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Primary Teachers' Understanding of Four Chemical Phenomena: Effect of an In-Service Training Course

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Abstract One hundred and thirty Greek primary school teachers participated in a study, where the effectiveness of a specially designed intervention on chemical changes was tested. The study took place in the wider context of an in-service training course where the key feature was an innovative approach based on the concept of a substance and its transformations, physical and chemical. In the present paper the focus is on the chemical transformations of substances. Pre-intervention, teachers were found to have a relatively limited ability in explaining chemical changes, which depends on the characteristics of the particular change, and they held a number of misconceptions similar to those of pupils. Post-intervention, teachers' descriptions and explanations were found to be significantly improved. Also, a relationship between teachers' particle ideas and their explanations was found. Implications for science education are also discussed.

Keywords Primary teachers · Particle ideas · Chemical phenomena · In-service training

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Introduction

The Introduction of Chemical Changes in Primary Schools

There has been recent discussion about the most appropriate age for the introduction of the concept of chemical change in the science curriculum and how to teach chemical change (e.g. Papageorgiou et al. 2010; Franco and Taber 2009; Liu and Lesniak 2006; Wiser and Smith 2008). The issue is complicated by the primary secondary transition which falls at different ages in different countries. For example, in England, students transfer at age 11, whereas the transfer in Greece is a year later at 12—Developmentally, the average 11 year old is not the same as the average 12 year old. Practically, in both England and Greece, primary schools do not have the specialised science laboratories of their secondary counterparts. Moreover, only few primary school teachers have higher level specialist science qualifications in chemistry, biology, physics or geology.

Central to this discussion are the results of many studies, which cover a range of ages from primary school through to undergraduate (e.g. Ahtee and Varjola 1998; Andersson 1990; Johnson 2000, 2002; Boo and Watson 2001; Brosnan and Reynolds 2001; Çalik and Ayas 2005; Cokelez et al. 2008; Driver 1985; Solsona Izquierdo and De Jong 2003; Stains and Talanquer 2008; Stavridou and Solomonidou 1998). Common to all of these studies is that chemical change seems to be a very challenging idea for the majority of students. Therefore, there is skepticism on whether we could teach primary pupils about chemical changes effectively at ages 11/12, let alone ages 10/11. However, a recent study (Papageorgiou et al. 2010) provides some empirical evidence to suggest that an appropriate context and teaching methodology can help upper primary students (ages 11/12) in understanding the idea of a chemical change. The study found that those who could understand the idea of a substance in terms of particle ideas had an increased chance of understanding chemical changes at the macroscopic level to a satisfactory degree. Of course, this does not necessarily mean that all pupils who can develop particle ideas can also understand the idea of chemical change. Nevertheless, these results do provide evidence showing that a number of students, who developed particle ideas to a high level, could also satisfactorily understand chemical changes at the macroscopic level. As Wiser and Smith (2008) argue, we should not underestimate the capacity of young pupils to work with simple particle models. Even if the teaching of particle ideas is only appropriate for the most able students, as Georgousi et al. (2001) recommend, the construction of the idea of chemical change in primary schools for some students, especially at ages 11/12, cannot be excluded as a possibility. Accepting this, the question shifts to the teachers. Are primary teachers ready to teach chemical changes? Can they understand chemical changes and to what extent?

Primary Teachers' Understanding of Chemical Change

There is little in the literature about pre- or in-service primary teachers' ideas on chemistry topics and more specifically their ideas on chemical changes. However, there are studies on related topics.

For example, it is known that prospective primary teachers have difficulties with concepts relating to matter and its composition, which are fundamental to understanding chemical change. According to del Pozo (2001), teachers' ideas about substance, element, compound, mixture, atom and molecule are limited or confused, resulting in the formation of incorrect, incomplete or misleading connections such as associations like element-atom or compound-molecule. Similarly, in a study for in-service primary teachers concerning such concepts (Papageorgiou and Sakka 2000), teachers displayed limited or superficial understanding. In responses they mainly resorted to reproducing the knowledge provided by school textbooks, which in many cases was associated with sensory ideas, e.g. *matter is anything is around us and/or we can sense*. Thus, they often failed to draw correct connections between the concepts. Limited knowledge and misconceptions of primary teachers also pertain to concepts dealing with the nature and the properties of substances. In a study on prospective primary teachers Kokkotas et al. (1998) found a significant lack of scientific knowledge concerning the particulate nature of substances, the existence of particles and their behaviour during changes like the thermal expansion of a sample in the gas state. Similarly, lack of scientific knowledge is also reported in studies on in-service primary teachers concerning changes of state or dissolving (e.g. Papageorgiou et al. 2010; Jarvis et al. 2003).

Studies on chemical changes have been mostly for prospective secondary chemistry or general science teachers (e.g. Çalık and Ayas 2005; Cheung et al. 2009; Haider 1997; Ozmen 2008; Stains and Talanquer 2008). Although many of these studies are focused on specific aspects of chemical change such as the conservation of matter, the classification of chemical changes, chemical equilibrium and so on, a common outcome is the lack of a satisfying understanding of chemical changes and a number of misconceptions for a significant number of teachers. For example, Çalik and Ayas (2005) report a number of teachers who cannot even recognize a chemical change, they retain an incomplete view of the phenomenon when invisible substances are involved, or they cannot apply their knowledge to unknown cases of chemical changes.

Interestingly, studies have noted the many similarities between teachers subjects' science knowledge and students' misconceptions at both primary and secondary level (Papageorgiou et al. 2010; Boz and Boz 2008; Çalik and Ayas 2005; Kokkotas et al. 1998). Putting the pieces together gives a picture of misconceptions held in school years being carried through pre-service training and into teaching careers. Subject matter knowledge is one of the main components of pedagogical content knowledge (Shulman 1987) and the lack of a satisfactory level of understanding of basic science knowledge will have a negative effect on the quality of teaching as a whole. A teacher cannot promote a creative classroom discourse and in fact he becomes a source of misconceptions and confusion.

Acknowledging the importance of teachers' subject matter knowledge development, a number of pre- and in-service training interventions have been undertaken. However, results indicate only a limited improvement in teachers' subject knowledge and the problems appearing to persist (e.g. Appleton 2002, 2003; Papageorgiou and Sakka 2000; Papageorgiou et al. 2007; Jarvis et al. 2003; Murphy et al. 2007). Most of these interventions, both pre- and in-service, were commonly designed on the basis of a constructivist teaching methodology and the extent to which such interventions adopted important innovations in the teaching content was not always clear (e.g. Çalik 2008; Javis and Pell 2004; Liang and Gabel 2005; Schibeci and Hickey 2000; Summers 1992). This paper concerns an in-service training course for primary teachers where the focus was on a rethinking of the science knowledge teaching content.

