task 4. Comparing Tables 3 and 4, overall, the trend
52 is similar to those we have found with pupils (Author #3, 1998a; Author#1 & #3, 2005). The
53 macroscopic-collective dimension appears to be more difficult than the continuous-particulate
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3 dimension. Furthermore, appreciating that changes in motion and spacing alone (regardless of
4 individual particle 'physical' nature) are sufficient to explain different states appears to be
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6 easier for a change of state than different substances in different states.
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10 [Insert Table 4 about here]
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13 14 15 *Part II: Describing and explaining phenomena*

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17 Tables 5 and 6 present categories and frequencies of the teachers' responses to the
18 four phenomena addressed in Part II of the test. There are two components for each
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20 phenomenon: the description of the event and the explanation.
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24 25 26 27 *Melting*

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29 Initially, most of the teachers described the liquid as still being wax (category C).
30 Small numbers were either not definite in their answer (e.g. 'it is a liquid'- category PC) or
31 referred to different names (e.g. *it is water* -category I). Neither of these necessarily implies
32 that melted wax is being considered as a different substance. The former is a general
33 description and the latter could be using 'water' as a 'prototype' for the liquid state. Indeed,
34 the concept of a substance itself is not always clear for teachers (Author #1 et al., 2000) and
35 the non-conservation of substance identity seems to go against common sense (Author #3,
36 2000, 2002). However, relatively few (28 – 17.3 %) gave acceptable particle structures for the
37 solid and liquid states in their explanations. Post-instruction, all but one clearly identified the
38 liquid as wax and 146 (90.1%) gave a 'correct' particle explanation.
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52 [Insert Table 5 about here]
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56 57 58 *Boiling*

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60 Pre intervention, similarly to pupils' answers in other studies (e.g. Authors #1 & #3,
2005; Author #3, 1998b; Hatzinikita & Koulaidis, 1997; Osborne & Cosgrove, 1983; Paik,

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3 Kim, Cho & Park, 2004), most of the teachers gave 'alternative' ideas when asked about the
4 content of the bubbles in boiling water. The most frequent response was 'air' (39%, category
5 NEI). Some caution in interpretation is needed here since 'air' could be a general term for the
6 gas state (Author#3 & Other, 1996). For Greek people this might have additional reason to
7 hold true since the words 'air' and 'gas' are alike in Greek language: air is '*aeras*' and gas is
8 '*aerio*'. For category I, 26% suggested either oxygen or hydrogen or both. Rather than some
9 kind of separation, in some cases this could reflect a lack of distinction between the concepts
10 of mixture (oxygen and hydrogen) and chemical compound (water, a compound of oxygen
11 and hydrogen). Whatever some teachers might have meant, only 25% gave the 'simple'
12 answer that the bubbles were water in the gas state (water vapour was accepted). Post-
13 intervention, the ideas concerning 'oxygen and /or hydrogen' were abandoned, but 15%
14 persisted with 'air'. Most were in the correct category (68%).

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32 To explore the changes in structure between the liquid and gas states, the teachers
33 were asked to give particle pictures for three areas: inside boiling water (liquid state), inside
34 the bubbles (gas state) and just above the upper surface (where water is still in the gas state -
35 not where condensation would be seen). Pre-intervention, results show teachers having
36 significant problems with the structure in each area. Misconceptions noted in Part 1 (Table 3)
37 seemed to impact on their answers here (Table 5). Since most teachers assigned 'a gas' of
38 some kind to the content of the bubbles (i.e., water vapor, air or some other gas – task 7a) it
39 might be expected that the percentage giving a gas structure for inside a bubble would be
40 high. However, only 50% of the teachers, pre- intervention, gave the correct structure for the
41 bubble. Interestingly, 40% of these (20% of the total) did not give a correct gas state structure
42 for the area just above the upper surface of the liquid. This indicates that these teachers had
43 not understood a crucial part of the mechanism of the boiling: i.e., that the structure just above
44 the upper surface is the same as the bubbles since this is where the content of the bubbles is
45 released. Post-intervention the overall situation shows a statistically significant ($p<0.000$)

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3 improvement. In relation to the gas state, 91.2% of the teachers gave the correct structure for
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5 the bubbles and only 7.4% of these could not give the correct structure for just above the
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7 upper surface as well.
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10 11 12 *Evaporation*