The Training Course

The rationale behind rethinking the content of an introduction to the science of the material world has been explicitly presented in a recent paper (Johnson and Papageorgiou 2010). To summarise, since physical and chemical changes involve substances, the approach is based on the concept of a substance as the key organising idea. This is in contrast to the more usual approach based on 'solids, liquids and gases'. We have argued that the 'solid, liquids and gases' approach is the cause of many misconceptions. Most damagingly, the notion that 'solids', 'liquids' and 'gases' are three separate types of matter. Key premises of the 'substance' approach are:

- A sample of a substance can be in the solid, liquid or gas states depending on its temperature and its melting and boiling points.
- The distinction between a substance and materials which are mixtures of substances should be made clear (e.g. mixtures do not have precise melting points).
- The particle model is integral to the construction of the concept of a substance. When introduced, particles should be identified with substances (rather than generic states of matter).
- Two levels of particle model should be distinguished. A general level which talks of the particles of a substance and a deeper level which identifies substances with arrangements of atoms. 'Basic' substance particles can explain changes of state and mixing, atoms are needed to explain the possibility of chemical change.

Within this framework, a training course was designed in two parts. The first part developed the concept of a substance and a 'basic' particle model to explain physical phenomena (including changes of states). Findings from this first part have already been presented (Papageorgiou et al. 2010). In this paper we report the findings from the second part which focussed on the implications of the key concept of a substance on the understanding of chemical changes.

The design of the in-service primary teacher course was also informed by similar content that has been used with Greek primary pupils (Papageorgiou and Johnson 2005; Papageorgiou et al. 2008, 2010). Table 1 outlines the content covered by the two parts of the course.

In sections 1–5 (Table 1), a 'basic' particle model is introduced to explain why a sample of a substance could change between the solid and liquid states. Importantly, the model introduces the idea of the particles having an 'ability to hold on to each other' and different strengths of 'hold' to explain different melting points. 'Hold'

Table 1 Outline of the content of the teaching scheme

Part I
1. Properties and the material/object distinction
Some properties depend on the material only
Some properties depend on the material, the amount (dimensions of an object) and the shape/structure of an object
2. Definition of a substance
Melting behaviour can be used to distinguish between a pure sample of a substance and a mixture of substances
3. A simple particle model
Particle ideas can explain melting
A sample of a substance was presented as a collection of particles with empty space between. Key points were:
The particles have an ability to 'hold on' to each other
They are always moving in some way (energy of movement)
The particles of a particular substance remain the same in a change of state
4. A sample of a substance could be in one of three states
A sample of a substance can be in the gas state
Explanations for the phenomena of boiling
Why different substances can be in different states at room temperature
5. Mixing and unmixing
Distribution of energy among the particles of a substance
Evaporation below boiling point into the air
Condensation of atmospheric water vapour
Part II
6. The structure of the substances
Introduction of the three types of particles (atoms, ions, molecules)
What the atom is
What the bond is
Molecular and giant structure—what the molecule is
Elements and compounds
7. The chemical change
Some changes lead to the formation of new substances
What a chemical change is (the example of sugar heating)
Chemical reactions and chemical equations
Studying the burning of a candle
8. Studying of some chemical reactions (macro-, micro-, symbolic levels)
Synthesis of iron sulphide
Electrolysis of water
Reaction between iron and copper sulphate (singe replacement)
Reaction between potassium iodide and silver nitrate (double replacement)
Reaction between copper and condensed nitric acid

rather than ‘attraction’ was used because ‘hold’ is more consistent with the idea of a bond as a balance between attraction and repulsion. The ‘ability to hold’ does not change with change of state and so this directs attention to the change in the energy of the particles rather than any change in the strength of attractions to explain a change of state. In section 4 the ideas are used to understand the gas state and explain boiling. In section 5 the idea of the random distribution of energy among the particles of a substance is introduced to explain evaporation below boiling point and condensation of water from air.

Section 6 is related to a closer look at the structure of substances. At that level, the particle model becomes more detailed and a distinction between atoms, molecules and ions is introduced. For the introduction of ions, a reference to the existence of electrons, protons and the corresponding balance of the charge inside the atom took place, but without an extended study of atomic structure. Thus, substances can also be categorised as ‘molecular substances’ or as ‘substances with a giant structure’ (Johnson and Papageorgiou 2010). When all atoms in a molecule or a giant structure are the same, the substance is an ‘element’. With two or more different atoms or ions, the substance is a ‘compound’. The initial concept of ‘hold’ is differentiated into ‘bond’ and ‘intermolecular force’. The word ‘bond’ is used for the strong holdings between atoms or between ions, whereas an ‘intermolecular force’ is a weaker hold between molecules. When bonds between atoms are broken and the formation of new bonds takes place, then chemical changes occur (section 7). How the formation of new substances can macroscopically be observed is also discussed with the help of the thermal decomposition of sugar as an example. Section 7 then studies the case of a burning candle in depth. The concept of a ‘chemical equation’ and its symbolic representation (using chemical symbols and formulas) are also introduced. Finally in section 8, some representative cases of chemical reactions are studied at the macroscopic, particulate and symbolic levels.

Methodology

The course was part of an in-service teachers’ professional development program under the direction of 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 open to Greek primary teachers with up to 25 years teaching experience, on a voluntary basis. In this context, the Democritus University of Thrace launched a 2-year program, where, among other courses, participants attended a 5 week (6 h per week) training course on basic concepts of chemistry. The whole course consisted of 30 1-h lessons; Half of the lessons covered Part I of Table 1 (the results are reported in Papageorgiou et al. 2010), and the remaining 15 h covered Part II of Table 1 on the structure of the substances and chemical change, which is the focus of this paper. The following two research questions are addressed:

- To what extent did this course and particularly Part II, improve primary teachers’ understanding of chemical changes?

- How did the particular characteristics of each one of four phenomena and the development of a deeper level of particle ideas affect the teachers' understanding of chemical phenomena?

In addition, commonalities with pupils' thinking were also evaluated.

Teaching

The teaching took place in nine independent locations, with a mean class size of 18 participants. All of the teaching was carried out by the first author.

Chemical reactions were studied through experiments that were performed by the trainer (1st author). For each of these, around two to three teachers were invited to participate (handling materials, heating etc.), while the rest observed. As with the physical changes in Part I, most of the teachers in each class did not volunteer, saying that they didn't feel comfortable with such experiments and preferred to watch. Only around 4–8 teachers in each class had direct involvement in one or more these demonstrations (basically, the same teachers as in Part I). However, almost all teachers participated fully in discussions on the observations and explanations.

Sample

Some teachers were absent for the completion of instruments to leave a sample of one hundred and thirty primary school teachers (56 male and 74 female) for the Part II study. All were working in primary schools in the area of East Macedonia and Thrace, Greece, and their teaching experience ranged from two to 20 years (mean 12.8 and SD = 4.3). The teachers had not participated in any similar in-service training programs previously. Their undergraduate studies on general science had been the only formal education on this matter. During their in-service teaching they would have acquired similar experiences, since all would have been using the same mandated textbook and guidance (Greek Pedagogical Institute 2003). That experience was quite limited on chemical changes, because these are only taught in a descriptive way in the context of the reactions between acids and bases to form salts. Although the concepts of atoms and molecules, together with the atom's components (protons, neutrons and electrons), are included in that textbook, they are not applied in the study of chemical changes.