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15 The difference between boiling and evaporation at room temperature can be described
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17 at the macroscopic level and the particulate level. As the particulate level is examined in tasks
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19 7a,b and 8b, the categorization in 8a considered the macroscopic level. For a correct response
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21 to 8a, answers were expected to address two criteria, explicitly or implicitly: i) that boiling
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23 takes place at a specific temperature whereas evaporation takes place over a range; ii) that the
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25 change takes place within the body of the liquid for boiling, whereas for evaporation it takes
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27 place at the surface. Pre-intervention, 43.2% of the teachers used both criteria for the
28
29 distinction between boiling and evaporation satisfactorily (category C) and 29% addressed
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31 one (category PC). Nearly all of the teachers in the latter category referred to the temperature.
32
33 Post-intervention, 91.4% fall in category C.
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39 Pre-intervention, very few teachers could use particle ideas to explain evaporation at
40
41 room temperature (task 8b). Only 6 cases (0.3%) approached scientific thought (category C)
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43 using elements and terms from kinetic theory. These answers referred to a distribution of
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45 energy and the escape (individually) of high energy particles to mix in with the air particles.
46
47 Those placed in category PC (0.4%) implied this process, but without reference to energy
48
49 distribution and the mixing with air particles. The majority (81%) of teachers gave
50
51 insufficient general descriptions (NEI). Many of these were tautologies (e.g. 'evaporation
52
53 happens when a liquid evaporates', or 'evaporation happens when a liquid goes to the gas
54
55 state'). Thus far, the teachers' formal science education (at least in Greece) seems to have
56
57 been quite ineffective with regard to understanding this common phenomenon. Post-
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59 intervention, increases to 33% for the category C and 43% for PC indicate a positive effect of
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3 the training course. However, it is quite clear that the challenge posed by evaporation at room
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5 temperature requires further attention.
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8 [Insert Table 6 about here]
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10 11 12 *Condensation*

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15 In contrast to pupils (e.g. Authors #1 & #3, 2005; Author #3, 1998c; Bar & Travis,
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17 1991; Hatzinikita & Koulaidis, 1997; Paik, Kim, Cho & Park, 2004), the majority of the
18
19 teachers seemed to appreciate that droplets appearing on a cold surface are water. Pre-
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21 intervention, 68% gave the correct answer, rising to 91% post-intervention. This could also be
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23 related to their richer everyday experiences compared to those of pupils. However,
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25 explanation is more problematic. Both, before and after the course, the large majority were in
26
27 the PC category, 80% and 77% respectively. Here, responses acknowledged the role of the
28
29 decreased temperature but went no further. Only one teacher pre-intervention and 22 post are
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31 in category C. This required links between the temperature decrease, loss of particle energy
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33 and the grouping together of (water) particles to give droplets in the liquid state. In
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35 comparison to pupils (e.g. Authors #1 & #3, 2005; Author #3, 1998c; Paik, Kim, Cho & Park,
36
37 2004), notwithstanding the teachers' greater comfort with the gas state (Part I) and their
38
39 appreciation that the condensation is water, they also seem to have difficulty in explaining the
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41 phenomenon. As with evaporation at room temperature, condensation of atmospheric water
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43 seems to need further attention.
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53 *Statistical Analysis*

54 *The effect of the development of particle ideas*

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57 The relationships between particle model scores in Part I and description/explanation
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59 of phenomena scores in Part II were tested by correlation analysis. Treating the
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3 continuous/particulate and macroscopic/collective dimensions separately, Table 7 gives the
4
5 calculated Spearman's rho correlation coefficients.
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8 [Insert Table 7 about here]
9

10 Pre-intervention for the continuous/particulate dimension, correlation coefficients
11 range from 0.16 to 0.58 and are all statistically significant. For the macroscopic/ collective
12 dimension the correlations are generally lower and are not significant for melting and
13 condensation. The latter lower correlations are not unexpected. Teachers holding weak
14 particle models, which do not regard the particles as being the substance, would not
15 necessarily think there would be any differences between individual particles for different
16 states and substances. Their models have little explanatory power but they could still score on
17 the measure of the macroscopic/collective dimension. About a third of the teachers had higher
18 scores on the macroscopic/ collective dimension than the continuous/particulate dimension.
19 Overall, the pre-intervention correlations give some indication of a relationship between the
20 nature of a person's particle model and its contribution to understanding physical phenomena.
21 Stronger indications have emerged in an analogous study with pupils, which used interviews
22 to probe thinking (Author #1 & #3, 2005). Post-intervention correlations are much lower but
23 this is probably a function of the much larger numbers of high scores all round.
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43 To further explore any relationship between the particle model dimensions and
44 understanding physical phenomena, lowest and highest achievement groups of teachers for
45 each dimension were selected for a two-way ANOVA. Each lowest-achievement group
46 includes every case with achievement score lower than $M-3SE$, and each highest-achievement
47 group includes every case with achievement score higher than $M+3SE$, where M is the mean
48 achievement and SE is the standard error of score distribution. For the continuous/particulate
49 dimension the lower and higher groups numbered 73 and 62 respectively. The parallel
50 numbers for the macroscopic/collective dimension are 83 and 54. A two-way ANOVA was
51 carried out using the total achievement score on physical phenomena as the dependent
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Running head: **Primary Teachers' Ideas of Physical Phenomena**