Measurements and Instruments

Teachers answered a written test at the end of Part I (where 'basic' substance particles had been introduced—section 3 of Table 1) before the start of Part II. They answered the same test again 1 month after the course had finished. The test took about an hour to complete.

For chemical change, the test consisted of four tasks: a burning candle, hydrogen combustion, iron oxidation (rusting) and heating sugar (thermal decomposition of sugar). It is important to note that while a burning candle had been studied in depth during the course and the thermal decomposition of sugar had been also addressed in the teaching content, the other two examples of chemical change had not. In each one of the tasks, there was a general description of the experiment and in three of the tasks this was aided with a diagram (see Fig. 1—for rusting this was not considered necessary). Teachers were asked to say what happens at a macroscopic level and what the substances at the end of the experiment are. At a second level, teachers were asked to imagine magnifying a huge number of times each substance involved, before and after the experiment and draw what would be seen in a sub-microscopic view. Although teachers were free to choose the level of their representations (atomic, molecular, or sub-atomic) they were asked to specify the particles represented in their drawings (if they referred to any) and name the substance assigned. A presentation of the instrument tasks is given in Table 2.

Data Analysis

In each one of the tasks, teachers' answers were categorized according to their correctness by the authors (1st and 2nd). The agreement percentage after discussion and negotiation became 100 %. In each one of the tasks, a teacher's answers for the questions directed at the macroscopic level were taken together and placed in overall categories of: correct (C), partially correct (PC) and incorrect (I). Category C corresponds to recognition of each product and a satisfactory explanation for its formation. Category PC corresponds to recognition of each product, but the explanation for its formation is incomplete, unclear or incorrect. In category I, at least one of the products is not recognisable or there is no answer. Similarly,

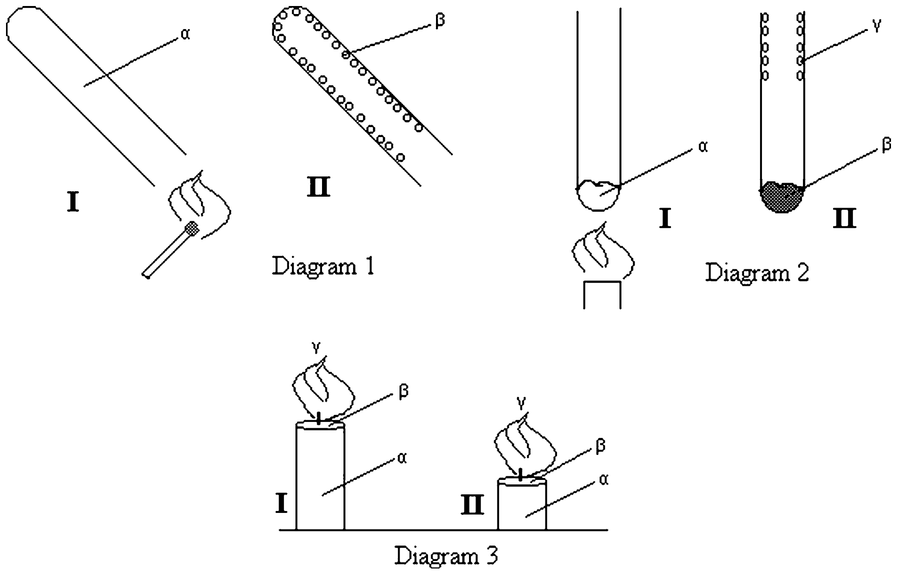

Fig. 1 Diagrams that supported the description of the phenomena. Teachers could see an aspect before (I) and after (II) of the phenomenon and they were asked to answer about the substances located in points α, β, γ. [*Diagram 1*: Hydrogen combustion, *Diagram 2*: Sugar heating, *Diagram 3*: A burning candle]

Table 2 Description of the instrument that was used for the measurement of the teachers' understanding of the chemical changes (Part II of Table 1)

Tasks	Chemical phenomena	Procedure of the relevant experiments	Description of the tasks
1	Hydrogen combustion	A flame is approaching to the open edge of a testing tube that is filled with hydrogen. A small explosion takes place and small droplets are formed in the inner surface of the tube (Fig. 1)	1. Explanations of what happens 2. Macroscopic description[a] of substances after (and before) the experiment 3. Drawing the microscopic view[b] of substances involved
2	Iron oxidation	An iron nail is left in the air for a long time. We usually say that it is then rusty	
3	Sugar heating	A small amount of sugar is located inside a test tube. As the tube is heated, the sugar terns gradually into a dark stuff, which becomes finally black, whereas small droplets appear in the inner upper surface of the tube (Fig. 1)	
4	Burning candle	A candle is burning. A liquid stuff is formed at the top of the candle around the base of the string, whereas the height of the candle is gradually reducing (Fig. 1)	

[a] Teachers were asked to describe what could be in each one of the points β, γ for tasks 2, 4 and β for task 1, whereas to describe iron and rust as substances for the task 3

[b] Teachers were asked to imagine and draw what would be seen if we could magnify anything could be located in a particular point (α, β for task 1, also α, β, γ for tasks 2 and 4, as well as inside iron and rust for task 3) by a very large number of times. In cases where teachers mentioned particles, they were asked to specify them

answers for each task at the sub-microscopic level were placed in overall categories of C, PC and I. For a C category, in all representations of a task, a teacher should specify correctly the particles drawn (e.g. molecules or atoms) and the substance assigned. For a PC category, particles in all representations are assigned to the correct substance but the kinds of particles are not manipulated correctly (e.g. although they draw molecules, they use them as atoms). For a category I, particles are assigned to an incorrect or unclear substance at least in one representation of a task or there is no answer. In cases of giant structures and/or ions in a substance's structure, their presence in the teachers' drawings was also evaluated according to a scheme specified in each one of the corresponding phenomena. For example, for the iron nail rusting, 'C' category representations inside the nail should be correct as for the kinds of particles (atoms), as substance (iron) and as structure (which should be compatible with the solid state of a metallic giant structure), also, representations inside the rust should be correct as substance (an iron oxide) and as for both, the kinds of particles (ions) and the structure (giant).

Further statistical analysis, used scores of 2, 1 and 0, awarded for C, PC and I categories in both levels, respectively. Total scores were calculated as sums.

For the present test, the validity 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 responses, respectively. These values are low, however, are not definitely related to lack of internal consistency; they are acceptable for statistical consideration, since in cognitive tasks low values of alpha are expected due to the diversity of constructs being measured (Hatcher and Stepansky 1994; Kline 1999).

Results and Discussion

Results for each chemical phenomenon are presented at both the macroscopic and sub-microscopic levels in the order hydrogen combustion, iron rusting, heating sugar and a burning candle. Although the burning candle was studied during the course, it proved to be especially difficult for the teachers and for this reason, it is put last. Afterwards, we examine the association between the macroscopic and sub-microscopic levels.

Hydrogen Combustion

For the hydrogen combustion, after the description of the relevant experiment (Table 2, task 1), teachers were asked both, to explain what they think had happened and to identify the product at point β (Fig. 1). The results of the analysis of teachers' pre- and post-responses at both the macroscopic and sub-microscopic levels are given in Table 3.

At the macroscopic level (1a), category C corresponds to recognition of the water as product and the description of its formation. Typically, pre- and post-intervention, teachers said that the hydrogen is burning, as it reacts with oxygen (of the air) producing water. Some are more detailed, e.g. 'the flame increased the energy of the hydrogen and so, it can react with the oxygen of air, producing water in forms of droplets on the inner surface of the tube'. Post intervention, a few (six), referred to breaking of bonds and the formation of new ones. Category PC

Table 3 Categories of teachers' descriptions concerning combustion of hydrogen ($n = 130$). Pre- and post-intervention frequencies

Task		Category	Score	Frequencies N (%)	
				Pre intervention	Post intervention
1a	Macroscopic level	I	0	20 (15.4)	2 (1.5)
		PC	1	55 (42.3)	38 (29.2)
		C	2	55 (42.3)	90 (69.2)
1b	Sub-microscopic level	I	0	22 (16.9)	1 (0.8)
		PC	1	76 (58.5)	54 (41.9)
		C	2	32 (24.6)	74 (57.4)

Pre–post comparisons: 1a = [$\chi^2 = 26.3$, Cramer's V = 0.32 $p < 0.000$], 1b = [$\chi^2 = 39.5$, Cramer's V = 0.39, $p < 0.000$]

corresponds to recognition of the water as product, but the explanation is incomplete, unclear or incorrect, e. g. 'the hydrogen is burning and water is produced' (a very frequent answer) or 'a chemical reaction with hydrogen happens and water is produced'. Among teachers' answers of this category, pre-intervention, some particular misconceptions were present such as, 'the hydrogen reacts with the oxygen of the air and produces water and carbon dioxide' (five teachers), 'the hydrogen reacts with the carbon of the match and water is produced' (three teachers) or 'the hydrogen reacts with carbon dioxide and produces water' (two teachers). In category I, water is not recognisable as product or there is no answer, e.g. 'the hydrogen is liquidised' (as product, hydrogen is reported) or 'the hydrogen combines with oxygen' (as product, hydrogen together with oxygen are reported).

Teachers were also asked to draw representations at the sub-microscopic level for hydrogen and water (points α and β of Fig. 1, diagram 1). The teachers' responses were categorised as 'C', 'PC' or 'I' on their own terms, irrespective to the level of detail in their representations. The majority drew circles and if they referred to them as molecules, they were coded as C (e.g. Fig. 2a). However, if referred to as atoms the response was coded as PC (e.g. Fig. 2c). Confusion between the concepts of atom and molecule is something that has also been reported for in-service primary teachers in a similar study (Papageorgiou and Sakka 2000). Hydrogen as monatomic gas was a common problem. A few teachers (six pre- and 14 post-intervention) used circles, correctly, to represent atoms making up molecules of both substances (e.g. Fig. 2b). Two cases with sub-atomic representations were incorrect. For category I, in addition to problems in distinguishing atoms and molecules at least one of the corresponding substances was incorrect (as at the macroscopic level).

Percentages for PC and C in Table 3 are generally high at both levels (macroscopic and particulate, pre and post intervention. Hydrogen combustion seems to be a reasonably understandable phenomenon. However, it should be noted that it only involves substances with molecular structures, there is only one product and they were not expected to show the substance oxygen as one of the reactants in their drawings. Although teachers just described what happened during the combustion, they recognized that a new substance is formed i.e. that it is about a chemical phenomenon. A comparison pre- and post-intervention shows a statistically significant increase in the frequencies of the improved answers for both macroscopic and sub-microscopic levels (see corresponding χ^2-test and Cramer's V, Table 3) which indicates the intervention had an effect.

Iron Rusting

Although the rusting of iron is a complex phenomenon, only a simplified treatment in terms of iron reacting with the oxygen of the air to produce an iron oxide was expected (in fact, we expected a reference to rust simply as FeO). We also hypothesized that the phenomenon is familiar to the teachers and thus there wasn't a supporting image in the test.

At the macroscopic level, teachers were asked to explain what happens when an iron nail goes rusty after being left outside for a long time in the air. They were also asked to state if rust is the same substance as iron in another form or a different one

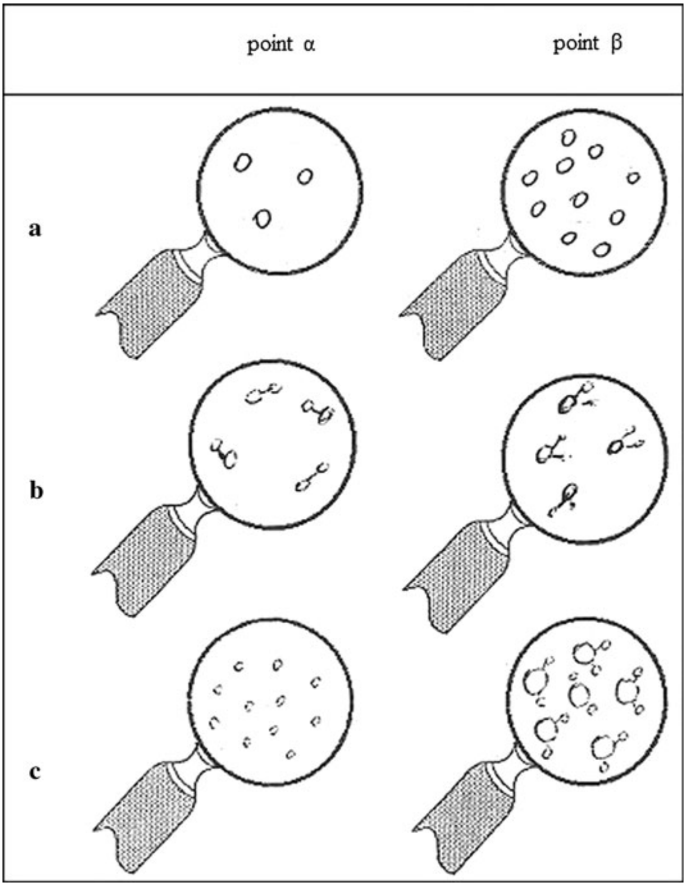

Fig. 2 Some examples of teachers' representations for C and PC categories of task 1. In example **a** (category C) particles in points α, β are said to be molecules of hydrogen and water, respectively. In example **b** (category C) particles are said to be atoms of hydrogen in point α, whereas atoms of hydrogen and oxygen (ration 2:1) in point β. In example **c** (category PC) particles are said to be atoms of hydrogen in point α, whereas atoms of hydrogen and oxygen (ration 2:1) in point β

(a multiple choice question). Table 4 gives the results for the macroscopic and sub-microscopic levels.