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3 variable with Continuous/Particulate and Macroscopic/Collective as independent variables.
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5 Results are shown in Table 8 for the pre-intervention scores. Levene's test does not reject the
6
7 equality of variances ($p=0.84$), thus accuracy in the final statistical test is expected. The two-
8
9 way ANOVA for pre-intervention test [$F(3,108)=30.4, p < 0.000$] explained 44.3% (Adj. R²
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11 0.44) of the total variance: The main effect of the Particulate dimension is statistically
12
13 significant and it explained 36.2% of the variance [$F(1,108)=61.1, p < 0.000$]. The main
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15 effect of Collective dimension is statistically significant but very small - it explained 4.1% of
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17 the variance [$F(1, 108)=4.57, p < 0.035$]. Interaction effects of Particulate x Collective were
18
19 not statistically significant.
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24 [Insert Table 8 about here]

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27 The above provides further support to the suggestion that understanding physical
28
29 phenomena is related to understanding the particulate theory of substances. The relationship is
30
31 only apparent in the pre-intervention measures, which reflect residual knowledge left from the
32
33 teachers' formal education. This association is not too surprising. Those holding a weak
34
35 particle model are not likely to find it useful for explanations. The key issue is the direction of
36
37 any causality. Does particle theory open up the understanding of physical phenomena or vice
38
39 versa? Our data do not provide any evidence either way. The large effect of the intervention
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41 obscures any relationship in the post-intervention scores.
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48 *Which teachers benefited from the course?*

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51 To give the overall picture, Figure 2 shows the distributions of the teachers' total
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53 scores for the pre and post tests. The effectiveness of the intervention per task is shown in
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55 Table 9. For each task the difference between pre-test/ post-test mean scores is statistically
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57 significant ($p < 0.0001$). In addition, the effect sizes (Type error II) estimated by using
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59 Pearson's r -values (Field, 2001; Rosenthal, Rosnow & Rubin, 2000) indicate that the
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magnitudes of these changes were substantial. Overall, the effect size on the total score is 0.89. Nonparametric tests, such as Wilcoxon Signed-Ranks test led to the same conclusions.

[Insert Figure 2 about here] and [Insert Table 9 about here]

The Spearman's rho correlation coefficient between pre-intervention and post-intervention total test scores is 0.05. Previous understanding is not a good predictor of success. Figure 3 depicts the changes between pre and post course performance in more detail. The different fill patterns labeled A, B, C, D and E represent the 15th, 35th, 50th, 65th and 85th percentiles of the post course scores respectively. With the pre-intervention scores divided into five bands, the shading patterns indicate the achievements of the teachers in each pre-course score band. All percentile destinations on the post test are found for each score band on the pre-test.

[Insert Figure 3 about here]

Effect of gender and teaching experience

Table 10 compares the test means for males and females. For both pre and post intervention there are no significant gender differences. To test the effect of teaching experience, lowest and highest experience groups were selected. The lowest-experienced group (LExp) includes all cases with teaching experience lower than $M-3SE$, and the highest-experienced group (HExp) includes all cases with teaching experience higher than $M+3SE$, where M is the mean teaching experience and SE is the standard error.

[Insert Table 10 about here]

Comparing the test means for these two groups, table 10 shows a significant effect of teaching experience on the post-intervention test. Even though the lowest-experienced group (LExp) and highest experienced group (HExp) scored equivalently in the pre-intervention test, post-intervention, the HExp group scored significantly lower ($p < 0.05$). The most experienced/ oldest teachers showed less progress, that is, the resistance to conceptual change

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3 was greater. This may indicate that less experienced teachers' ideas are less consolidated and
4 more easily changed (Sakonidis, Kaldrimidou & Tzekaki, 2006) or reflect more general
5 differences between attitude to change and age (Hewstone & Stroebe, 2001). However,
6 although statistically significant, the difference between the experience groups is small in
7 comparison to the overall progress made by both groups.
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17 **Conclusions**