At the macroscopic level, for category C (task 2a) an iron oxide is recognised as the product and a satisfactory description is given for its formation. Many teachers (pre- and post-intervention) said oxygen (of the air) reacts with iron, producing iron oxides. Additionally, some teachers' referred to the participation of air humidity or rain but, without any further clarification (14 teachers pre- and 12 post-intervention). A few (post-intervention) referred to bonds between atoms of iron and oxygen (six teachers). Category PC corresponds to recognition of rust as a substance different to iron, but the teachers' explanations, although referring to the formation of iron oxide, are incomplete, unclear or incorrect. For example, 'an oxidation of the iron happens', 'the iron is oxidized due to the moisture of the air' or 'a reaction occurs since iron

Table 4 Categories of teachers' descriptions concerning iron rusting ($n = 130$). Pre- and post-intervention frequencies

Task		Category	Score	Frequencies N (%)	
				Pre intervention	Post intervention
2a	Macroscopic level	I	0	7 (5.4)	2 (1.5)
		PC	1	92 (70.8)	46 (35.4)
		C	2	31 (23.8)	82 (63.1)
2b	Sub-microscopic level	I	0	36 (27.7)	7 (5.4)
		PC	1	91 (70.0)	100 (76.9)
		C	2	3 (2.3)	23 (17.7)

Pre–post comparisons: 2a = [$\chi^2 = 17.3$, Cramer's V = 0.24, $p < 0.000$], 2b = [$\chi^2 = 35.4$, Cramer's V = 0.37, $p < 0.000$]

reacts with oxygen of the air'. In category I, rust is not recognised as a different substance to iron or there is no answer. As noted elsewhere (Abraham et al. 1992; Krnel et al. 1998), 'rust' is considered as the iron in another form. For instance, rust is viewed as a mixture of iron and water coming from the moisture of the air (four teachers pre-intervention).

For the sub-microscopic level task (2b), teachers were asked to draw representations for a point inside the iron nail before rusting and for one in the rust (after the rusting). In this phenomenon, giant structures and ions are involved. During the course, teachers had encountered similar examples (Table 1, section 8). However, none of the teachers (pre- or post intervention) used ions in their representations. Here it must be noted that ions were not a strong point of focus during the course. The emphasis was on the more fundamental issue of structure. To that extent, category C does not represent the exact scientific view, but refers only to atoms as particle units of giant structures for both iron and iron oxide (e.g. Fig. 3a). Category PC includes all representations that referred correctly to iron and an iron oxide as such, but there were problems with the kinds of particles and the structures for both substances. To this extent, PC is quite a wide category. Figure 3b, c give two examples. It was common for rust to be represented as molecules that were said to be iron oxide (drawn as circles in a pattern compatible with solid state) and in some cases similarly for iron. It is worth noting that qualitatively, representations in this category were more sophisticated post-intervention. For instance, amongst nine teachers, who drew atoms of oxygen and iron bonded inside molecules of iron oxide post-intervention, six had simply drawn molecules of iron oxide pre-intervention. In category I, in addition to problems with the kind of particles and structures, there was no clarification of what rust is or, rust is presented as the same substance as iron, or there is no representation. An interesting case of 'uncertified rust' is the representation of rust by atoms or/and molecules of iron, oxygen and hydrogen either isolated or as mixture of iron and water (eight teachers pre- and three post-intervention).

Comparing the frequencies pre- and post-intervention (Table 4), a statistically significant improvement is observed for both macroscopic and sub-microscopic items. Although many teachers seem to have an idea of the phenomenon

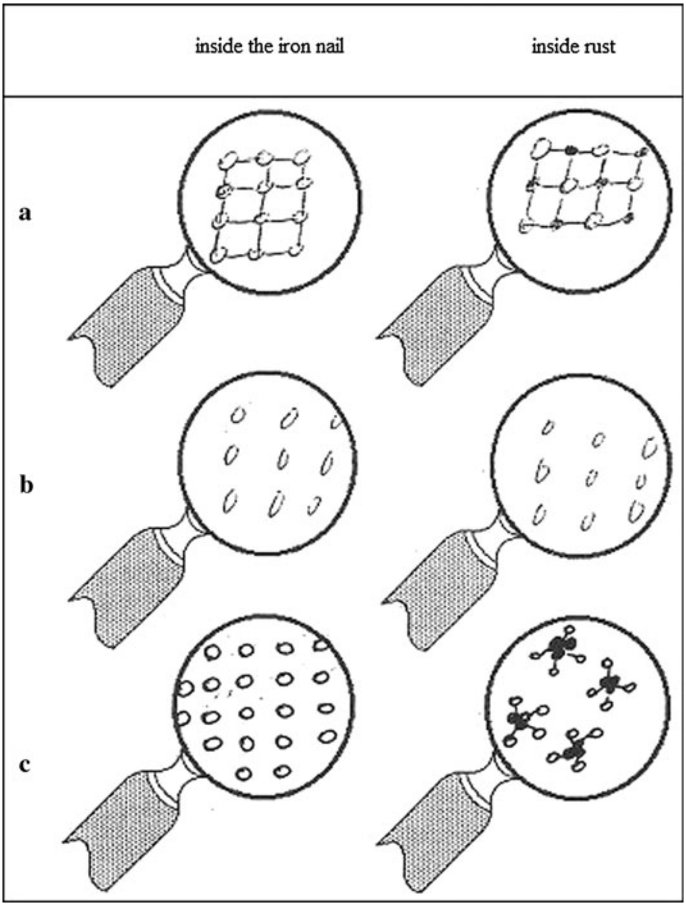

Fig. 3 Some examples of teachers' representations for C and PC categories of task 2. In example **a** (category C) particles inside nail are said to be atoms of iron, whereas inside rust, atoms of iron and oxygen. In example **b** (category PC) particles inside nail are said to be atoms of iron, whereas inside rust, molecules of iron oxide (the simpler representation). In example **c** (category PC) particles inside nail are said to be atoms of iron, whereas inside rust, atoms of iron and oxygen in molecules (the most sophisticate)

pre-intervention (PC category), the number of 82 teachers for category C post-intervention is a good improvement. For the sub-microscopic level, although there is an accumulation in PC category (probably due to the complexity of the structure of the iron oxides, which put many partial correct cases in the same category) the number of the teachers in category C was a distinct improvement.

Sugar Heating

Heating sugar is also a complex event, since, after melting, thermal decomposition leads to a number of substances as products (like carbon, water, hydrogen, methanol, carbon monoxide and dioxide). We presented a simpler version to the teachers, focusing on carbon and water as the products of a chemical change, because these are the most apparent (Fig. 1). To help stimulate teachers' thinking, as well as a description of the two products (black solid for the carbon and droplets of a liquid for the water), the task (3 in Table 2) also included a note that sugar is a carbohydrate. Teachers were asked again to explain what they think happens at the macroscopic level, as well as to represent substances involved (points α, β, γ, Fig. 1) at the sub-microscopic level. The results are given in Table 5.

For the macroscopic level, category C corresponds to recognition of both products and a satisfactory description of their formation, e.g. 'due to the heating, sugar decomposes. Hydrogen and oxygen join up and when cooling, they form water, whereas the carbon stays at the bottom of the test-tube.' For category PC the recognition of products was correct, but the explanation was incomplete, unclear or incorrect. A common answer of this category was 'the sugar is burned. Water and carbon is produced'. Maybe the everyday use of the expression 'it is burned' for anything has been overheated (and goes black) has an impact on teachers' thinking. As Abell and Smith (1994) suggests, primary teachers' conceptions are often influenced by everyday science and language. A number said the formation of carbon and water was due to the combustion of sugar, which was considered to be made of carbon and hydrogen, with the oxygen of the air (16 pre- and seven post-intervention). Probably, in this case there is the misconception that 'carbohydrate' means a substance with carbon and hydrogen as its components. Also interestingly, this category included descriptions where hydrogen and oxygen were considered as being in the form of water inside sugar before the decomposition (26 pre- and 19 post-intervention). In some of these cases, teachers spoke of an evaporation of water from sugar. In category I, at least one of the products is not recognisable or unclear, or there is no answer, e.g. 'the sugar is burned. Water and carbon dioxide is produced'. Teachers, who thought that burning is just turning black and thus identified the substance at point β as black sugar, fell into this category. 'Burned sugar' or 'liquid state of sugar' were other answers. Again, such responses are similar to students' perceptions reported in the literature. Boujaoude (1991) reports

Table 5 Categories of teachers' descriptions concerning the sugar heating ($n = 130$). Pre- and post-intervention frequencies

Task		Category	Score	Frequencies N (%)	
				Pre intervention	Post intervention
3a	Macroscopic level	I	0	35 (26.9)	4 (3.1)
		PC	1	86 (66.2)	68 (52.3)
		C	2	9 (6.9)	58 (44.6)
3b	Sub-microscopic level	I	0	57 (43.8)	6 (4.6)
		PC	1	64 (49.2)	82 (63.1)
		C	2	9 (6.9)	42 (32.3)

Pre–post comparisons: 3a = [$\chi^2 = 62.6$, Cramer's V = 0.49 $p < 0.000$], 3b = [$\chi^2 = 64.9$, Cramer's V = 0.50, $p < 0.000$]

13–14 years olds saying that such a phenomenon lead to the formation of liquid sugar or a simple change of its colour.

At the sub-microscopic level, given the complexity of the sugar molecule, a simple representation rather than a structure of carbon, oxygen and hydrogen atoms was expected. Indeed, simple molecules for sugar (and also water) were very common. However, a small number of them did draw atoms of C, O and H inside a sugar molecule (three pre- and eight post-intervention) and H–O–H for water (four pre- and nine post-intervention). In category C, there were correct representations for all the points (α, β, γ, Fig. 1). Some examples are given in Fig. 4. In category PC, although the products were correctly assigned to the corresponding substances, the problem of confusing the kind of particles, or the structure was present again. A common problem pre- and post-intervention, was the representation of molecules for the carbon and also post-intervention a giant structure with O, H and C atoms bonded to each other inside sugar. For category I, problems in representations were combined again with incorrect products and kind of particles, or there wasn't any answer. It should be noted that, due to the complexity of the structure of the

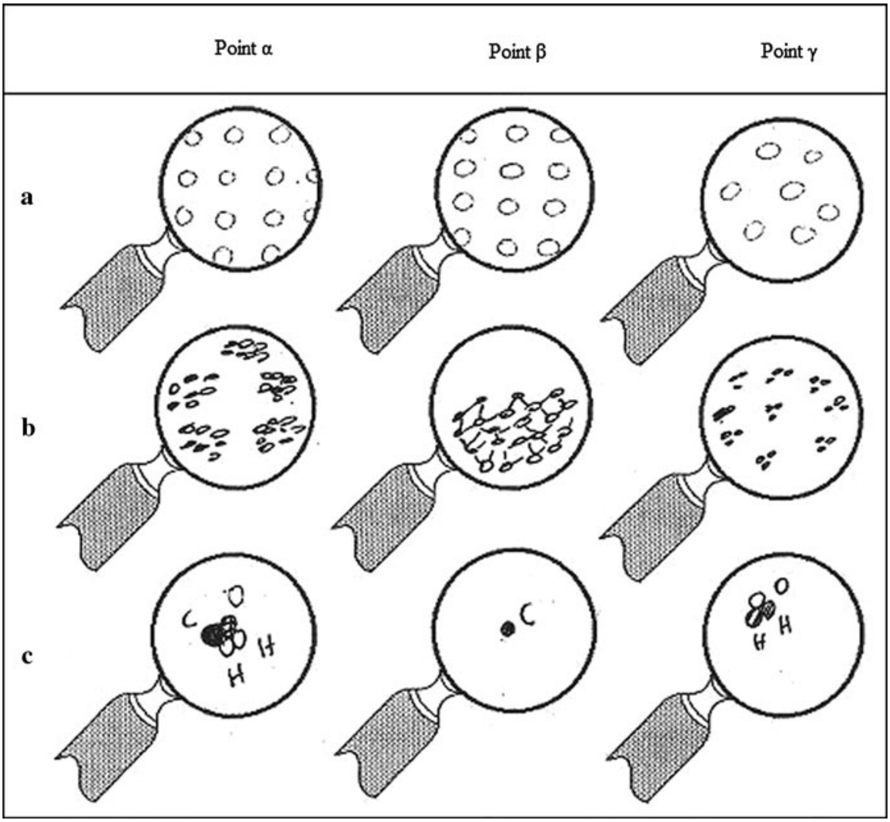

Fig. 4 Some examples of teachers' representations for C category of task 3. In example **a**, particles in points α, γ were said to be molecules of sugar and water, whereas atoms of carbon in point β. Examples **b** and **c** are different correct views of the atomic level

substances involved and the preference of the teachers in drawing molecules (avoiding representations at the atoms level) it is not possible to have a clear picture of their sub-microscopic thinking.

The frequencies in Table 5 indicate a substantial and statistically significant improvement at both the macroscopic and sub-microscopic levels. The discussion of this phenomenon in the course seems to have had an effect.

A Burning Candle

Like decomposing sugar, a burning candle was also studied during the course; however, it proved to be more challenging. In task 4, after the description of the event (Table 2), at the macroscopic level teachers were asked to explain why the height of the candle is gradually reducing, what happens to the missing wax and identify the substances at points α, β, γ (Fig. 1, diagram 3). At the sub-microscopic level representations of the substances at α, β, γ were asked for. The categorisations of the teachers' responses are given in Table 6.