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20 The pre-intervention test showed that the primary teachers did not have a secure
21 understanding of the physical phenomena and appeared to hold misconceptions similar to
22 those that would be expected of their pupils. It seems reasonable to suppose that their thinking
23 dates back to when they, themselves, were pupils. Furthermore, their experience of teaching
24 these topics does not seem to have engendered any significant conceptual changes. There is
25 nothing in the literature to suggest these teachers are atypical. A vicious cycle appears to be
26 operating which allows misconceptions to persist from generation to generation. In an attempt
27 to break this cycle, we have used a new conceptual approach to introducing the particle model
28 in the context of physical changes. **In this approach particle ideas are introduced within a
29 substance-based framework rather than a 'solids, liquids and gases' framework. The focus is
30 on explaining why a substance can be in any of the three states.** Overall, the progress made by
31 the teachers was encouraging. In comparison to in-service courses adopting constructivist
32 teaching methodology within a 'solids, liquids and gases' approach we cannot say whether
33 progress is better or worse. However, we would argue that our intervention has addressed
34 important ideas, which teachers can take to and which offer the chance of breaking the cycle.
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The almost zero correlation between the pre and post scores is in keeping with the course
providing a new conceptual approach. As might be expected, the more experienced teachers
were found to be more resistant to change but the effect was not large. Many of the older
teachers did make good progress.

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However, good progress is not complete progress. The teachers made the better progress with melting and boiling. For these changes of state, the taught model considered the particle energy collectively without reference to energy distribution. Melting was explained by the particles having enough energy to partially overcome the hold between particles. Boiling was explained by the particles having enough energy to completely overcome the hold. For a beaker of boiling water, the emphasis was on the water being in the gas state (the bubbles). The idea that enough water particles have enough energy (i.e. drawing on ideas of energy distribution) was not addressed. However, for evaporation below boiling point, ideas of energy distribution were introduced as a development of the particle model. This proved to be more difficult. Many teachers did not adopt ideas of energy distribution to explain room temperature evaporation. Similar difficulties have transpired in our work with primary pupils (Author#3 & #1). However, a 'reduced' model where room temperature evaporation is explained by bombarding air particles 'knocking out' water particles (without reference to energy) had more appeal. The parallel, here, is with dissolving rather than a change of state. This does make a distinction from boiling and perhaps is sufficient for primary level. Identifying the condensation on a cold object as water was generally not a problem (pre and post). This implies appreciation that water exists within the air and this may be related to the teachers' willingness to accept the gas state. However, for most, the mechanism for condensation proved challenging. Understanding how water can exist as part of a gaseous mixture at room temperature and how this behaves on cooling is not easy. In addition to energy distribution, the idea of a balance between competing processes is also required: the chances of lower energy water particles meeting up versus the chances of clusters being broken up by higher energy particles (most likely air). After one intervention it is too early to judge whether such ideas are beyond most primary teachers and whether explaining the condensation of atmospheric water should be the preserve of specialist science teachers in secondary schools. The appropriateness for the primary curriculum is very doubtful.

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Notwithstanding issues surrounding mixtures of air and water, at the core of our approach is the use of the particle model to explain substances and their states. Our findings suggest this is accessible to primary pupils and their teachers. Like others (e.g. Jarvis, Pell & Mckee, 2003) we would recommend continuous in-service training programs where ideas could be revisited. Such programs should start as soon as teachers enter the classroom. There seems to be no advantage in waiting for teachers to gain some classroom experience. Furthermore, the present intervention course was focused on prerequisite content knowledge and attention should move on to enhancing pedagogical content knowledge (Boz & Boz, 2008; Grossman, 1990; Park & Oliver, 2008). A frequent reinforcement and development of the relevant ideas holds the potential for better teaching. Perhaps, in time, it might be possible to tip the vicious cycle into a virtuous cycle.

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Running head: **Primary Teachers' Ideas of Physical Phenomena**

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3 Table 1. Outline of content of the teaching scheme concerning physical changes.
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5 **1. Properties and the material/object distinction**

6 Some properties depend on the material only.

7 Some properties depend on the material, the amount (dimensions of an object) and the
8 shape/structure of an object.
9

10 **2. Definition of a substance.**

11 Melting behaviour can be used to distinguish between a pure sample of a substance and a
12 mixture of substances.
13

14 **3. A simple particle model**

15 Particle ideas can explain melting.

16 A sample of a substance was presented as a collection of particles with empty space between.

17 Key points were:

- 18
- 19 • The particles have an ability to 'hold on' to each other:
 - 20 • They are always moving in some way (energy of movement): and
 - 21 • The particles of a particular substance remain the same in a change of state.
- 22
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24 **4. A sample of a substance could be in one of three states.**

25 A sample of a substance can be in the gas state.

26 Explanations for the phenomena of melting and boiling

27 Why different substances can be in different states at room temperature.
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29 **5. Mixing and unmixing.**

30 Distribution of energy among the particles of a substance.

31 Evaporation below boiling point into the air.

32 Condensation of atmospheric water vapour.
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Table 2. Description of the instrument. Parts and tasks.

Parts	Description of Parts	Tasks	Description of Tasks
I	<i>Particulate- Continuous</i>	Solid state	1 Description of what can be seen inside a grain of sugar, if it could be magnified a huge amount. ¹
		Liquid state	2 Description of what can be seen inside a drop of water, if it could be magnified a huge amount. ¹
		Gas state	3 Description of what can be seen inside a spotted area of oxygen (in gas state in a vase), if it could be magnified a huge amount. ¹
	<i>Macroscopic- Collective</i>	Same Substance in different states	4 Description and comparison between single particles of water in the three states. ²
		Different substances in different states at room temp.	5 Description and comparison between single particles of sugar, water and a gas in room temperature. ²
II	Physical Phenomena	Melting	6 Description and comparison between the two states of wax during melting, i.e., before and after melting. ³
		Boiling	7 Description and comparison among three areas of boiling water, i.e., the liquid area, inside a bubble and upper the surface of boiling water. ⁴
		Evaporation	8 Description /explanation of evaporation of water. ⁵
		Condensation	9 Description /explanation of condensation of water on a cool surface. ⁶

- Teachers were asked to draw a relevant picture and to explain what they draw: There were some pictures given in order to stimulate their imagination (Figure 1). Teachers could pick up one of these pictures or draw their own, in case none of these satisfied them. In any case teachers should explain what the picture presents indicating and naming any part of the picture.
- Teachers were asked to answer this question only if there were a reference to particles in their previous answers. Otherwise, they encouraged to proceed to part II.
- A macroscopic description of a piece of wax melting is given as stimulus. Teachers were asked to name the material after melting and to describe the structure of wax before and after melting drawing corresponding microscopic picture (teachers could also use pictures of Figure 1).
- A macroscopic picture of boiling water inside a beaker is given as stimulus. Teachers were asked to name the material in the liquid area, inside a bubble and right upper the surface of boiling water and to describe the structure of these three areas drawing corresponding microscopic pictures (teachers could also use pictures of Figure 1).
- A macroscopic description of evaporation (below boiling point) of water is given as stimulus. Teachers were asked to describe and explain the phenomenon of evaporation (of water), as well as, to make a distinction between boiling and evaporation.
- A macroscopic description of the formation of drops on a cool surface of a can is given as stimulus. Teachers were asked to name the material of drops and give explanations for their formation.

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Table 3. Categories of teachers' responses (n=162) in Continuous/Particulate dimension. Pre- and post-intervention frequencies* for substances in the three states of matter at room temperature.

Category	Score	Solid		Liquid		Gas	
		<i>Pre</i>	<i>Post</i>	<i>Pre</i>	<i>Post</i>	<i>Pre</i>	<i>Post</i>
I	0	48	6	37	0	40	1
NEI	1	82	24	67	9	21	14
PC	2	25	75	43	77	74	64
C	3	7	67	15	76	27	83

C (correct)= complete picture of microscopic structure.

PC (partially correct)= notion of particles but not clearly address the nature of the free space.

NEI (not entirely incorrect)= particles in continuous matter.

I (incorrect)= continuous matter, irrelevant or no answer

* Pre - post comparisons: Solid= [$\chi^2 = 692, p < 0.0000$], Liquid=[$\chi^2 = 325, p < 0.0000$],

Gas= [$\chi^2 = 119, p < 0.0000$].

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Table 4. Categories of teachers' responses in Macroscopic-Collective dimension. Pre- and post-intervention frequencies* (n=162).