At the macroscopic level, only five teachers pre- and 42 post-intervention are categorized as C. These teachers recognised wax in the solid and liquid states (points α and β respectively of Fig. 1, diagram 3), water and carbon dioxide (or water and carbon monoxide or/and carbon for an incomplete combustion) as products (point γ), as well as providing a satisfactory explanation of the formation of the products involving the oxygen. For example 'The flame melts the wax, which then turns into a gas. The gas wax is burned with the oxygen of air and water together with carbon dioxide is produced'. Teachers, who correctly recognized substances in points α, β, at least one of the products in point γ of Fig. 1, diagram 3, and their explanation was incomplete, unclear or incorrect, are categorized as PC. Commonly, teachers referred to the burning of the wax without explicitly noting the participation of oxygen (39 pre- and 38 post-intervention) and/or there was an absence of water from the products (30 pre- and 22 post-intervention). It is not possible to know how many of those not mentioning oxygen did so because it was not part of their understanding or because they took it as self-evident. Not reporting water as a product is consistent with the

Table 6 Categories of teachers' descriptions concerning a burning candle ($n = 130$). Pre- and post-intervention frequencies

Task		Category	Score	Frequencies N (%)	
				Pre intervention	Post intervention
4a	Macroscopic level	I	0	80 (61.5)	39 (30.0)
		PC	1	45 (43.6)	49 (37.7)
		C	2	5 (3.8)	42 (32.3)
4b	Sub-microscopic level	I	0	85 (65.4)	44 (33.8)
		PC	1	29 (22.3)	36 (27.7)
		C	2	16 (12.3)	50 (38.5)

Pre–post comparisons: 4a = [$\chi^2 = 43.4$, Cramer's V = 0.41 $p < 0.000$], 4b = [$\chi^2 = 31.3$, Cramer's V = 0.35, $p < 0.000$]

absence of oxygen, but carbon dioxide was the most frequent response. There is perhaps something particularly difficult about the idea of water coming out of a flame. In category I, none of the products in point γ is identified or responses are unclear, or there is no answer. Notably, many teachers in this category considered the whole phenomenon as a kind of evaporation, even post-intervention. These teachers said that at point γ was wax in the gas state (36 pre- and 32 post-intervention). It seems that these teachers had difficulty in dealing with the chemical changes of the phenomenon and they focus only on the physical ones. This kind of limited thinking is similar to what is already known about students (Abraham et al. 1994; Papageorgiou et al. 2010; Johnson 2002). Interestingly, some of the teachers who put wax at point γ used 'burning' to describe the change of state (10 pre- and five post-intervention), e.g. 'the wax is burning and so, it turns to the gas state'. Evidently, 'burning' doesn't have the same meaning for all teachers. Smoke, air or generally gases are also responses in category I.

Matters were somewhat complicated at the sub-microscopic level (task 4b). Teachers were not aware of the wax composition pre-intervention and, although this was explained during the course, only few of them used that knowledge in their answers. Once again representations of simple molecules dominated teachers' drawings. Only 10 post-intervention (none pre- intervention) drew a more sophisticated version with atoms inside molecules of wax, carbon dioxide and water (none of them drew the whole picture of the molecule of wax, but some showed part of it), e.g. Fig. 5. For the C categorization, the correct representation of as many products as were identified macroscopically correctly at point γ of Fig. 1, diagram 3, was needed. Since in this phenomenon there are more than one substances at the same point (γ), a teacher could identify one of them (e.g. carbon dioxide) and be categorized as PC at the macro level, but he could also be in category C at the sub-micro level when the corresponding representation is correct. As a result, the number of teachers in category C, although small especially pre-intervention, is greater than category C at the macroscopic level. Furthermore, since points α and β correspond to the same substance, the arrangement in drawings

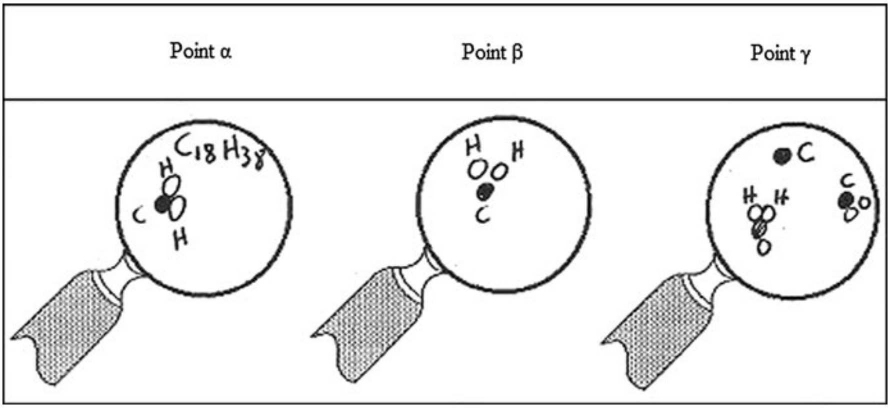

Fig. 5 An example of teachers' representations for C category of task 4 in atomic level

needed to correspond to the state (solid or liquid). In category PC, wax at points α, β and as many products as identified macroscopically correctly for point γ were represented, but issues of confusing the kind of particles, or the arrangements for the states of wax were present. A particular problem for teachers here was representing the C and/or H and/or O in wax, water or/and carbon (di)oxide as molecules. For instance, in a representation of carbon dioxide, circles were drawn in an arrangement commensurate with the gas state, which were said to be molecules of C and O (eight pre- and three post-intervention). Also there were cases, mostly pre-intervention, where isolated atoms of C, H and O, were drawn for water and carbon dioxide. Responses involving incorrect substances and problems in representations together with no answers were placed in category I.

As with the other phenomena, Table 6 shows a statistically significant improvement for both macroscopic and sub-microscopic levels. However, given this example of chemical change was studied in depth within the course, a relatively large number of teachers still only considered a burning candle in terms of changes of state. Of course, it is a complex phenomenon, with at least four substances involved in its simplest version as well as the physical changes occurring at the same time. If this phenomenon is to be studied, it would seem to be more appropriate for the higher end of the age range at primary level.

Sub-Microscopic Representations Versus Macroscopic Explanations: An Association

In order to study the effect of the development of particle ideas (sub-microscopic level) on the teachers' descriptions and explanations of the phenomena (macroscopic level), a categorical variable of two categories was created, namely *high* and *low achievers* for the sub-microscopic-level part, based on the median of the distribution. The two groups, *high* and *low achiever*s in sub-microscopic-level part, were compared (by t test) in their competence in the macroscopic-level part, both pre- and post-intervention. Table 7 shows that the high achievers in sub-microscopic-level part scored higher in macroscopic-level part as well.

Since the majority of teachers operated at the level of molecules rather than atoms (and the changes in bonding between atoms) any conclusions from these results about the relationship between particle ideas and understanding chemical change macroscopically must be treated with caution. It must also be recognized

Table 7 Comparison of competence in macroscopic-level part between high and low achievers (in sub-microscopic-level part). Pre-intervention and post-intervention scores

	Low achievers		High achievers		*T*-test
	Mean	SD	Mean	SD	t
Pre intervention	2.64	0.48	5.26	0.44	−45.6***
Post intervention	5.54	0.83	7.1	1.00	−11.3***

* $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

that in the scoring there is a degree of inbuilt dependence of the sub-micro and the macroscopic because the identity of the products was required. However, products could have been identified without necessarily using particulate ideas, but this seems not to be the case. Furthermore, one-way analysis of covariance (ANCOVA) of the two groups (*high* and *low achiever*s in sub-microscopic-level part) on the macroscopic-level part, post intervention, with the macroscopic-level part pre-intervention as a covariate was carried out (Table 8). The results show that both the effect of predictor and covariate are statistically significant and moreover the ANCOVA model explained 81 % of the variance, thus supporting a high association between the development of particle ideas and the understanding of chemical phenomena at a macroscopic level.

What do Figures Say for the Overall Benefits from the Course?