Task	Category	Score	Frequencies	
			<i>Pre intervention</i>	<i>Post intervention</i>
4a- Comparison between particles in different states (Same substance)	I	0	75	16
	PC	1	43	28
	C	2	44	118
4b- Description of particles in different states (Same substance)	I	0	118	34
	PC	1	17	25
	C	2	27	103
5a- Comparison between particles in different states (Different substances)	I	0	100	76
	NEI	1	17	10
	PC	2	10	16
	C	3	35	60
5b- Description of particles in different states (Different substances)	I	0	114	62
	NEI	1	11	49
	PC	2	37	32
	C	3	0	19
4a,b	C (correct)= Single particles of ice/water/vapor same – Differences specified in relevant distances and motions. PC (partially correct)= Single particles of ice/water/vapor are alike in shape (size) but have different size (shape). Differences also reported in relevant distances and/or motions (poor justification). I (incorrect)= macroscopic character on particles (or no answer).			
5a,b	C (correct)= single particles of different substances are different in size and shape (complete justification) – Differences also reported in relevant distances and motions. PC (partially correct)= single particles of different substances are different (poor justification or no justification). NEI (not entirely incorrect)= single particles of different substances are different (the difference in the state prevails), I (incorrect)= macroscopic character on particles (or no answer).			
* Pre - post comparisons: 4a= [$\chi^2 = 272.0, p < 0.000$], 4b=[$\chi^2 = 266.1, p < 0.000$], 5a= [$\chi^2 = 25.1, p < 0.000$], 5b=[$\chi^2 = 73.9, p < 0.000$]				

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Table 5. Categories of teachers' descriptions concerning melting wax and boiling of water (n=162). Pre- and post-intervention frequencies.

Task	Category	Score	Frequencies	
			<i>Pre intervention</i>	<i>Post intervention</i>
6a- Identity of the melted wax	I	0	20	0
	PC	1	12	1
	C	2	130	161
6b- Structure of the substance before and after melting	I	0	32	3
	NEI	1	38	3
	PC	2	64	10
	C	3	28	146
7a- The content of the bubbles	I	0	42	2
	NEI	1	63	24
	PC	2	12	26
	C	3	45	110
7b - Structure of liquid and gas states	I	0	57	7
	NEI	1	40	6
	PC	2	22	16
	C	3	43	133
6a	C (correct)= same substance in liquid state.			
	PC (partially correct)= not definitely same substance.			
	I (incorrect)= different substance (or no answer).			
6b	C (correct)= correct structure for both solid (pre) and liquid (after melting) states.			
	PC (partially correct)= correct structure of one state and not clearly specified structure of the other.			
	NEI (not entirely incorrect)= not clearly specified structure for both states.			
	I (incorrect)= incorrect structure for both states (or no answer).			
7a	C (correct)= water in gas state.			
	PC (partially correct)= reference to a gas, not clearly water vapor.			
	NEI (not entirely incorrect)= air.			
	I (incorrect)= oxygen and or hydrogen (or no answer).			
7b	C (correct)= correct structure for both liquid and gas states.			
	PC (partially correct)= correct structure of one state and not clearly specified structure of the other.			
	NEI (not entirely incorrect)= not clearly specified structure for both states.			
	I (incorrect)= incorrect structure for both states (or no answer).			

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Table 6. Categories of teachers' descriptions of evaporation and condensation (n=162). Pre- and post-intervention frequencies.

Task	Category	Score	Frequencies	
			<i>Pre intervention</i>	<i>Post intervention</i>
8a- Differences between evaporation and boiling	I	0	43	3
	NEI	1	2	0
	PC	2	47	11
	C	3	70	148
8b- Explanations concerning evaporation mechanism	I	0	18	4
	NEI	1	131	36
	PC	2	7	69
	C	3	6	53
9a- The nature of the condensed drops	I	0	2	0
	NEI	1	21	8
	PC	2	28	7
	C	3	111	147
9b- Explanations concerning condensation mechanism	I	0	7	2
	NEI	1	24	13
	PC	2	130	125
	C	3	1	22

8a C (correct)= boiling addresses the whole mass at 100 °C, evaporation occurs at the surface at room temp.

PC (partially correct) = partially complete (address one of the above differences).

NEI (not entirely incorrect) = not entirely incorrect (e.g. boiling needs heat).

I (incorrect) = incorrect, irrelevant or no answer.

8b C (correct) = scientific view, implementing notion of kinetic energy.

PC (partially correct) = approach of science view without use of scientific terms.

NEI (not entirely incorrect) = not entirely incorrect (no provision of mechanism).

I (incorrect) = incorrect/irrelevant answer or no answer.

9a C (correct) = water (in liquid state).

PC (partially correct) = water vapor (instead of water).

NEI (not entirely incorrect) = air/oxygen.

I (incorrect) = incorrect/irrelevant answer or no answer.