To give the overall picture, Fig. 6 shows the distributions of the teachers' total scores for the pre and post tests. The effectiveness of the intervention per task is shown in Table 9. For each task the difference between pre-test/post-test mean scores is statistically significant ($p < 0.0001$). Nonparametric tests, such as Wilcoxon Signed-Ranks test led to the same conclusions. In addition, the effect sizes (Type error II) estimated by using Pearson's *r*-vales (Field 2001; Rosenthal et al. 2000) indicate that the magnitudes of these changes were raged from good to substantial. Overall, the effect size on the total score is 0.94.

Conclusions

Overall, what did teachers gain from the course? Although pre-intervention, the primary teachers seemed to have a slightly better understanding of chemical

Table 8 One-way ANCOVA on post-intervention scores in macroscopic-level as dependent variable and macro pre-intervention scores as a covariate

Tests of between-subjects effects
Dependent variable: post-intervention scores in macroscopic-level

Source	Type III sum of squares	*df*	Mean square	*F*
Corrected model	259.2	2	129.6	556.8***
Intercept	365.0	1	365.1	1,568.7***
Sub-micro, post-intervention achievement	53.9	1	53.8	231.4***
Macro-pre-intervention achievement-(covariate)	140.7	1	140.7	604.6***
Error	59.8	257	0.23	
Total	9,488.0	260		
Corrected total	319.0	259		

R squared = 0.81, * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

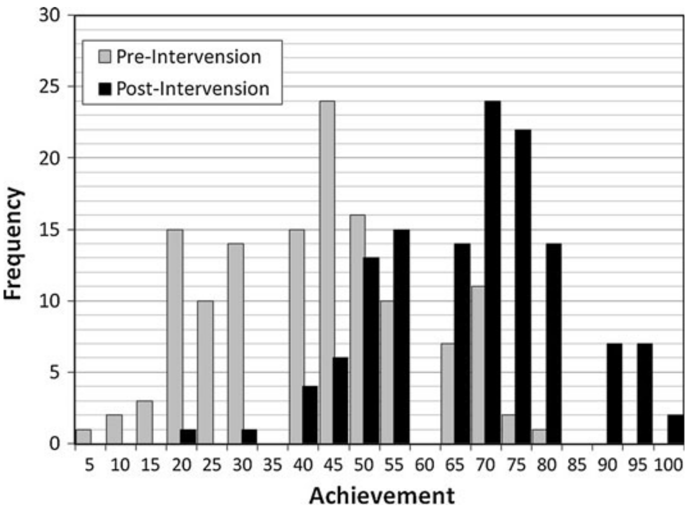

Fig. 6 Distribution of total achievement scores for pre-intervention and post-intervention tests

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

	Pre intervention		Post intervention		*T*-test	Effect size
	Mean	SD	Mean	SD	*t*	*r*
Hydrogen combustion	49.3	25.4	75.1	19.6	−18.5***	0.85
Iron rusting	55.4	23.7	68.4	27.3	−16.7***	0.83
Sugar heating	37.4	23.3	85.7	21.0	−41.1***	0.96
Burning candle	16.9	35.5	45.6	46.1	−11.8***	0.72
Sub-micro-level	29.2	24.2	63.1	14.5	−28.0***	0.93
Macro-level	50.3	17.4	74.2	13.9	−37.2***	0.96
Total	39.8	20.2	68.7	14.1	−32.7***	0.94

*** $p < 0.0001$

changes compared to what is generally known from the corresponding literature for primary pupils, the results of the present study also show a number of teachers' misconceptions, with many similarities to those of their pupils. It seems that neither their increased age nor their experience in teaching similar topics could make a significant conceptual change in themselves. One could suppose that their thinking is still influenced by everyday life and hadn't changed much from the time they were pupils. It seems that a vicious cycle appears to be operating allowing misconceptions to persist from generation to generation (see also Papageorgiou et al. 2010). In this intervention, we tried to break that cycle by using a new conceptual approach, based on the key premises presented earlier. First, the understanding of the concept of a substance in terms of particle ideas is established and then, the conditions under which substances can be transformed through chemical changes into others. Evaluating the overall progress made by the primary teachers, although we can still see misconceptions remaining and constraints in explaining chemical changes for a number of the teachers, we could argue that it was significant and encouraging progress. Moreover, the intervention seems to address important ideas, which teachers could apply to new chemical phenomena further to those they had studied during the course. It seems therefore, that the intervention shows promise towards breaking the cycle.

However, although there was progress, it wasn't equally spread across all phenomena. Post-intervention, teachers seemed better able to manage the combustion of hydrogen and the heating of sugar, than the burning candle which had been studied in the course. On the one hand, this supports the distinctiveness of each instance of chemical change, which contributes to the challenge of teaching chemical phenomena in a systematic way. A change of state, 'melting' for instance, is much the same in the context of any substance and leads to the same substance in another form. On the contrary, a chemical change, like the reaction of a substance with the oxygen, is a different procedure for each one of the substances and a suitable order for teaching purposes is more problematic. For example, with hydrogen combustion, the change results in the formation of one product (water), whereas for burning wax, we can have a different processes depending on the amount of oxygen available for burning and products could vary respectively as they can be for instance carbon dioxide, carbon monoxide or simple carbon along with water. This distinctiveness means some chemical changes are probably more appropriate for the introduction of the idea of the chemical change, than others. A burning candle, which features so prominently in school science, seemed to present more challenges to the primary teachers. How can teachers cope with this phenomenon in the classroom, when the majority of them work on it as being a physical event? The simplicity of hydrogen combustion or the (plausibly) convenient appearance of the substances involved in the simple version of the sugar heating, seem to have better possibilities for a successful teaching outcome. However, this does not necessarily mean that their appropriateness for the primary curriculum is ensured. The effectiveness of such a teaching approach depends also on the overcoming pupils' known problems concerning 'invisible' substances in gas state, such as hydrogen and oxygen (e.g. Johnson 2002; Liu and Lesniak 2006; Papageorgiou et al. 2010).

Further to the selection of the most appropriate case for the introduction of chemical changes in primary school, the development of particle ideas appears to be helpful, if not requisite. The analysis explicitly indicates that the teachers who showed a better understanding of the particulate nature of matter are more likely to understand and therefore explain chemical changes at the macroscopic level. Since an analogous relation has been also found for primary pupils (Papageorgiou et al. 2010), science curricula designers might anticipate the development of particle ideas before the study of phenomena, especially chemical ones. The results of these studies suggest that a rethink of the science content along the lines of the teaching scheme presented here, could be used as a pilot in a curriculum reform towards improved teaching and learning of chemical phenomena. From primary teachers' perspective at least, more effective teaching in this context seems possible.

The present training course had a significant effectiveness on teachers' understanding of chemical changes but one 'shot' is not enough. As other researchers suggest (e.g. Jarvis et al. 2003) we would recommend continuous and long term in-service training programs, where duration, timing and frequency of programs are very important. Together with also enhancing other components of pedagogical content knowledge, the development of such courses for the improvement of primary teachers' content knowledge could help towards more understandable primary science for both pupils and teachers.

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