9b C (correct) = explanation in terms of kinetic energy decrease.

PC (partially correct) = Acknowledge the role of temperature implementing no scientific terms.

NEI (not entirely incorrect) = Using tautologies (with or without mentioning temperature).

I (incorrect) = incorrect/irrelevant answer or no answer.

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Table 7. Correlation analysis (n=162) of the Continuous/Particulate and the Macroscopic/Collective dimension with the achievement in explaining physical phenomena.

Spearman's rho	Dimension	Melting	Boiling	Evaporation	Condensation	Total
Correlations						
Pre Intervention	<i>Particulate</i>	0.44**	0.46**	0.26**	0.16*	0.58**
	<i>Collective</i>	0.07	0.28**	0.29**	0.05	0.32**
Post Intervention	<i>Particulate</i>	0.20*	-0.11	0.20*	0.19*	0.14
	<i>Collective</i>	0.14	0.11	0.15	0.16*	0.24**

** $p < 0.01$; * $p < 0.05$

Table 8. Two-way ANOVA: (Pre intervention).

Tests of Between-Subjects Effects: Dependent Variable: Pre-intervention scores						
Source	Type III Sum of Squares	df	Mean Square	F	p	
Corrected Model	614.6623	3	204.8874	30.37	0.000	
Intercept	20881.07	1	20881.07	30.95	0.000	
Particulate	412.2559	1	412.2559	61.12	0.000	
Collective	30.84193	1	30.84193	4.57	0.035	
Particulate x Collective	8.418619	1	8.418619	1.25	0.266	
Error	728.4449	108	6.74486			
Total	24372	112				
Corrected Total	1343.107	111				

R Squared = 0.458 (Adjusted R Squared =0.443)

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Table 9. Teachers' mean scores and standard deviations expressed as percent achievement in all tasks. T-test between pre-intervention and post-intervention scores and the effect size.

	<i>Pre Intervention</i>		<i>Post Intervention</i>		<i>T-test</i>	<i>Effect size</i>
	Mean	SD	Mean	SD	<i>t</i>	<i>r</i>
Particulate	35.7	21.6	73.6	19.6	-15.4*	0.77
Collective	26.5	24.1	54.8	25.4	-12.2*	0.69
Melting	64.4	25.0	96.8	10.7	-15.6*	0.78
Boiling	44.8	28.7	86.7	21.1	-16.4*	0.79
Evaporation	53.5	20.6	85.9	13.2	-18.7*	0.83
Condensation	71.7	15.8	81.5	13.4	-6.0*	0.42
Total	44.5	14.2	76.5	10.1	-24.1*	0.89

* $p < 0.0001$

Table 10. The effects of teaching experiences and gender on the % total achievement score.

Total score		N	Mean	SD*	<i>T-test</i>		<i>Effect size</i>
					<i>t</i>	<i>p</i>	<i>r</i>
Pre intervention	Male/ Female	68/94	46.6/ 42.8	14.3/ 14.2	1.66	0.098	0.13
	Lexp/ Hexp	52/42	40.9/ 46.6	13.6/ 13.6	-1.97	0.052	0.20
Post intervention	Male/ Female	68/94	76.2/76.6	10.6/ 9.8	-0.23	0.821	0.02
	Lexp/ Hexp	52/42	78.5/73.0	9.8/ 11.1	2.46	0.016	0.26

* In all cases, Levene's test does not reject the equality of variances.

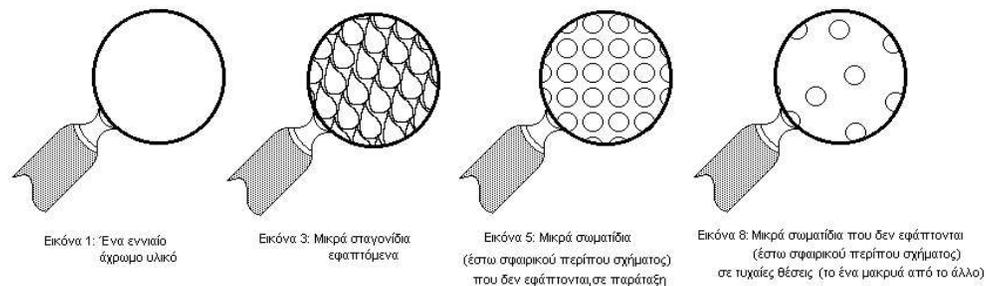


Figure 1: Some of the pictures, which were included in the test as a stimulus. Clarifications on what the picture presents, are also given below the pictures. [Picture 1: A continuous colourless material, Picture 3: Small droplets, the one touch on the other, Picture 5: particles (like small spheres, the one does not touch on the other, in certain positions), Picture 8: particles (like small spheres, the one away from the other, in random positions)]
224x69mm (96 x 96 DPI)

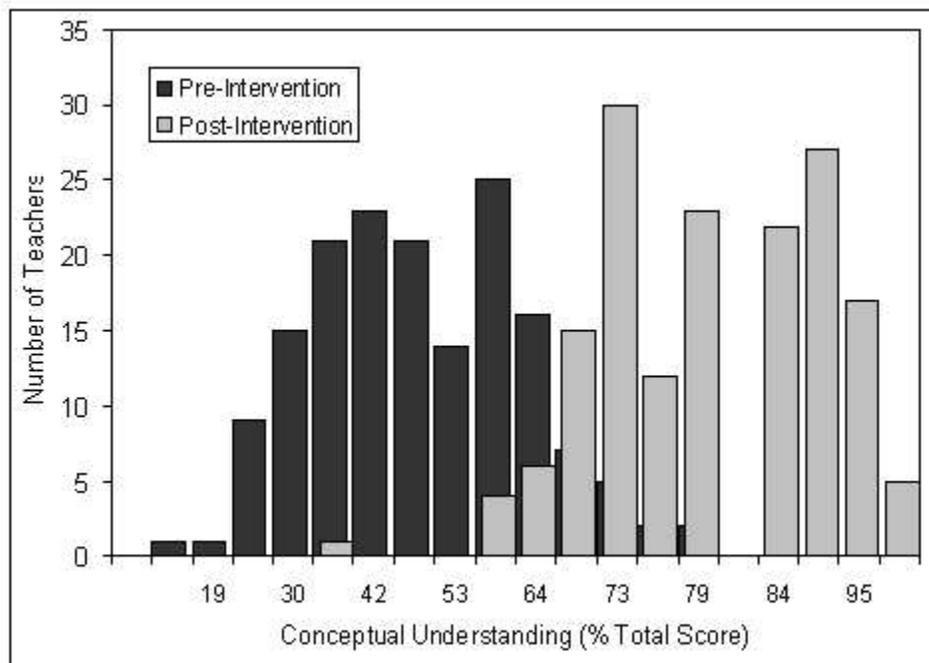


Figure 2: Distribution of total score for pre-intervention and post-intervention tests.
127x90mm (96 x 96 DPI)

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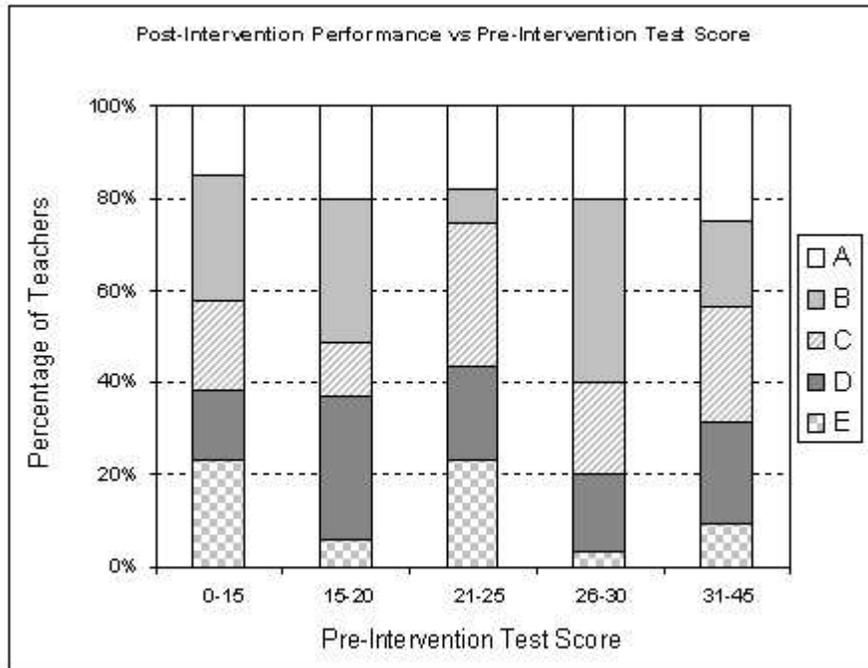


Figure 3: Post-intervention performance versus pre-intervention tests scores. 119x91mm (96 x 96 DPI)

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